



A review on the trends and technologies in biomass composting

Emmanuel F. Borre

Nueva Ecija University of Science and Technology, Nueva Ecija, Central Luzon, Philippines

*Corresponding author.

Email address: emmanuelfborre@gmail.com

doi: 10.14456/abe.2026.1

Received 24 July 2025
Revised 13 October 2025
Accepted 13 November 2025

Abstract

Biomass resources abound in the Philippines, including agricultural crop residues, forest residues, animal waste, agro-industrial waste, urban solid waste, and aquatic garbage. The common agricultural wastes in the country are rice straws, rice husks, corn cobs, sugarcane debris, cacao waste, coconut shell, and coconut. Composting is the controlled aerobic biological breakdown of organic materials into a stable, humus-like product called compost. It's essentially the same process as natural decomposition, but it's accelerated and enhanced by mixing organic waste with other substances that promote microbial development. Composting has long been recognized as an effective method for recycling organic waste. However, despite its benefits, traditional composting still faces several limitations that hinder its wider adoption and efficiency. According to Ayilara, et al. [1], the major challenges include difficulty in detecting and controlling pathogens, inconsistent material quality, prolonged composting and mineralization periods, and issues related to odor generation. These constraints reduce overall productivity and limit the potential of composting as a scalable waste management solution. Chemical fertilizers contribute to greenhouse gas emissions, environmental degradation, the extinction of soil organisms, marine life, ozone layer depletion, and even human diseases. Composting agricultural wastes has been a regular technique among farmers in rural areas in recent years. With the inclusion of other materials, organic waste is degraded into organic fertilizer in a natural composting process. Compost is acknowledged as one technique to improve the soil's nutritional status by releasing accessible nutrients such as nitrogen and phosphorus from additional organic leftovers via microbial decomposition. Composting is an important part of agriculture since it promotes the recycling of farm waste. Due to the presence of materials that take longer to compost, particularly during co-composting, and a lack of proper composting technology, the protracted composting process and laborious hand mixing of the compost pile are definitely challenging. This review article examines how waste is managed through different composting methods, different elements that affect composting, the long composting processes and the theories behind them, compost bioreactor technologies, and current trends and future possibilities in composting. In addition, this review article also shows that the degradable organic components used in composts are evaluated for their capacity to mineralize slowly, making them beneficial to crops. As a result, the composting processes have been improved.

Keywords: Composting, Waste management, Decomposition, Agricultural waste, Bioreactors, Biodegradability

1. Introduction

Having a land size of 30 million ha, the Philippines is considered as a country that is rich in agriculture. Agriculture covers 47% of the country's total land area. Agricultural crops, which include food grains, food crops, and non-food crops, cover a total of 13 million ha. Among the crops grown, rice, coconut, and sugarcane make significant contributions to biomass energy resources [2]. Rice husk, rice straw, sugarcane trash, cacao waste, corn cobs, coconut husk, coconut shell, bagasse, and manure from poultry and piggery farms are the most frequent agricultural wastes in the Philippines.

Nowadays, composting of agricultural wastes has become a common practice of farmers in rural areas. Composting of biomass by natural process is where the organic waste is decomposed into organic fertilizer with the addition of other material. Compost is recognized as one way of improving the nutrient condition of the soil as a result of the release of available nutrients such as nitrogen and phosphorus from the added organic residues, through microbial decomposition [3].

Composting helps to improve soil fertility, stabilize the environment, reduce global warming by providing an alternative to direct burning, and improve waste management. Furthermore, organic composting transforms ammonia waste into beneficial nitrogen-rich compounds. Although segregation is essential for natural organic composting, the favorable circumstances achieved for microorganisms to break down the waste will result in organic compost being produced in less time. Composting is a safe waste management strategy. During the aerobic composting process, microorganisms degrade and transform a range of degradable materials

into organic and inorganic byproducts. The byproducts are distinguished from natural soil, coal, and peat by 'humic-like' components. Composting is the process of converting various degradable wastes into compounds that can be used as biofertilizers and soil additions in a safe and efficient manner [4].

Unlike landfilling, which risks subsurface water pollution due to leachate, the composting process actively aids in protecting underground water. This protection is achieved through the thermophilic phase, where high temperatures (55°C to 65°C) effectively eradicate pathogenic bacteria. Furthermore, the extensive microbial decomposition breaks down and stabilizes complex organic compounds and many chemical contaminants, significantly reducing the generation of mobile, toxic leachate that could otherwise infiltrate the groundwater. Composting elevates agricultural production and soil organic matter content by sufficient suppletion of nutrients and the presence of plant growth-promoting organisms in decomposed materials [1]. This has a significant bearing on food security. Compost can be used for bioremediation, plant disease management, weed control, pollution mitigation, erosion control, landscaping, and wetland restoration, to name a few. Composting also improves soil biodiversity and alleviates the damaging effects of synthetic fertilizers on the environment [1]. Composting is done in a controlled environment rather than a natural decomposition process. Composting varies from decomposition in that it takes longer to complete, emits an unpleasant odor, mineralizes slowly, and may contain germs that can defy high temperatures.

This review article evaluates the challenges associated with the conventional composting process and the future prospects and technologies that can make the composting ensure the sustainable agriculture.

1.1 Biomass waste

Organic materials found in wastes and residues from agriculture, livestock waste, forestry, and other industries, such as fishery waste and municipal wastes, are referred to as biomass waste. The methods for converting biomass are shown in Table 1.

Table 1 Biomass conversion methods

Conversion methods	Advantages	Disadvantages
Chemical conversion methods		
1. Hydrolysis	Low temperature	Low sugar yield, expensive
2. Ozonolysis		Expensive technology
3. Meteorinization		
4. Hydripyrolysis		
Thermo-chemical conversion methods		
1. Burning	Efficient	Pollutant formation
2. Gasification	Gas cleaning equipment that is less expensive 40–50% efficiency	Higher NOx
3. Pyrolysis		Higher NOx
4. Liquidation	Waste is converted directly into high-quality fuel	Complex & Expensive
Biochemical conversion methods		
1. Enzymatic hydrolysis		
2. Fermentation	Large scale application	Complex
3. Anaerobic decomposition	Available in the market Can handle wastes containing 80–90%wb	low amounts of substrate

Source: U.S Department of Energy (DOE)

With the appropriate treatment, biomass can be converted to energy. Biodiesel, biogas, bioethanol, solid fuels (briquettes/pellets), bio-fertilizer, and bio-insect repellants are just few of the high-value-added products that may be made from biomass utilizing the above-mentioned conversion technique. In the Philippines, biomass waste is used in multi-purposes such as energy generation in the agricultural and fishing industries, as well as energy production in wastewater treatment plants.

1.2 Agricultural and livestock biomass waste

As a preliminary step for the anaerobic digestion process, biomass is required. Agricultural waste (wheat, sorghum, rice, corn, cacao waste, sugarcane and other residues), livestock waste and food waste are all abundant and often unlimited sources of biomass energy. Despite the fact that pretreatment treatments are usually required for optimal methanogen efficacy, the amount of methane produced by these materials is typically quite significant [5].

According to waste generation data from the National Solid Rubbish Management Commission, they estimate to produce 16.63 million t of waste in 2020, up from 14.66 million t in 2014, a 13.44 % growth. According to 2018 data, The Philippines produces the third most solid waste per year among ASEAN countries. The only countries that produce more are Thailand and Indonesia.

1.3 Advantages of biomass waste

Biomass energy resources such as rice straw, wheat, rice husk, corn husk, corn cobs, sugarcane wastes, cacao pods, and livestock waste offers some benefits for power generation. The advantages of biomass energy sources as follows:

- Renewable energy sources – agricultural waste, dung, and livestock waste are all continuously created by human activity; this supply of biomass will never run out.
- Carbon-neutral – the use of biomass power generation follows the principle of carbon-neutral cycle.
- Cost and effective - as compared with other forms of renewable energy generation, biomass is much more affordable.
- Small scale power generation - in rural areas, power production can be done on a small scale through the gasification method.

- e. Variety of Feedstock – rice husk, rice straw, corn cobs, cocoa pod waste, and other biomass feedstocks can be used to generate electricity.
- f. Reduces methane gas - the breaking down of organic matter releases methane gas in an indirect manner; however, the emission of methane gas could be controlled by burning biomass for energy.

2. Conventional practices in composting

Composting is described as the controlled aerobic biological breakdown of organic materials into a stable, humus-like product known as organic matter. It's essentially the same process as natural decomposition, but it's accelerated and encouraged by mixing organic waste with other substances that promote microbial development. Composting animal waste and other organic matter can potentially contribute to manure management, limit weed seeds and infections, and reduce emissions and other vector problems. When compost is added to the ground, it fertility of the soil, tilth, and water holding capacity. It also has no disagreeable odor and may be stored for an extended period of time. Composting organisms require specific nutritional and environmental conditions to develop and function.

Composts can be successfully widely used in agriculture with changing and fertilizing processes to restore degraded degenerated soils or maintain/ or increase soil fertility; to exert plant disease; to remove carbon from the soil, thus mitigate climate change; to cut costs and adverse effects of farming activities by limiting inputs of organic manure, pesticides, and fuel; and to reduce cost and negative impacts of agricultural activities by limiting inputs of fertilizers, pesticides, and fuel [6].

The mixture of raw materials such as dead leaves, farm wastes, residential and commercial rubbish, buffalo or goat manure, and carbonaceous rice husk is placed into piles and physically stirred every two weeks to facilitate consistent decomposition in traditional composting systems.

Degradable organic wastes can be eliminated through composting. Biodegradable wastes are organic wastes that can be degraded [7]. Composting is a viable method of converting diverse organic wastes into compounds that can be utilized as biofertilizers in a safe and efficient manner. Recalcitrant materials, such as polythene bags and plastics, cannot be decomposed. Composting is a safe approach to rid of organic waste; however, it is related with the emission of odors and of greenhouse gasses (CO₂, SO₂, and NO₂). Table 2 further demonstrates the contrasts between traditional and composting waste management systems.

Table 2 Comparison between composting and conventional waste management

Conventional	Composting
- Conventional waste management techniques (dumping in the open, rivers, and the seas, etc.) pollutes the environment (sanitary landfills and incineration) the land, the air, and the bodies of water.	- Composting contributes to environmental protection because it aids in the retention of soil particles. As a result, erosion is prevented. It aids in the recycling of garbage into valuable items such as fertilizer and other biomass products in a controlled setting.
- They (animal feeding, incineration, open dump, river and ocean dumping) are home to pests, diseases, and insects that are harmful to human and animal health.	- It also contributes in the prevention of plant diseases, and soil enrichment
- They make a significant contribution to the greenhouse effect. This occurs as a result of waste combustion.	
- Water waste from river, ocean etc.	- They contribute in the reduction of greenhouse gases by reducing the production of methane.
	- Reduces the amount of waste and pollutants produced.
	- It also increases biodiversity in the soil.

2.1 Composting process

The biological decomposition and presence of organic matter is known as composting. The process increases the temperature, resulting in a final product that is stable, free of pathogens, and contains viable plant seeds that can be put to the ground. As the product stabilizes, odors are reduced, and infections are eliminated, where it can be usefully applied to the ground [8].

Composting is the best method of handling crop wastes and residues, which are still in the field. Composting speeds up decomposition. It is a clever way of producing humus or the organic part of the soil made of decayed matter. The method by which the production of humus is speeded up from normal rate of cellulose decomposition is called “composting” [9].

Composting is carried out by a vast group of mostly aerobic microorganisms that breakdown organic matter to grow and reproduce. The carbon to nitrogen (C:N) ratio, oxygen levels, moisture content, temperature, and pH of the compost pile are all managed to increase the activity of these microbes.

The composting process can be separated into two phases, the USDA [10]: (1) active composting and (2) curing. The active decomposition phase is the period of high microbial activity during which easily degradable materials, as well as some more decay-resistant materials like cellulose, are degraded. Curing happens following active composting and is characterized by decreasing bacterial growth and further degradation of the active composting stage's output. The compost is said to be stabilized when it has reached the end of the curing process. When the compost has completed the curing process, it is considered to be stabilized. During the active composting period, the compost pile experiences a wide variety of temperatures. As the temperature changes, certain microorganisms find themselves in inappropriate surroundings, while others find themselves in excellent conditions.

The psychrophilic, mesophilic, and thermophilic temperature ranges exist throughout the three active composting periods. Psychrophilic temperatures are below 10°C. Mesophilic temperatures are between 10 and 40°C. Thermophilic temperatures are over 40°C. Depending on the ambient temperature and the temperatures of the compost mix material, the early stage of composting is defined by either psychrophilic or mesophilic temperatures. Before the temperature starts to rise significantly during the composting process, there is usually a small lag period. The lag period is the amount of time it takes for a microbial colony to evolve. As the microbial population expands and begins to degrade the most readily degradable material, the heat generated by microbial activity is trapped by the self-insulating compost material. The temperature of the compost pile continues to climb as the heat within the pile rises. The microbial population is growing [10].

The Figure 1 shows the temperature changes in composting, the environmental advantage of composting over landfilling is best understood by reviewing the temperature changes during decomposition. Unlike landfilling, which creates toxic leachate that risks subsurface water pollution, the composting process actively protects groundwater through its staged decomposition. Specifically, the high-temperature thermophilic phase (reaching 55-65°C) is significant, as the intense heat effectively eradicates pathogenic bacteria. Following this, the stabilization/maturation phase ensures that complex organic and chemical contaminants are broken down and converted into stable, non-toxic humic substances, thereby dramatically reducing the potential for soluble pollutants to leach into the water table. Additionally, for heterotrophic microorganisms, there are two possible forms of energy-producing metabolism throughout the composting process: respiration and fermentation. Aerobic or anaerobic respiration is possible. Aerobic microbes use oxygen in aerobic respiration, whereas fermentation is the most basic form of energy creation. It is inefficient and does not require any use of oxygen. While only a small amount of energy is generated, most of the carbon released by fermentation is converted to end-products rather than cell replacements.

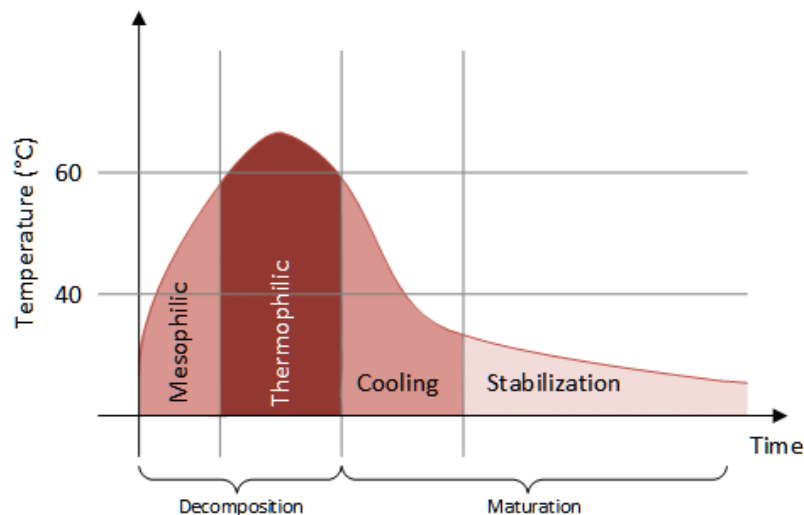


Figure 1 Temperature changes in composting.

2.2 Factors affecting composting

The texture of the source materials, the compost temperature, moisture content, pH, oxygen, and the C/N ratio are all factors that influence composting.

2.2.1 Temperature

As a result of their metabolism, the temperature of the compost gradually rises. The amount of waste handled can sometimes affect the temperature (heat generation); if the volume of waste is low, the high temperature may not be obtained. Pathogens may expire even if the temperature in the composting materials does not reach 45-50°C during the composting process [11].

2.2.2 Moisture content

The moisture of composting materials should be maintained between 40% and 60%, according to Ameen, et al. [12]. Compost is believed to get its moisture from either the water added at the start or the metabolic water produced by microbial activity. Excess water inhibits oxygen transport, slowing the metabolic activities of organisms. Microbial cells require water to complete their metabolic operations. As a result, microbes can only eat organic compounds that have been dissolved in water. The moisture level of the compost decreases as the process progresses, and it becomes dry matter.

2.2.3 pH and Oxygen

The presence of oxygen is key during the composting process. When organisms oxidize carbon to create energy, the environment's oxygen supply is diminished, and gasses are generated. If there isn't enough oxygen, the composting process would become anaerobic, and gasses (methane, carbon dioxide, and ammonia) will be produced, resulting in foul odors [13].

According to Ameen, et. al. [12], composting rate is influenced by the pH of the materials being composted. Composting is said to be best when the pH is alkaline. Composting takes a long time when the pH is acidic because the microorganisms are destroyed.

2.3 Composting techniques

There are various composting methods, each with its own set of advantages and disadvantages. As a result, the composting method to be used is dictated by the approach that best meets the researcher's purpose and the kind of material to be used for the compost. The following are some of the composting processes.

2.3.1 On-site composting

According to Calkins [14], onsite composting is basically a process of collecting trimmings such as food scraps, dead animals, manure, and farm wastes into a bin or pile. In the process, the pile has to be monitored and turned to mix and break down the trimmings using a mixer. It basically helps reduce the amount of food that is thrown away. It is indeed helpful for both the people and the environment. However, onsite composting is not an easy task because it follows certain considerations and procedures. Meg Calkins explains that depending on the temperature, available composting materials, space limits, and other considerations, different sites will have varied requirements for composting systems. A few guidelines for onsite composting were given by Calkins [14].

- a. Using a slightly damp wrung-out sponge, keep the pile moist.
- b. Before adding huge woody trash to the pile, chop it up into smaller pieces.
- c. To maintain the proper carbon nitrogen ratio, mix green resources like fresh grass clippings with brown carbon-heavy materials like dry leaves.
- d. Keep invasive plant scraps and deceased plants out of the compost.

Moreover, there are some other factors to consider when doing on-site composting such as the shift of seasons where a little adjustment has to be made, managing food scraps properly to make sure they don't cause unpleasant odor and attract unwanted insects and animals, and the length of time in creating the compost.

In Figure 2, shows the on-site composting, a common method of organic waste management where decomposition occurs directly at the source of waste generation rather than at a centralized facility. The Figure 2 shows a dedicated, covered "Composting Facility" and workers actively mixing or screening compost material. This decentralized approach is advantageous because it minimizes the transportation costs and emissions associated with hauling organic waste to distant landfills or large processing plants. This method is highly effective for managing organic waste from specific sources like large institutions, schools, parks, or communities. The resulting compost is then immediately available for use on-site in landscaping, gardening, or agriculture, effectively closing the nutrient loop. By promoting localized resource management and the diversion of organics from landfills, on-site composting directly supports sustainability goals, reduces the volume of waste sent for disposal, and contributes to soil health and local food security.



Figure 2 On-site composting

2.3.2 Aerated windrow

Windrow composting is the method of placing a composite of raw materials in long, thin stacks called wind-rows, which are disrupted or stirred on a regular basis [15]. Turning the composting materials improves passive aeration by mixing them together.

Windrow systems are a form of composting system that is simple and low-cost as shown in Figure 3. The feedstock is stacked in long piles on a gentle slope surface that can be open to the air or covered. The windrows are aerated using convective heat transfer, which is helped by occasional turning with front-end loaders or specialized turning equipment. The wetness, texture, and stability of the material, as well as aeration methods and operational goals like odor control, composting pace, and pest management, all influence the frequency of rotation. Blowers can be used to force air through the windrows for more efficient aeration and heat removal. To decrease odors, process controls are applied in both windrow and aerated windrow plants [16].

2.3.3 Aerated static pile

As explained by De Bertoldi, et al. [16], the simplest type of composting is static pile composting, however it is rarely employed due to the possibility for odor emission. Aeration is aided in this method of composting by a set of perforated pipes running beneath each compost pile and connected to a mechanical blower system. A coating of coarse bulking material is applied to the pipes, which functions as a manifold to ensure uniform aeration. Finally, cured compost is applied to the piles for insulation and regular aeration. Industrial fans or blowers are used to blow or pull air through the piles. The pile is "static" since it is not turned. Blower power varies from 1 to 5 hp, depending on pile size, mixture density, and piping configuration. The main difference between a passively aerated windrow as well as an aerated static pile is that the second uses pressurized blowers to suction or blow air into the pile [17].

Air can be supplied to a static pile composting system in two cases: a suction tool that draws air through the pile, or a pressure system that pushes air into the pile via a blower. Air is suctioned in from the pile's exterior and collected in the aeration pipe. If odors arise during the decomposition process, the exhaust air can simply be purified because it is enclosed in the discharge pipe

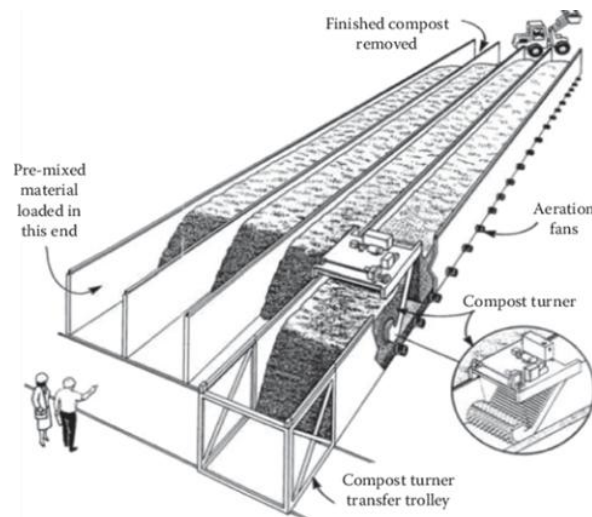


Figure 3 Aerated windrow

The Figure 4 illustrates the setup of an Aerated Static Pile (ASP) composting system, a method designed to efficiently manage materials like sewage sludge and other hard-to-compost wastes. In this system, the waste material (sludge) is mixed with a bulking agent (such as wood chips or shredded yard waste) to maintain porosity, which is essential for air circulation. This mixed material is then constructed into a large, static pile over a network of perforated pipes. The term "static" means the pile isn't regularly turned or mixed after its initial formation.

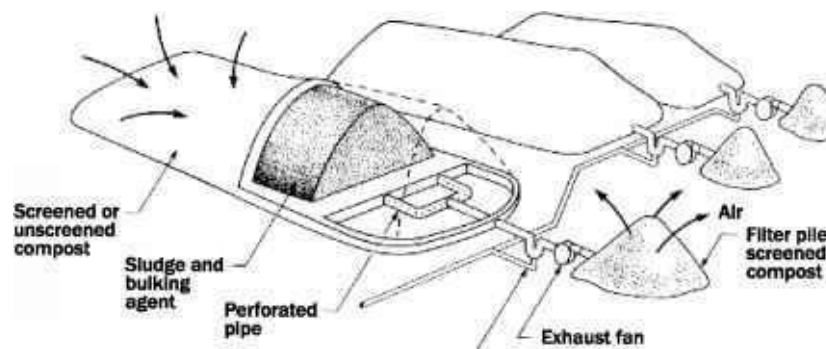


Figure 4 Aerated static pile

The key to this method is the forced aeration system. Air is either pushed into or pulled out of the pile through the perforated pipes by an exhaust fan, ensuring that the entire mass receives the oxygen necessary for the microbial decomposition process. This controlled airflow maintains the ideal temperature range (the thermophilic phase) throughout the pile, ensuring pathogen kill and rapid stabilization. Exhaust air is often channeled through a filter pile of screened, finished compost to remove odors before being released. Once the composting is complete, the pile is broken down, and the material is typically screened to separate the finished compost from the remaining bulking agent.

2.3.4 Bio-composting

Keswani [18] explained that bio-composting is a natural and sustainable biological process that permits highly decomposing organic biomasses to be turned into composted biomasses through the action of endogenous microorganisms that colonize them during the curing phase. Keswani also added that the biomass is subjected to complicated interactions between substrate and microbiota in this method of bio-oxidative transformation in the solid phase, to which it is subjected if stacked in oxygenated heaps utilizing forced air. The materials added into the compost heap have a significant impact on the soundness of the composting process and the ultimate product quality (compost). Moreover, Maheshwari [19] explains further that composting should include a variety of materials as well as a C:N ratio that is suitable. Various bacteria at work in the pile could provide extremely high profitability in terms of producing nutrient-rich compost.

2.3.5 Vermicomposting

According to Sherman [20], vermicomposting is a technique that uses earthworms and microorganisms to break down organic matter and convert its biological, physical, and chemical properties into a stable product that may be utilized as a soil amendment and plant fertilizer source. Vermicomposting transforms organic waste into vermicast, a nutrient-dense, microbially active soil additive or plant growth medium as shown in Figure 5. When vermicast is mixed with soil, it increases the amount of nutrients available to plants while also improving the structure and drainage of the soil. Vermicast promotes plant growth and production while also reducing the impact of pests and diseases.

Based on the article Compendium on Solid Waste Management by Vermicomposting, *Eisenia foetida* and *Lumbricus rubellus* are the only two earthworm species utilized in vermicomposting. Red worm is a common name for both of these species. *Lumbricus terrestris* (the nightcrawler) and *Allobophora caliginosa* are two more species that have purportedly been used in experimental trials (the field worm). The lower reaches of composting windrows are frequently invaded by these species. Because earthworms are involved in the indirect stimulation of microbial populations through fragmentation and absorption of fresh organic compounds, which results in a greater surface area available for microbial colonization, significantly changing biological functions, earthworms are critical factors in the biochemical degradation of organic materials. The presence of earthworms in the soil encourages the growth of bacteria.



Figure 5 Vermicomposting

2.4 Uses of compost

Compost is used to improve soil fertility, agricultural yield, erosion management, and soil amendment, among other things. Compost, according to Majbar, et al. [21], improves soil fertility and plant output. Another method of applying compost for plant growth is to supplement it with synthetic fertilizer. Because the majority of the evidence suggests that synthetic fertilizer is more effective than compost in promoting plant development, we recommend combining the two in appropriate quantities. Plant-growth-promoting bacteria are also found in composts, which contribute to soil fertility and plant growth.

Furthermore, it helps with disease preventive measures, bioremediation, and waste treatment. Compost is used as a biological control for plant diseases. Compost microorganisms employ a variety of strategies to combat their hazardous rivals. Resources competition, parasitism, predation, antibiotic synthesis, lytic production, and other extracellular enzymes or chemicals are all examples of extracellular enzymes or chemicals [22].

2.5 Major component in compost

Compost must have certain elements in sufficient quantities to provide necessary nutrients to plants in order to be helpful. If the compost is meant for landfills, these components may not be necessary.

2.5.1 Nitrogen

According to Khater [23], Plant growth and development are hampered by a lack of nitrogen, which is one of the most essential components for plant development. Nitrogen is an important component of chlorophyll, which gives plants their green hue. Compost has been found to have the ideal Nitrogen content for plant growth. The nitrogen that has accumulated in the compost as fertilizer is eventually released. Excess nitrogen can cause quick growth, high contrast color, and a weakened root system in plants. Excess nitrogen can burn the leaf tissue in rare situations, while a nitrogen deficiency can cause the leaves to turn yellow.

2.5.2 Phosphorus

The phosphorus is the important cell division in plants; it can generate new tissue and complex transformation plants. Adding the phosphorus to the soil, it promotes the root growth, stimulates tilling, and fruit development delays in maturity. Also, there could be a change in color in the leaves. According to some studies, the compost has a phosphorus concentration that is necessary for the growth of plants.

2.5.3 Potassium

Potassium is a vital mineral for plant growth [1]. It promotes plant growth, carotene production, and chlorophyll production. It boosts plant color and vitality. Potassium is required by the plant in order to create carbohydrates. It's also vital since it helps the plant resist illness and tolerate extreme environmental conditions like drought and cold. Potassium deficiency in plants can induce blistering and browning of older leaves' tips, which can gradually spread to the entire leaf. Weak stalks may also be connected to a potassium deficiency. According to Kammoun, et al. [24], composts are a good source of considerable phosphorus for plant growth.

2.6 The microbiology of composting

According to Hafeez, et al. [25], the resident microbial community is the essential component responsible for biodegradation and conversion during the breakdown process. Composting is accomplished through the action of a diverse microbial community. Composting involves two types of aerobic microorganisms: mesophilic and thermophilic. Bacteria, actinomycetes, molds, and yeasts are among the organisms that dominate different stages of composting [26].

Biodegradative activity has been discovered in actinomycetes, which release a wide spectrum of extracellular enzymes [26]. They can also metabolize substances that are resistant to decomposition. They can also break down resistant molecules. According to Ghanbarzadeh, et al. [27], some lignocellulose degrading bacteria are involved in composting. Polysaccharides (cellulose and hemicellulose), phenolic polymer, and lignin make up lignocellulose. The capacity of organisms to decompose organic materials is determined by their ability to produce enzymes that breakdown the substrate's components (cellulose, hemicellulose, and lignin); Furthermore, whereas some fungi can break cellulose, they can only partially decompose lignin. As a result, regulating these bacteria can aid in the composting process's acceleration.

3. Composting reactor technologies

The bioreactor is a vessel that is used to carry out a biological response or transformation. It's a device that naturally digests organic stuff, primarily agricultural and livestock waste, to produce biogas and environmentally pure fertilizers for use in agriculture and other industries. It transforms waste into a nutrient-rich solution that works as a carbon dioxide, nitrogen oxide, and sulfur oxide absorber. A bioreactor has the advantage of allowing sustained biological digestion of agricultural and animal waste, as well as the creation of organic fertilizer and biogas as byproducts, without the need for additional filters or water. Biological systems included include enzymes, bacteria, and other cells. The bioreactor is a technology that generates the optimal external environment for the biological reaction system, resulting in a high bioprocess yield [28].

One of the technologies that are used in composting is the bioreactors. This paper comprehensively reviews the different types of bioreactors that will appropriate the in compost production such as tubular or plug-flow reactors, fixed bed reactors and agitated bioreactors.

3.1 Tubular/plug-flow reactors

The tubular flow reactor, also known as the Perfect Flow Reactor (PFR), is the simplest chemical reactor in which chemicals and reagents are supplied at one tail end, move through pipes at a constant speed for a set amount of time, and then mix as they flow towards the output. This reactor's tube acts as a continuous source of input and output material. Pipe reactors with/without static mixing internals provide a more efficient and cost-effective place for blending where faster mixing, brief hold-ups, and minimal cost are sought [29]. Plug-flow reactors (Figure 6) are less expensive and take up less room to build, but they have a low Reynolds number. Furthermore, between the entrance and exhaust of these bioreactors, substantial temperature fluctuations occur at various points [28].

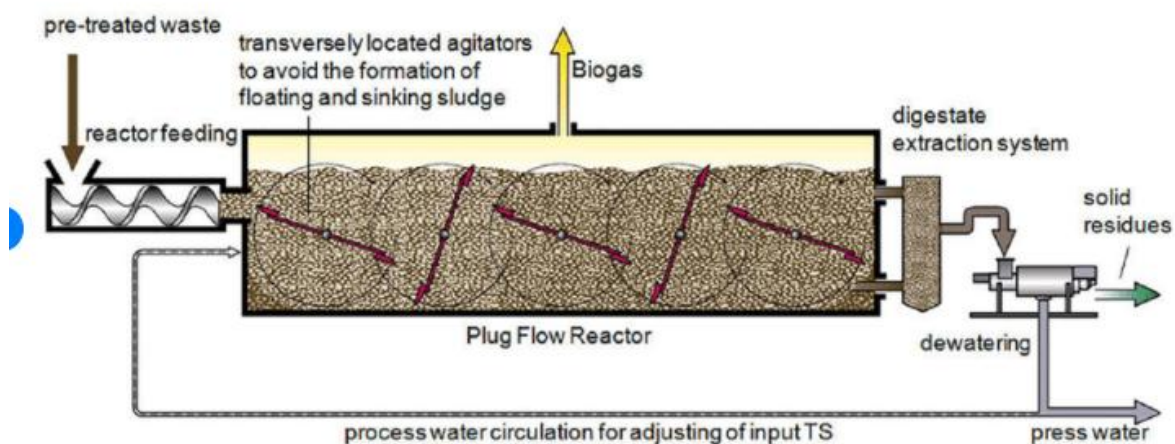


Figure 6 Plug flow reactor anaerobic digester

3.2 Agitated reactors

Agitated bioreactors are a type of fuel diffusion reactor that comprised of a cylindrical container with no movable mechanical components and compact air or gas mixture introduced at the bottom of the vessel through nozzles, perforated plates, or a ring sparger for aeration, mixing, and fluid circulation. In comparison to mechanical stimulation reactors, these bioreactors are tall and slender. In pneumatically agitated bioreactors, the height-to-diameter ratio is often high. In bubble columns, air is bubbled at the bottom of the column, agitating the medium. Airlift (Figure 7) and bubble-column bioreactors (Figure 8) are the two basic types of agitated bioreactors, both of which have minimal shear stress and are easy to design and construct. They are made up of a main body, an air-bubbling device, a steam generator for sterilizing, an air intake, an air vent system, different temperature, oxygen, and pH monitoring systems, and pipeline systems for transporting steam, air, medium, and product masses [28].

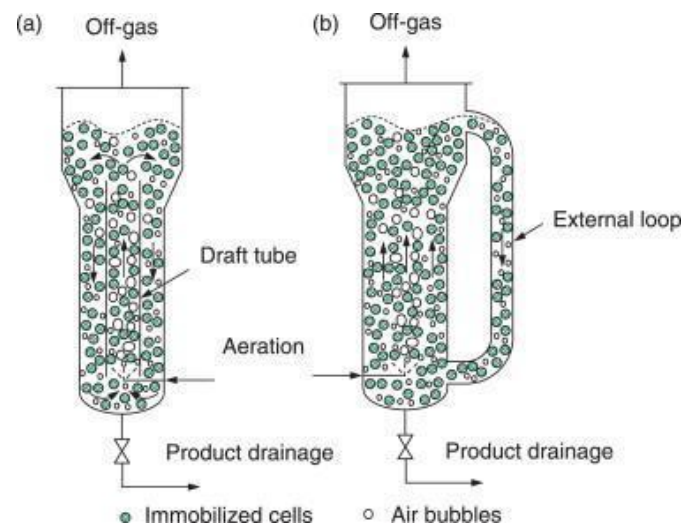


Figure 7 Air lift bioreactors

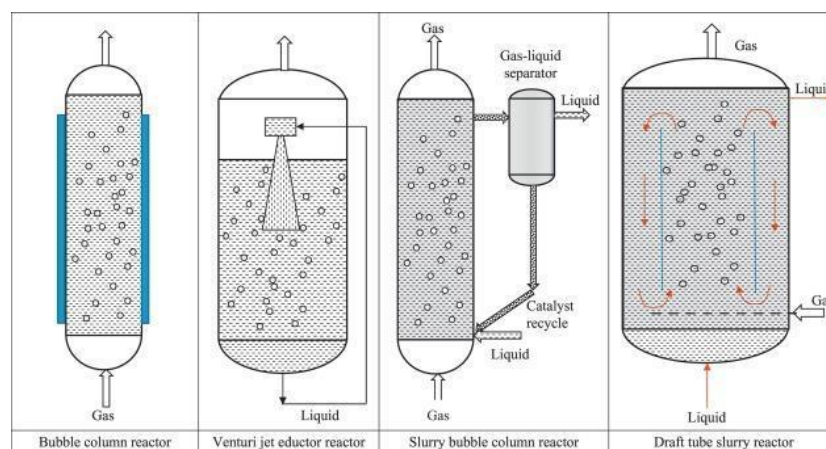


Figure 8 Bubble column bioreactors

3.3 Fixed bed reactors

The simplest sort of reactor to construct is a fixed bed reactor, which consists of solid catalyst particles being loaded and packed into the bed. The ease of usage and rapid response rates of this type of reactor are two of its benefits. Large solid–liquid specific interfacial contact areas occur from the immobilization of enzymes or cells in appropriate carriers packed in fixed reactors, and the acceleration of liquid moving over the static solid particles dramatically reduces film resistance to mass transfer. Due to low fluid velocities, one of the fundamental limitations of fixed-bed bioreactors is that they have poor mass and heat transfer coefficients. Effective gas–liquid interaction and carbon dioxide removal are critical for aerobic biological systems. Gas flooding and poor liquid distribution are common in fixed-bed reactors due to stationary gas pockets. As a result, it's rarely used in aerobic microbial fermentation.

The Figure 9 shows three different fixed-bed reactor design concepts commonly used in biochemical and industrial processes, where cells or biocatalysts are immobilized on a solid support (the fixed bed). Diagram (A) illustrates the simplest design, a fixed bed with axial flow and plug flow. In this setup, the liquid substrate (feed) enters at one end and flows straight through the bed along its axis, and the product (harvest) exits at the other end. The flow is idealized as "plug flow," meaning the entire volume of fluid moves through the reactor as a single, coherent slug with minimal mixing.

Diagrams (B) and (C) show more complex configurations. (B) features a fixed bed with axial flow coupled to an external conditioning vessel. The substrate flows through the fixed bed, but a separate, stirred conditioning vessel is used to manage and recirculate the fluid, allowing for better control over parameters like pH and nutrient concentration, and facilitating the separation of waste gases and products. (C) depicts a system with a plug flow from a fixed bed with radial flow included in the conditioning vessel. Here, the fixed bed, containing cells immobilized on a macroporous carrier, is integrated within the conditioning vessel. The feed is introduced, and the internal structure allows the fluid to flow radially through the fixed bed while the larger vessel provides continuous mixing and harvesting capabilities, enhancing mass transfer and overall process efficiency. Table 3 shows the pros and cons of reactor technologies.

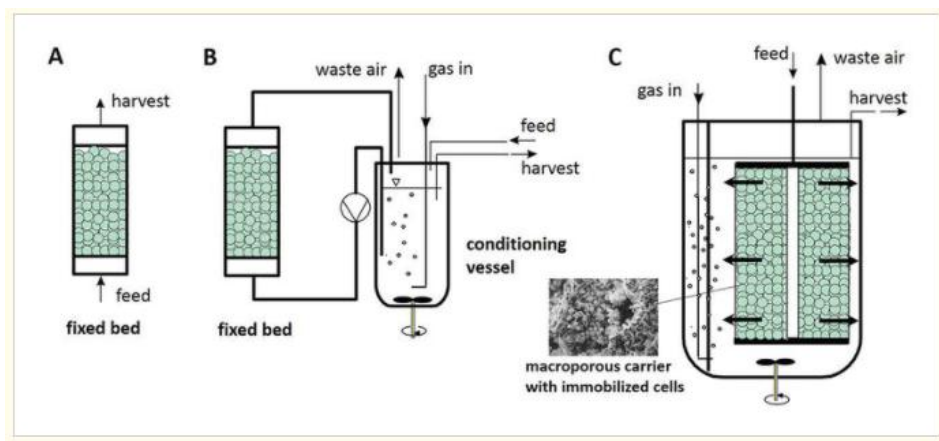


Figure 9 Examples of fixed-bed reactor design concepts. (A) Fixed bed with axial flow and plug flow. (B) Fixed bed with axial flow and external conditioning vessel. (C) Plug flow from a fixed bed with radial flow included in the conditioning vessel

Table 3 Pros and cons of reactors technologies

Type of Reactors	Advantages	Disadvantages
Plug flow reactors	The simplest design of reactors Steady state operation To improve mixing, it's compatible with side-stream additive injection devices and other mixers. More efficient and economical Efficient use of reactor volume Low-cost construction and capital space Easy to Clean, easy to use	Operative at stationary conditions No requirement for agitation and baffling Requiring low-mixing, low power requirement
Agitated reactors	High-intensity mixing Mode: continuous or batch Heat and mass transport rates are high. Operating costs are low	Complicated design, not suitable for continuous mode
Fixed bed reactors	Extremely high pressure and temperature Semi-continuous or batch mode Simple and cost-efficient process	Lower heat transfer and more complex temperature regulation, side effects are more likely to occur

4. Composting technology gaps and trends

Composting operations have been made easier thanks to technological advancements, which have resulted in significant changes in the methods and materials used in composting. A lot of technologies have been improved to develop a better waste management system through the composting process. According to Jindo, et al. [30], the application of biochar as a co-compost element has improved the decomposition process and has a good quality of compost product. The presence of biochar accelerates the composting cycle and reportedly improves seed germination percentage when seeds are sown directly in the finished compost. Biochar's influence on composting primarily involves altering the microbial populations, leading to an increased prevalence of certain microbes. This shift in the microbial community ultimately enhances their decomposition efficiency and speeds up the overall process. According to Ahmed, et al. [31], the biochar is important in composting because of its high stability, strong nutrient sorption, porosity, good water holding capacity, and low bulk density. Biochar also helps to regulate pH and speed up the composting process by acting as a catalyst. Composting efficiency will be greatly improved if odor and bioaerosols generated during the process are controlled. Better aeration, as well as oxygen feedback management and an aeration process with a switch, can assist reduce odor emission in compost piles. Rice straws, sawdust, and wheat straws are bulking agents that help to remove moisture from the compost pile while simultaneously improving air porosity. To mitigate environmental impact, modern composting utilizes technologies like airbag bioreactors and spray scrubbers to effectively trap toxic gaseous emissions. Airbag bioreactors are particularly effective for recovering ammonia (NH_3), which is then recycled back into the compost, enhancing its nutritional value by resulting in a higher concentration of nitrate [32].

Microbial diversity in composting has been monitored for decades using a variety of methodologies, including culture-based and culture-independent methods. However, there are significant drawbacks to using culture-dependent approaches; hence culture-independent procedures are preferred. This was also found to be limited in community review, prompting the employment of molecular approaches more recently. Evaluations and characterizations are made easier and more economical using molecular approaches.

4.1 Long composting process

Agriculture, livestock waste, forestry, and other industries' waste, such as waste from the fishing industry and municipal waste, are all examples of biomass waste. According to Lewis, et al. [33], due to their complicated chemical composition, highly phenolic substances take longer to compost. Phenol can be degraded by two types of bacteria. *Arthrobacter*, *Micrococcus*, *Alcaligenes*, *Acinetobacter*, *Corynebacterium*, and *Staphylococcus* are among the bacteria that use phenol as a carbon source, whereas the second group uses diverse forms of carbon.

Controlled aerobic degradation, also known as co-composting, is the process of combining materials when composting. This is done largely to produce an appropriate C:N ratio, accelerate the composting process, and improve the quality of the fertilizer. While aerobic decomposition occurs, a variety of factors may impede the composting process. Adding a highly nutritious substrate to compost significantly stimulates microbial activity, which in turn accelerates the rate of decomposition and shortens the composting cycle. Organic materials (OM) with a high C:N ratio are difficult to compost because microbes do not prefer them. To accelerate the composting cycle, activators—which are often specialized microorganisms are critical for breaking down raw materials and adjusting the unfavorable C:N ratio of carbon-heavy substrates. These activators enhance the aerobic decomposition necessary to achieve the optimal nutrient balance. For maximum efficiency, materials with longer decomposition times should be composted separately, ensuring they do not impede the processing speed of more readily degradable wastes.

4.2 Low nutrient and agronomic value

By evaluating the compost's effect on the growth of specific plants and measuring the yield of plants planted with compost, the agronomic evaluation of compost is used to determine the compost's quality. Compost as a fertilizer boosts crop output by increasing nutrient availability, according to numerous research. There have also been complaints of compost with insufficient nutrient levels, which has stifled plant growth. As a result, it's critical to determine the nutritional composition of composts and supplement them with nutrient-rich substrate to boost their nutritive and agronomic value. Compost is subjected to a chemical analysis to establish the quality and concentration of the components present.

4.3 Detection of pathogens in composts

According to Wu, et al. [34], *Thermoactinomyces* has also been discovered in mushroom compost. *Thermoactinomyces* are thermophilic bacteria that can cause "farmer's lung," a respiratory allergy that affects farm workers. Composts should be properly evaluated for microbiological and chemical components to ensure the safety of plants, soil creatures, animals, and humans.

5. Future prospects and further development

The need to improve the composting process and technologies that are relevant is growing as research in composting and the innovation in waste management become more important components for future success and development for sustainable agriculture, improving the design of bioreactors to produce a good quality of compost product such as fertilizer. The use of solar energy could help to reduce energy expenses, and the operational cost. A solar composting plant is a new technology that attempts to reduce total air pollutants by substituting solar energy for diesel generators and maximizing solar energy consumption to power aeration equipment. To properly restrict methane and nitrous oxide emissions throughout the composting process, proper management practices are required, which involves a greater understanding of enzymes, microbial populations, substrates, and processing conditions.

Researchers' backgrounds will usually dictate their agenda in terms of the perceived worth of research in various specialized areas for future research in some areas where research is required. Develop bioreactors that can readily measure basic parameters in composting operations, including adding sensors to measure gas phases and adding automation systems to the reactors to make the composting process less laborious. This could open up more possibilities for developing and improving composting processes and waste management technologies.

6. Conclusions and recommendation

Biodegradable garbage has long been recognized as a source of raw materials by researchers and industries. The R&D institution and government incentives could lead to a new development, such as the combination of bioenergy processes (anaerobic digestion, biochar) with composting, with bioenergy byproducts composted to optimize their value, agronomic, and environmental benefits. The ability of compost to improve soil structure and nutrient availability by supplementing nutrients already present has been a major motivator for its use in crop development.

In the Philippines, biomass wastes and industries provide a significant contribution to the energy and agriculture sectors. In combination with the Department of Energy's renewable energy projects, biomass waste generation will provide the sector with new prospects for research development. Biomass waste use might result in value addition, as well as a reduction in the worldwide problem of waste management and disposal, as well as cost savings in particular businesses. More research study should be done to learn more about the possible applications of biomass waste products and its application.

Compost can also be enhanced with anti-nematode, bactericide, and fungicides derived from plants. This will aid in the promotion of organic farming by preventing chemical applications. Slowly decomposing objects should be composted separately from other components in order to avoid extending the composting time of other materials. It will take more investigation to see if materials that take longer to compost also mineralize over time.

7. References

- [1] Ayilara MS, Olanrewaju O, Babalola O, Odeyemi O. Waste management through composting: challenges and potentials. Sustainability. 2020;12(11):4456. <https://doi.org/10.3390/su12114456>.
- [2] Zafar S. Agricultural wastes in the Philippines. Bioenergy [Internet]. 2023 [cited 2025 Nov 2]. Available from: <https://www.bioenergyconsult.com/agricultural-resources-in-philippines/>.
- [3] Quinto JC. Composting of agricultural waste using Indigenous Microorganisms (IMO's) [Unpublished undergraduate thesis]. Central Luzon State University; 2014.
- [4] Cai QY, Mo CH, Wu QT, Zeng QY, Katsoyiannis A. Concentration and speciation of heavy metals in six different sewage sludge-composts. J Hazard Mater. 2007;147(3):1063-72. <https://doi.org/10.1016/j.jhazmat.2007.01.142>.
- [5] Rekleitis G, Haralambous KJ, Loizidou M, Aravossis K. Utilization of agricultural and livestock waste in anaerobic digestion (A.D): Applying the biorefinery concept in a circular economy. Sustainability. 2020;12(23):10074. <https://doi.org/10.3390/en13174428>.

- [6] Pergola M, Persiani A, Palese AM, Di Meo V, Pastore V, D'Adamo C, Celano G. Composting: The way for a sustainable agriculture. *Applied Soil Ecology*. 2018;123:744-50. <https://doi.org/10.1016/j.apsoil.2017.10.016>.
- [7] Abdel-Shafy HI, Mansour MS. Solid waste issue: Sources, composition, disposal, recycling, and valorization. *Egypt J Petrol*. 2018;27:1275-90. <https://doi.org/10.1016/j.ejpe.2018.07.003>.
- [8] Atia A. Manure Composting Manual [Internet]. 2006 [cited 2025 Nov 2]. Available from: [http://www1.agric.gov.ab.ca/\\$department/deptdocs.nsf/all/agdex8875](http://www1.agric.gov.ab.ca/$department/deptdocs.nsf/all/agdex8875).
- [9] PCARRD. PCARRD bulletin 2002. *Greenfields Magazine*. 2002;48.
- [10] USDA. Chapter 2: Composting (National Engineering Handbook, Part 637). Department of Agriculture, Natural Resources Conservation Service US. 2000.
- [11] Artemio MM, Robles C, Ruiz-Vega J, Ernesto CH. Composting agroindustrial waste inoculated with lignocellulosic fungi and modifying the C/N ratio. *Rev Mex Cienc Agric*. 2018;9:271-80.
- [12] Ameen A, Ahmad J, Raza S. Effect of pH and moisture content on composting of municipal solid waste. *Int J Sci Res Publ*. 2016;6:35-37.
- [13] Gonawala SS, Jardosh H. Organic waste in composting: A brief review. *Int J Curr Eng Technol*. 2018;8(1):36-8. <https://doi.org/10.14741/ijcet.v8i01.10884>.
- [14] Calkins M. The sustainable sites handbook: A complete guide to the principles, strategies, and best practices for sustainable landscapes. John Wiley and Sons; 2012.
- [15] Food and Agriculture Organization of United Nation (FAO). Selection, testing and evaluation of agricultural machines and equipment (FAO Agricultural Services Bulletin 115). FAO; 1995.
- [16] De Bertoldi M, Rutili A, Rismondo D, Moreschi M. Composting: Industrial and commercial practices. In de Bertoldi, M. Sequi P, Lemmes B, Papi T (Eds.). *The science of composting: Part 2*. Blackie Academic & Professional; 1996. p. 953-75. <https://doi.org/10.1007/978-94-009-1569-5>.
- [17] Graves R, et al. Composting. Department of Agriculture, Natural Resources Conservation Service, US; 2000.
- [18] Keswani C. (Ed.). *Agri-based bioeconomy (Reintegrating trans-disciplinary research and sustainable development goals)* (1st ed.). CRC Press Taylor and Francis Group; 2021. <https://doi.org/10.1201/9781003033394>.
- [19] Maheshwari DK. (Ed.). *Composting for sustainable agriculture*. Springer; 2014. <https://doi.org/10.1007/978-3-319-08004-8>.
- [20] Sherman R. *The worm farmer's handbook*. Green Chelsea Publishing; 2018.
- [21] Majbar F, Zeroual Y, Fikri-Benbrahim K, El Khyari D. Integrated use of compost and synthetic fertilizer improves soil fertility and enhances pepper (*Capsicum annuum* L.) productivity in a semi-arid region. *International Journal of Recycling of Organic Waste in Agriculture*. 2018;7(1):77-86.
- [22] Olanrewaju OS, Glick BR, Babalola OO. Mechanisms of action of plant growth promoting bacteria. *World J Microbiol Biotechnol*. 2017;33(1):197. <https://doi.org/10.1007/s11274-017-2364-9>.
- [23] Khater E. Some physical and chemical properties of compost. *Int J Waste Resour*. 2015;5(1):1-5. <https://doi.org/10.4172/2252-5211.1000172>.
- [24] Kammoun M, Ghorbel I, Charfeddine S, Kamoun L, Gargouri-Bouزيد R, Nouri-Ellouz O. The positive effect of phosphogypsum-supplemented composts on potato plant growth in the field and tuber yield. *J Environ Manag*. 2017;200:475-83. <https://doi.org/10.1016/j.jenvman.2017.06.016>.
- [25] Hafeez M, Gupta P, Gupta Y P. Rapid composting of different wastes with Yash Activator Plus. *Int J Life Sci Res*. 2018;4(4): 1670-4. <https://doi.org/10.21276/ijlssr.2018.4.2.9>.
- [26] Limaye M, Nene S, Gunjal B. Microbiological aspects of composting: A review. *International Journal of Current Microbiology and Applied Sciences*. 2017;6(1):140-7.
- [27] Ghanbarzadeh B, Haghbeen K, Moosavian F. Enhancement of lignocellulose degradation in composting process using a novel bacterial strain. *International Journal of Environmental Science and Technology*. 2013;10(2):291-300.
- [28] Zhong JJ. Bioreactor engineering. *Comprehensive Biotechnology*. 2011;165-77. <https://doi.org/10.1016/B978-0-08-088504-9.00097-0>.
- [29] Tabatabaei M, Aghbashlo M, Chisti Y. Bioreactors for industrial processes. *Bioreactors: Design, operation and control*. CRC Press; 2019. p. 1-28.
- [30] Jindo K, Mizumoto SK, Sawada Y, Sanchez-Monedero MA, Roig A. Physical and chemical characterization of biochars derived from different agricultural residues and their composting properties. *Journal of Agricultural and Food Chemistry*. 2012;60(14): 3615-20.
- [31] Ahmed M, Ahmad S, Qadir G, Hayat R, Shaheen FA, Raza MA. Innovative processes and technologies for nutrient recovery from wastes: A comprehensive review. *Sustainability*. 2019;11(17):4938. <https://doi.org/10.3390/su11184938>.
- [32] Yang S, Ma J, Wang S, Wang H, Chen J. A comprehensive review on composting and co-composting for waste management: State-of-the-art, challenges, and future perspectives. *Bioresource Technology*. 2019;293:122177.
- [33] Lewis PT, Lo KV, Liao PH. A review of aerobic composting and its process control. *Waste Management*. 2010;30(2):291-301.
- [34] Wu H, Liu B, Pan S. *Thermoactinomyces Guangxiensis* Sp. Nov. A thermophilic actinomycete isolated from mushroom compost. *Int J Syst Evol Microbiol*. 2015;65(8):2859-64. <https://doi.org/10.1099/ijs.0.000342>.