

Chapter 2

Literature review

2.1 Background

Composting represents a sophisticated method of waste bioconversion, wherein organic waste materials are decomposed into stable, nutrient-rich humus through the controlled activity of diverse microbial communities. [12]. This aerobic process unfolds through a series of distinct phases, each characterized by specific microbial activity and corresponding physicochemical changes.

2.2 Composting phases and microbial dynamics

The initial mesophilic phase (20-45°C) is dominated by mesophilic microorganisms, primarily bacteria, which rapidly metabolize simple organic compounds, such as sugars and amino acids, generating heat that drives the compost into the next phase, as shown in *Figure 2.1*. As the temperature rises due to the exothermic reactions of microbial metabolism, the system transitions into the thermophilic phase (45-70°C) [13]. This phase is marked by the proliferation of thermophilic bacteria and fungi, which possess the enzymatic capability to break down more complex and recalcitrant organic compounds, including cellulose, hemicellulose, and lignin [12]. The degradation of these complex substrates is essential for reducing pathogen load, as the high temperatures effectively inactivate many harmful organisms. The subsequent cooling phase signals a gradual decline in temperature as the easily degradable substrates are exhausted, leading to a shift in the microbial community. Mesophilic organisms re-establish dominance during maturation, where the compost stabilizes, and humification processes predominate. In this phase, *actinomycetes*, a group of filamentous bacteria, become particularly active, contributing to the breakdown of more resistant organic

materials and the formation of humic substances, which impart the characteristic earthy odor to mature compost [14].

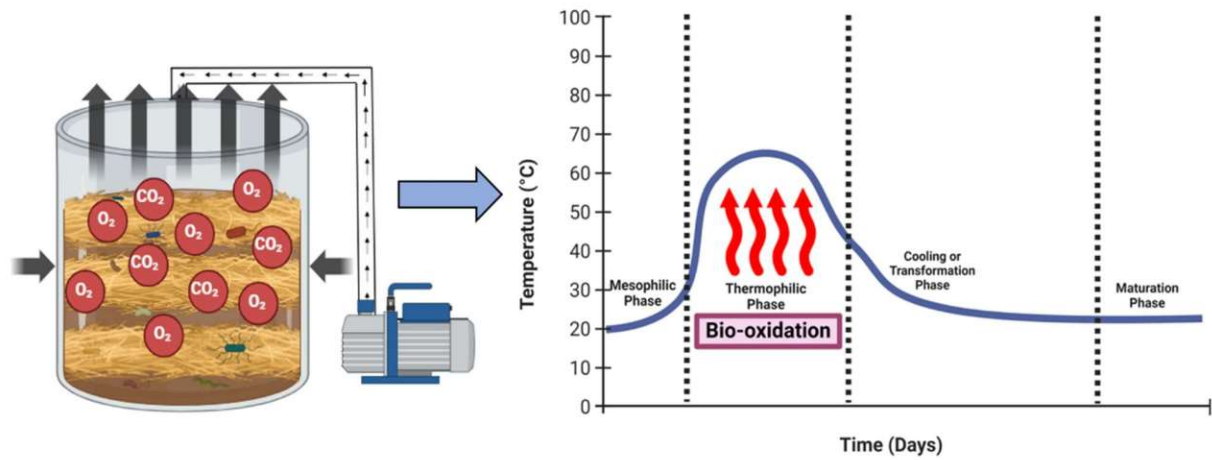


Figure 2.1. Detailed stages of the composting process: from initial decomposition to final maturation

2.3 Design, operational, and technological innovations

2.3.1 Centralized composting system design

A centralized composting system is meticulously engineered to efficiently handle large volumes of organic waste. The design encompasses a large, open site strategically divided into distinct zones dedicated to waste reception, preprocessing, composting, curing, and storage. This segmentation streamlines operations and ensures a smooth flow of materials through each phase of the composting process [15]. The site is typically paved with durable materials like reinforced concrete or asphalt. This not only facilitates the movement of heavy machinery but also serves as a protective barrier to prevent leachate—a liquid byproduct of composting—from infiltrating and contaminating the underlying soil. In windrow composting, organic waste is arranged in long, narrow piles known as windrows, usually about 3 meters high and 4 to 6 meters wide. This configuration optimizes aeration, allowing oxygen to permeate the pile and support aerobic microbial activity essential for decomposition [15]. Specialized equipment such as windrow turners or front-end loaders are employed regularly to aerate and mix the

compost piles, promoting uniform decomposition and preventing anaerobic conditions that can lead to odors and slower processing. To manage leachate, the flooring is sloped with integrated drainage channels that direct the liquid to collection tanks for treatment, thereby mitigating environmental risks. Alternatively, aerated static pile systems utilize an aeration infrastructure comprising pipes or perforated floors connected to blowers. This setup supplies air to the compost pile, maintaining aerobic conditions without physical turning. Cover materials, such as layers of finished compost or biofilters, are applied over the piles to control odors, retain heat, and enhance the overall efficiency of the composting process. The infrastructure of a centralized composting facility is further enhanced by a well-equipped waste reception area featuring weighbridges for measuring incoming waste quantities and sorting stations for separating non-compostable materials. Preprocessing facilities with shredders and mixers homogenize the waste, optimizing particle size and composition for efficient composting. Stormwater management systems, including retention ponds and filtration units, are integral to the design to prevent runoff contamination and comply with environmental regulations. The facility emphasizes durability and environmental protection in terms of materials and construction. The use of reinforced pavement supports heavy machinery operations and prevents leachate infiltration. Fencing and establishing buffer zones serve dual purposes: they secure the site against unauthorized access and mitigate noise and odor impacts on the surrounding community.

2.3.2 Centralized tunnel composting system design

Centralized tunnel composting systems are advanced, enclosed structures designed to provide controlled conditions for the composting process. The tunnel structures were constructed from reinforced concrete or steel, typically measuring between 30 to 50 meters in length, 3 to 5 meters in width, and approximately 4 meters in height [16]. The walls and ceilings are insulated to retain the heat generated during composting, which is crucial for maintaining the

thermophilic conditions that accelerate microbial activity and pathogen reduction. The tunnel floor features a perforated design that supports the compost material while allowing air to flow upward from beneath. An integrated air distribution system, consisting of a network of ducts and blowers, supplies and extracts air to maintain optimal oxygen levels throughout the compost mass. Ventilation is carefully managed through forced aeration, controlled by variable-speed fans that adjust airflow based on real-time data from temperature and oxygen sensors embedded within the compost [16]. This precise control ensures an optimal environment for decomposition and minimizes the risk of anaerobic conditions. Air exiting the tunnels passes through biofilters to address environmental concerns such as odor and emissions. These biofilters effectively remove odors and volatile organic compounds (VOCs), ensuring compliance with environmental standards and minimizing impact on nearby communities. The loading and unloading of compost material are facilitated by equipment such as front-end loaders or conveyor belts, which deposit pre-processed organic waste into the tunnels. Some designs incorporate automated systems like mechanical pushers or screw conveyors to move material through the tunnel, enhancing efficiency and reducing manual labor. Control systems are a critical component of tunnel composting facilities. Sensors monitor key parameters such as temperature, moisture content, and oxygen levels, all connected to a central control unit. Software integration allows for automated adjustments to aeration and moisture based on this real-time data, ensuring optimal conditions are consistently maintained throughout the composting process. Materials and construction considerations focus on durability and maintaining a controlled environment. Interior surfaces are coated with corrosion-resistant materials to withstand the acidic conditions that can develop during composting. Sealed, heavy-duty doors with airtight seals are installed to prevent external air intrusion and maintain the integrity of the composting environment.

2.3.3 Decentralized composting system design

Decentralized composting systems are tailored for community-level or institutional settings, emphasizing accessibility and adaptability to local needs. Site selection is a critical design aspect, with facilities ideally near waste generation sources such as residential areas, markets, or institutions. This proximity minimizes transportation requirements, reducing both costs and environmental impact [17]. The space requirements for decentralized systems are significantly smaller than those of centralized facilities. Composting methods may include smaller-scale static piles or windrows, adjusted to handle the specific volume of waste produced by the community. In-vessel units, which are enclosed containers or reactors, can also be installed on-site to provide a controlled composting environment, often enhancing efficiency and reducing odors. [15]. Infrastructure design includes designated waste collection points where community members can deposit their organic waste. A processing area is allocated for the composting units and curing piles, organized to optimize workflow and space utilization. To foster community engagement and ensure the success of the composting program, educational signage is installed to provide instructions and information about the composting process. [17]. Aesthetic considerations, such as landscaping and thoughtful design elements, help integrate the facility into the community setting and promote acceptance. Materials and construction practices focus on sustainability and cost-effectiveness. Locally sourced materials like wood, recycled plastics, or metal are used to construct compost bins and other infrastructure components, supporting the local economy and reducing environmental impact. [17]. Modular designs are favored, allowing the facility to be easily assembled, expanded, or relocated as community needs evolve.

2.3.4 Decentralized compost bin design

Compost bins designed for household or small-scale use prioritize simplicity, efficiency, and user-friendliness. There are two primary types of compost bins: stationary bins and tumblers.

Stationary bins are fixed units, often with an open-bottom design that allows direct contact with the soil. This feature facilitates the migration of soil microorganisms and earthworms into the compost, enhancing decomposition [18]. Tumblers are rotating drums mounted on a frame, enabling users to easily mix the contents by turning the drum and accelerating composting by improving aeration. Key design features of compost bins focus on creating optimal conditions for aerobic decomposition. Ventilation is achieved through air vents or slats, promoting airflow and maintaining aerobic conditions essential for efficient composting [18]. Access points, such as lids or doors, are incorporated to add organic waste and remove finished compost conveniently. Moisture control is addressed by including drainage holes to prevent waterlogging and the buildup of leachate, which can lead to anaerobic conditions and unpleasant odors [19]. Materials used in constructing compost bins are chosen for durability and environmental considerations. Plastic bins are often made from recycled or UV-resistant plastics to withstand outdoor conditions over time. Wooden bins are constructed from rot-resistant wood species like cedar or treated lumber, offering a natural aesthetic and biodegradability. Size and capacity are essential considerations to match the bin with the user's needs. Compost bins typically range from 200 to 400 liters in volume, suitable for the average household's organic waste production [20]. Compact dimensions are designed to fit in various settings, including backyards, patios, or even balconies in urban environments. Additional features enhance the functionality and convenience of compost bins. Pest deterrents, such as fine mesh screens or tight-fitting lids, prevent rodents and insects from accessing the compost. Some designs include insulation, using double-walled construction to retain heat, and enhancing the composting speed, especially in cooler climates [19].

2.3.5 Decentralized rotary drum composter design

Rotary drum composters are engineered to provide efficient composting in a compact and enclosed system suitable for households, educational institutions, or small communities. The

core of the design is a cylindrical vessel, typically made of steel or heavy-duty plastic, mounted horizontally on a sturdy frame. The drum size varies, ranging from small units of around 200 liters for household use to larger units of up to 10,000 liters suitable for institutional needs [21]. The rotation mechanism is a defining feature of these composters. For smaller units, manual operation is facilitated through handles or cranks, allowing users to rotate the drum by hand easily. Larger units may incorporate motorized systems with electric motors that automate rotation, reducing manual effort and ensuring consistent mixing [20]. Aeration and mixing are optimized by including internal baffles or paddles attached to the drum. These structures enhance the blending of contents during rotation, ensuring that oxygen is evenly distributed throughout the composting material and that decomposition occurs uniformly [21]. Ventilation ports with adjustable settings allow users to regulate airflow and oxygen supply according to the composting stage and material moisture content. Loading and unloading are designed for user convenience and to maintain the composting environment. Hinged doors or lids provide secure openings for adding waste and removing finished compost. At the same time, some designs feature removable end caps to facilitate easy access to the interior of the drum. The base and support structure of the composter are critical for stability and functionality. A robust frame or stand elevates the drum, providing space underneath for leachate collection and simplifying the rotation process [22]. The design ensures stability through a broad base or anchoring system, preventing the unit from tipping during operation. Materials and construction focus on longevity and resilience. Using corrosion-resistant materials protects the composter from the acidic conditions that develop during composting. Weatherproofing measures, such as sealed designs and protective coatings, safeguard the unit against rain and external moisture, extending its service life [22]. Additional features may include built-in thermometers for temperature monitoring, allowing users to track internal conditions and adjust as necessary to optimize the composting process. Leachate management systems, such as

collection trays or reservoirs, capture excess liquids, preventing environmental contamination and enabling users to utilize leachate as a nutrient-rich liquid fertilizer.

2.4 Physicochemical parameters and their dynamics

Critical physicochemical parameters, including temperature, moisture content, pH, and the carbon-to-nitrogen (C/N) ratio, must be monitored and dynamically regulated throughout the composting process to optimize microbial activity and ensure high-quality compost production, as shown in Table 2.1.

Table 2.1. Comparison of different inoculum sources for composting various types of waste

Waste	Parameters	Values	Duration (days)	References
Digestate + Raw manure	pH	8.01 ± 0.01	60	[20]
	EC (mScm ⁻¹)	15.73 ± 0.03		
	NH ₄ ⁺ (gkg ⁻¹ dw)	15.91± 1.49		
	NO ₃ ⁻ (gkg ⁻¹ dw)	0.82 ± 0.08		
	Total carbon %	38.06 ± 0.43		
	Total nitrogen %	2.30 ± 0.04		
	C to N ratio	16.58 ± 0.58		
Digestate + sawdust	pH	8.5 ±0.02	30	[24]
	Moisture content (%)	54.7 ±1.20		
	EC (mScm ⁻¹)	3 ±0.30		
	NH ₄ ⁺ (gkg ⁻¹ DM)	2605 ±134		
	Total organic carbon %	43.4 ±0.04		
	Total nitrogen %	1.5 ±0.02		
	C to N ratio	28.9 ±0.02		
Digestate + Food	pH	8.1	48	[25]
	Dry matter (%)	5.1		
	NH ₄ ⁻ N (kg/t fw)	5.8		
	NO ₃ ⁻ N (kg/t fw)	<0.1		
	Total nitrogen (kg/t fw)	8.0		
Digestate + municipal solid waste	pH	8.5±0.05	100	[26]
	EC (μScm ⁻¹)	1075±8.49		
	Total solids (%)	37±0.20		
	Bulking density (kg m ⁻³)	790±48		
	Volatile solids (%DM)	48±40		

Waste	Parameters	Values	Duration (days)	References
	NH ₄ ⁺ (gkg ⁻¹ dm)	6.1±88		
	NO ₃ ⁻ (gkg ⁻¹ dm)	0.004.21±0.24		
	Total carbon (%DM)	24.5±1.80		
	Total nitrogen (%DM)	1.60±0.10		
Digestate + woodchips	pH	9.04 ± 0.03	105	[27]
	Water content (%)	81.5 ± 0.37		
	NH ₄ ⁺ (gkg ⁻¹ dw)	100 ± 57.80		
	NO ₃ ⁻ (gkg ⁻¹ dw)	8.48 ± 2.89		
	Total carbon %	6.81 ± 0.20		
	Total nitrogen %	0.54 ± 0.01		
	C to N ratio	12.6 ± 0.20		
	P ₂ O ₅ (%)	0.41 ± 0.00		
	K ₂ O (%)	0.99 ± 0.03		
Digestate + Food waste + Corn stalks	pH	8.79 ± 0.03	30	[28]
	EC (mScm ⁻¹)	2.63 ± 0.05		
	TS (%)	19.00 ± 0.18		
	VS (%)	14.00 ± 0.11		
	VS/TS	0.74 ± 0.00		
	NH ₄ ⁺ (gkg ⁻¹ dw)	0.68 ± 0.05		
	Total phosphorus (g/kg)	2.34 ± 0.14		
	Total potassium (g/kg)	9.14 ± 0.11		
Digestate + Sawdust	pH	8.1 ± 0.04	45	[29]
	EC (mScm ⁻¹)	7.06 ± 0.50		
	Moisture content (%)	51.2 ± 1.50		
	NH ₄ ⁺ (gkg ⁻¹ dm)	1712.3 ± 18.90		
	Total carbon %	33.8 ± 0.60		
	Total nitrogen %	1.1 ± 0.04		
	C to N ratio	29.70		
Digestate + Cornstalks	pH	8.3±0.00	45	[30]
	Moisture content (%)	84.3±0.30		
	EC (μScm ⁻¹)	2.0±0.10		
	Germination index (%)	78.7±2.10		
	NH ₄ ⁺ (mg kg ⁻¹)	2.43±0.04		
	NO ₃ ⁻ (mg kg ⁻¹)	363.1±0.10		
	Total carbon (%)	35.6±0.40		
	Total nitrogen (%)	1.6±0.00		
	C to N ratio	22.6±0.20		

These parameters significantly influence microbial growth, the decomposition rate of organic matter, and the overall composting efficiency. Temperature is a vital indicator of microbial activity and the composting process's progression [31]. The composting process begins with a mesophilic phase (20-45°C), followed by a thermophilic phase, where temperatures often exceed 55°C. This thermophilic phase is crucial for effective pathogen reduction, eliminating weed seeds, and breaking down complex organic molecules such as cellulose, hemicellulose, and lignin [32]. Sustaining these high temperatures accelerates microbial activity and ensures a faster breakdown of organic material. The temperature gradually decreases as the process matures, indicating reduced microbial activity and compost stabilization [32]. Moisture content is another essential factor, typically maintained between 40-60% to support microbial metabolism. Adequate moisture ensures that microbes can perform metabolic processes efficiently, as water is the medium for nutrient transport and enzymatic reactions [33]. However, excessive moisture levels can result in anaerobic conditions, leading to the production of methane (CH₄) and other undesirable byproducts, while too little moisture slows microbial activity and inhibits decomposition. Maintaining optimal moisture content is critical for keeping aerobic conditions and sustaining microbial communities [33]. pH levels also fluctuate throughout the composting process. Initially, the pH tends to be slightly acidic (pH 5-6) due to the production of organic acids during the early stages of decomposition [34]. As composting progresses, these acids are metabolized by microorganisms, and nitrogenous compounds like ammonia (NH₃) are released, gradually increasing the pH to a neutral or slightly alkaline range (pH 7-8). Monitoring pH is essential, as extreme acidic or alkaline conditions can inhibit microbial activity and slow the composting process [34]. Furthermore, excessive alkalinity above pH 8 can lead to ammonia volatilization, causing nitrogen loss. The Carbon-to-nitrogen (C/N) ratio is one of the most crucial parameters in composting, as it directly affects microbial growth and activity. A starting C/N ratio of 25-30:1 is ideal for

composting, ensuring a balance between carbon, which serves as an energy source, and nitrogen, which is necessary for protein synthesis [35]. As composting progresses, carbon is oxidized and released as carbon dioxide (CO₂), while nitrogen is either incorporated into microbial biomass or volatilized as ammonia. A final C/N ratio of 10-15:1 indicates compost maturity and stability, meaning the compost is ready for use as a soil amendment.

2.5 Analytical techniques for microbiome and physicochemical monitoring

Advanced analytical techniques are employed to investigate the complex interactions between microbial communities and physicochemical changes during composting. These techniques provide valuable insights into how microorganisms drive the decomposition process and influence compost quality. Metagenomic sequencing was used to analyze microbial community composition and abundance before and after composting. Although primer bias limits the representation of particular taxa, and the taxonomic resolution of metagenomic sequencing is less certain at lower levels of taxonomy [36]. The advantage of metagenomic sequencing may be compromised if DNA from non-target organisms also amplifies in the sample, and this could skew the completion of target taxa [36]. Samples for metagenomic analysis were collected from the point where composting began and again at the end to account for succession and environmental shifts. Additional considerations necessitated amending the methodology of the sampling approach to account for heterogeneities in the compost and a potentially unclear picture of how to depict microbial community dynamics. Lastly, increased sequencing depth is important for microbiome resolution. These techniques allow researchers to track changes in microbial diversity and community composition over time, revealing which microbes are responsible for the degradation of specific organic compounds [37]. Metagenomic sequencing further provides insights into the functional potential of microbial communities, offering a deeper understanding of the biochemical pathways active during composting [38]. In addition, flow cytometry was increasingly being used to analyze microbial populations in composting.

This technique allows for the rapid quantification of microbial cells by measuring the physical and chemical characteristics of individual cells [39]. Flow cytometry enables rapid, real-time analysis of microbial communities during composting by detecting changes in cell characteristics, allowing researchers to monitor shifts in microbial population structure throughout the process [39]. Physicochemical analyses play a crucial role in monitoring the changes in the physical and chemical properties of compost throughout the process. Moisture content and organic matter loss are routinely measured to track the rate of decomposition. Elemental analysis, such as CHNS analysis, is employed to assess changes in the carbon, hydrogen, and nitrogen content of the compost over time, providing valuable insights into nutrient dynamics and compost stability. Additionally, Fourier-transform infrared spectroscopy (FTIR) is used to characterize the chemical composition of organic matter in compost. FTIR detects changes in functional groups such as carboxyl, hydroxyl, and amino groups, enabling researchers to track the transformation of organic compounds like carbohydrates, proteins, and lignin during the composting process [40].

2.6 Bacterial communities

Bacteria are the predominant microorganisms during the initial and thermophilic phases of composting. Their rapid metabolism of easily degradable organic materials (such as sugars, proteins, and fats) generates heat, which accelerates the composting process and facilitates pathogen destruction [41]. Bacterial communities are dynamic and change during composting as conditions such as temperature, moisture, and oxygen availability shift. During the thermophilic phase (temperatures above 40°C), thermophilic bacteria such as *Bacillus*, *Thermus*, and members of the class Actinobacteria dominate. These bacteria have high-temperature tolerance and are primarily responsible for degrading complex organic compounds like cellulose, hemicellulose, and proteins [32]. Their activity generates the heat required for effective composting, aiding in the breakdown of organic materials that are more resistant to

decomposition. As the compost cools and enters the mesophilic phase (20°C to 40°C), mesophilic bacteria such as *Pseudomonas* and *Flavobacterium* become more active. These bacteria are essential for the degradation of organic matter during the later stages of composting, where they break down intermediate degradation products left by thermophiles [42]. MP disrupts compost bacteria by reducing microbial diversity and altering community structure. Some bacteria thrived while others declined, affecting the overall balance. This disruption slowed down organic matter degradation and reduced the efficiency of composting processes. Additionally, MP promoted the growth of certain pathogenic bacteria, further impacting compost quality and safety, as presented in Table 2.2.

Table 2.2 Influence of microplastics on biological treatment processes

Raw material	Treatments	Microplastic types	Particle size (μm)	Findings	References
Cow manure	Composting	PVC, PE, PHA	Less than 5000	PE and PVC slowed organic matter degradation, while PHA accelerated it. PE and PHA raised CH_4 and NH_3 emissions, whereas PVC reduced them. Microplastics also decreased nitrate levels and compost maturity.	[43]
Sewage sludge	Plant growth	PBAT, PLA, and PS	PS: $5\mu\text{m}$ and 70nm ; Bioplastic: 4.5mm	Soils contaminated with bioplastics and/or PS reduced α -diversity and significantly affected the dominant fungi.	[44]
Cow manure	Composting	PE, PVC, PHA	Less than 5000	PE and PHA microplastics reduced humification and increased pathogenic bacteria, destabilizing the community structure.	[45]
Sewage sludge	Vermicomposting	PE	100–200	Microplastics at 200,000 particles/kg lowered bacterial diversity and inhibited sludge degradation and stabilization during vermicomposting.	[46]
Cow manure	Composting	PHA, PVC, PE	Less than 5000	Microplastics decrease bacterial diversity and richness during the thermophilic stages.	[47]

Raw material	Treatments	Microplastic types	Particle size (μm)	Findings	References
Sewage sludge	Vermicomposting	HDPE, PP	HDPE: 146–500; PP: 1650–2000	Microplastics had no impact on pH, EC, C/N ratio, or pathogen levels. Their abundance decreased while oxygen-containing functional groups (C-O and C=O) increased.	[48]
waste activated sludge	Anaerobic digestion	PET	25	Acidogenesis, hydrolysis, and methane production were suppressed.	
Sewage sludge	Hyperthermophilic composting	PS	Less than 500	hTC technology boosted microplastic removal by altering their structure and enhancing microbial biodegradation.	[49]
Sludge + Earthworm	Vermicomposting	HDPE, PP	HDPE: 1650 – 2000; PP: 146–500	Vermicomposting with <i>E. eugeniae</i> earthworms effectively bioremediates sewage sludge with microplastics, improving soil quality and reducing microplastic pollution.	[50]
Sewage sludge	Aerobic	PLA, PCL, PE	20	Mater-bi was the most biodegradable, while PCL, EB, and PLA degraded mainly under aerobic conditions, with PLA being the least biodegradable.	[51]
Cow manure + sawdust + biochar	Composting	PHA	Less than 2	Biochar enhanced PHA-MP degradation, boosting carbon loss and microbial activity.	[52]
Cow manure + sawdust	Composting	PE, PVC, and PHA	Less than 2	PE and PHA MPs decreased by 13–29%, with slight PVC reduction, while composting increased oxygen by 3–30% and influenced bacterial diversity.	[47]
Waste activated sludge	Anaerobic digestion	PVC	1000	Low levels of MPs increased methane production, but higher concentrations suppressed it.	[53]

Mesophilic bacteria play a crucial role in nutrient cycling, converting organic nitrogen to ammonia, which is later nitrified to form nitrates by other microorganisms [42]. Actinobacteria, a subgroup of bacteria, are known for degrading recalcitrant organic matter such as lignin and complex polysaccharides. Actinobacteria such as *Streptomyces* are particularly important in the later stages of composting when the more readily degradable materials have been consumed [54]. These bacteria contribute to the formation of humus, the stable organic matter in compost that improves soil structure and nutrient retention. Bacterial diversity is highly responsive to the composted organic materials, the inoculants used (such as anaerobic digestate or raw manure), and environmental conditions like aeration and moisture. The presence and activity of specific bacterial communities are critical for determining the efficiency of the composting process and the quality of the final compost product.

2.7 Applications and implications for sustainable waste management

Understanding the intricate interplay between microbiome dynamics and physicochemical changes during composting is essential for optimizing the process and producing high-quality compost. The maturity and quality of the compost are determined by its structural stability, nutrient content, absence of pathogens, and appropriate C ratio. High-quality compost is valuable in agricultural applications, where it enhances soil structure, increases water retention, and provides essential nutrients, reducing reliance on chemical fertilizers [55]. Moreover, the ability to manage and optimize composting processes through careful monitoring of microbial communities and physicochemical parameters has significant implications for sustainable waste management. By improving composting efficiency and expanding its application to diverse organic waste streams, it is possible to reduce the environmental impact of waste disposal, contribute to carbon sequestration in soils, and promote the circular economy through the recycling of organic matter. This detailed study of waste bioconversion through composting, with a focus on microbiome dynamics and physicochemical analysis, provides

crucial insights into optimizing this process for environmental and agricultural benefits. Future research may explore novel microbial consortia or advanced monitoring technologies to further enhance the efficiency and sustainability of composting practices.