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REVIEW ARTICLE OPEN ACCESS

Microbial Activity during Composting and Plant Growth Impact: A Review

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Abstract

Replacing harmful chemical pesticides with compost extracts is steadily gaining attention, offering an effective way for plant growth enhancement and disease management. Food waste has been a major issue globally due to its negative effects on the environment and human health. The methane and other harmful organisms released from the untreated waste have been identified as causes of this issue. Soil bacteria impart a very important role in biogeochemical cycles. The interactions between plants and bacteria in the rhizosphere are some of the factors that determine the health and fertility of the soil. Free-living soil bacteria are known to promote plant growth through colonizing the plant root. PGPR (Plant Growth Promoting Rhizobacteria) inoculants in compost are being commercialized as they help in the improvement of crop growth yield and provide safeguard and resistance to crops from disease. Our focus is to understand the mechanism of this natural, wet waste recycling process and implementation of a sustainable operative adaptation with microbial association to ameliorate the waste recycling system.

Keywords: Microbial activity, Composting and Plant, PGPR, Microbial ecology, Green waste

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INTRODUCTION

Generally, composting means the controlled breaking down of the degradable organic materials to a stable product by microorganisms. During this process, the major bulk of organic waste is reduced by volume and is directly used by plants through recycling. This is the noblest way of reducing the environmental and economic costs where the fundamental objective is to recirculate and reuse nutrient solutions. Composting results in a very low quantity of nitrogen, phosphorus, potassium as well as macro and micronutrients as compared to the chemical fertilizers. It is also a fact that plants can fulfil their requirement of nutrients immediately from chemical fertilizers, but their negative effect outweighs their positive effect on plants and the environment. Chemical fertilizers are the major cause of greenhouse effects, environmental pollution, death of soil organisms and marine inhabitants, ozone layer depletion, and human diseases. Although high-quality compost may be better and more beneficial to soil, low-quality compost cannot be considered. It must also be safe for people, plants, and the environment. Pathogenic bacteria should not be present in the compost, and foreign materials should be kept to a minimum. Along with improving soil fertility and quality, compost fertilization delivers several other beneficial effects, such as suppression of plant diseases.[1-3] Beneficial microorganisms in compost might play significant roles in maintaining plant health and productivity.[4,5] It must have a minimal amount of trace elements and organic pollutants, as well as should be mature and stable.[6] Composting is discouraged by pathogens, nutrient deficiency, time-consuming procedures, and odours. Therefore, compost does not yet offer many advantages over other soil-fertilizing sources, including lack of knowledge about microbial activity. A comprehensive literature review is very essential if the end goal is providing solutions for all the above-mentioned challenges to a wide range of populations including the common people, farmers and researchers. The present review article aims to collect information from the existing literature and compile all the collected data for the solutions made possible Under One Roof.

Components of composting

Composting can be carried out both aerobically and anaerobically. In aerobic composting, organic compounds are oxidized to carbon dioxide, nitrites and nitrates by aerobic microorganisms. The mass temperature rises due to exothermic reactions and facilitates the degradation process. During the anaerobic process, the organic compounds are broken down by anaerobic microorganisms through reduction while metabolism is going on. The least amount of energy is released and the temperature of the decaying mass does not rise much during this process.

Green vegetable waste, a combination of food waste, animal bedding and manure and straw, dairy waste, cow dung, organic fertilizer waste, municipal solid waste, agriculture waste could make good compost depending on their content. Currently, solid organic wastes (SOW), such as MSW (municipal solid waste), animal manure, agricultural residues, etc., are disposed of in conventional ways including landfilling or incineration, but these methods are not sustainable due to limited space.[7] Green waste (GW) is a common source for composting that is converted to nutrient-rich humus, used to improve the quality of soils.[8] Comparatively, green waste composting is a very slow process since its main constituents are slowly degradable compounds. Since lignocellulosic material makes up such a large part of green waste,[9] it is necessary to add some additives to enhance the decomposition rate. There are varieties of additives used for this purpose: coal fly ash,[10] biochar and animal dung,[11] and sewage sludge.[12] Eggshells and their membranes are considered good sources of fertilizer due to their availability.[13] The role of these shells in compost as a stabilizing agent is well known as it provides negatively charged components like carbonates and glycosaminoglycans.[14] Rice husk is abundantly produced in rice mills of China and other rice-producing countries enhance the composting process as additive.[15] Another study had explained how the particle-size distribution influences bulk density, the permeability of compost to water and air, and compost maturity.[16] Small particles in compost adversely affect its porosity while the presence of very large particles reduces water retention. All of the above additives have a significant impact on the microbial communities.

Different types of composting processes

- On-site composting: Recycling of household wastes that include residual cooked/uncooked food, grasses and leaves from garden and papers etc. need a small space and minimum attention. It is widely used in homes.
- Vermicomposting: Use of soil invertebrates such as earthworms, red wigglers etc. for eating and breaking down the waste materials in the compost pile into fertilizers.
- Windrow composting: It is prepared in a comparatively larger space in a form of long thin piles of wind-rows. Sometimes it is prepared in open air space. But when under shelter it has to be aerated by the use of cooling machines.
- In-vessel composting: In this method, an enclosed large container is used which is connected with various electrical controlling systems for proper adjustment of temperature, aeration and turning skills etc.

Microbial ecology of composting

Effective Microorganism (EM) compost is a bio-organic fertilizer prepared by a combination of microorganisms, which stimulates plant growth and soil fertility. A group of microorganisms referred to as "friendly microbes" was proposed by Professor Teruo Higa, of the University of Ryukyus in Okinawa, Japan.[20] As described by Friedrich, M. W. Composting is a natural process characterized by microbial community transitions that actively decompose materials under humidity, self-heating and aerobic conditions.[21] The microbial extract of compost was found to be effective in promoting plant growth and suppressing fungal diseases.[22]

However, exogenous microbes are added in order to accelerate the biodegradation rate by the indigenous microbial community in compost piles. Inoculating with selected microbes artificially could improve the degree of humification and maturation processes.[23] Both bacteria and fungi play an important role in the representation of microbial community structure during the composting process. The entire process gets affected either negatively or positively by the presence of both bacteria and fungi. There are two important processes involved in composting that are commonly studied; Characterization of microbial activities & Conversion of organic material.

The microbial functions in the Aerobic Digestion process

Aerobic composting is a commonly used technique to produce organic fertilizer from agricultural waste which happens in the presence of oxygen. This is an effective way to utilize this resourceful waste product.

Aerobic fermentation is a process that involves aerobic microbes (bacteria, actinomycetes, fungi, etc.) that can oxidize organic compounds in fermentation substrates to provide the energy needed for biological growth. This process is accomplished under appropriate conditions such as ventilation, oxygen supply, temperature, moisture content, pH value, CO2/N ratio, particle size, etc.

The microbial functions in the Anaerobic Digestion process

A major part of anaerobic digestion (AD) depends on microbial activity; factors such as syntrophic relationships between microbes and delicate balances among them are considered for this process to function effectively.[24]

Anaerobic digestion generally consists of four consecutive stages of bio methanogenesis, namely hydrolysis, acidogenesis, acetogenesis and methanogenesis; the first three stages are mediated by bacteria and the last stage is accomplished by archaea.[25]

Hydrolysis

During hydrolysis, the first stage of Anaerobic Digestion, fermentative bacteria break down complex organic matter, including carbohydrates, proteins, and lipids into soluble and biodegradable components such as monosaccharides, amino acids, higher fatty acids, and alcohols.

Fermentative bacteria contain extracellular enzymes called cellulases, lipases, and proteases. These enzymes start the degradation process and increase the bioavailability of organic matter in the bacteria's cells.[26] Among the common hydrolytic fermentative bacteria that are found in anaerobic digestion are *Firmicutes, Bacteroidetes, Actinobacteria, Proteobacteria,* and *Chloroflexi*.[27]

Acidogenesis

Most common fermentative bacteria such as Firmicutes, Bacteroidetes, Enterobacter, and *Clostridium* are playing a major role in the acidogenic phase. Most probably the fermentation

and metabolization of hydrolyzed products are continued by these acid forming microorganisms which leads towards short-chain volatile fatty acids (VFAs) and alcohols including acetic acid, propionic acid, butyric acid, valeric acid ethanol.[28]

As a result of their spores, these bacteria secrete lytic enzymes to degrade organic matter and are capable of living in extreme conditions and environment.[29]

Acetogenesis

In acetogenesis, soluble organic acids from hydrolysis and acidogenesis are converted into acetate, hydrogen, and carbon dioxide by acetogenic bacteria.[30] These microorganisms reduce the H_2 and CO_2 into acetate. While both compounds are oxidized by the syntrophic acetate-oxidizing bacteria (SAOB). Generally, the acetogenic and SAOB belong to genera *Clostridium* and *Acetobacterium* (phylum: *Firmicutes*).[31]

Methanogenesis

Methanogenic archaea reduce CO_2/H_2, acetate, and methylated compounds to methane in the last phase of anaerobic digestion. As a result, acetate is split into methyl groups and CO_2 by aceticlastic methanogens, and the methyl groups are reduced to methane. Hydrogenotrophic methanogens produce methane through reduced CO_2 as the source of carbon and energy.[32] Methanosaeta, Methanobacterium, and Methanosarcinaceae are commonly detected in methanogenesis processes.[33]

Determination of compost maturity and longevity

The functional biodiversity of soils will be assessed by assessing the microbial communities because they are ubiquitous, dominant and active. In terms of biomass, structure/diversity, and activity, they are vital to the functioning of ecosystems and provide services to customers.[34] In the first phase of microbial activity, the decomposition process begins with the increase in temperature through the oxidation of organic matter. The organic residue stability is increased by the decomposition efficiency of biodegradable materials. The presence of some specifically selected microorganisms can shorten the composting time, accelerate the biodegradation and transformation of organic matter, and improve the efficiency of composting i.e. influencing the maturity of the compost.[35] A variety of microbiota communities can occur during composting depending on the temperature, C/N ratio, moisture level, and type of organic components.[36] During this process, pathogens, herbs and plant toxins and some unprofitable microbial species are eliminated with the addition of a new functional bacterial community in a phenomenon of self-purification. In a study performed by[37] the diversity of microbial communities were observed in different days of composting and it was found that the microbial species would change with various stages of the composting process. A study reported the presence of *Bacteroidetes* and *Proteobacteria* phylum in raw material of activated sludge which was changed distinctly during the composting process.[38] Initial stages are predominated by protein and amino acid degrading Bacteria such as *Firmicutes,*[39] whereas the Bacteroides are responsible for hydrolyzation of high molecular weight polysaccharides and degradation of lignocelluloses.[40]

Thus, the maturity of the compost is correlated with the microbial activities in the compost. The microbial activity can be determined by studying the microbial metabolic activities, observing the colony-forming units (CFU) and the concentration of composting constituents.[41] Microorganisms like bacteria and fungi can switch organic waste to humus and improve the physical, chemical and biological properties of the soil.[42] It was found that *Proteobacteria, Bacteroidetes, Firmicutes, Actinobacteria, Chloroflexi,* and *Planctomycetes* were the dominant phyla in the passive ventilation composting process of dairy manure, and significant changes were observed between these phyla at the four stages of composting.[35] *Pseudomonas, Acinetobacter, Steroidobacter, Bacillus* and *Sphingobacterium* were the most abundant genera in rice straw, sugar cane bagasse, and coffee hull composting processes with cow manure additions.[43] *Ureibacillus, Tepidimicrobium, Kribbella* and *Bordetella* were reported to be the dominant genera in sludge and cattle dung composting.[44] *Sporosarcina, Bacillus, Cellvibrio, Devosia* and *Cellulomonas* were the most abundant genera in the maize straw composting process.[45]

Overall, a diverse variety of microbial communities are involved in the composting process. Bacteria from the genera *Anthrobacter, Bacillus, Enterobacter, Escherichia, Micrococcus,*

Morganella, Nitrobacter, Proteus, Pseudomonas, Staphylococcus, Humicola, Penicillium, Rhizopus, Sordarla and *Trichurus* have been found to be associated with composting processes as observed by various researchers.[46]

The development of new molecular approaches called -Omics have recently allowed the characterization of the overall microbial genetic and functional diversity through the high throughput analysis of DNAs (genomics), RNAs (transcriptomics), proteins (proteomics), enzymes activities (enzymomics) or metabolites (metabolomics).[47] In particular, the advent of next-generation sequencing techniques, such as complete genome shotgun sequencing, high-throughput sequencing and single-molecule long-read sequencing, has allowed the identification of the microorganism communities present in the soil. By applying different -Omic approaches to the same target, microbial community diversity can be linked to ecological processes, ecosystem services and potentially food quality. In this regard –Omics approaches can help to further understand the link between soil microbial diversity, its community composition and abundance, and ecological functions provided; hence, highlighting the benefit of ecological intensification.

Presence of pathogenic microbes in compost

Inadequately handled compost may be a disease source in the environment. Reports in municipal wastes, sewage sludges and other organic sludge found to contain a number of harmful pathogens.[54] Sewage sludge is generally richer in pathogens than municipal solid waste.[55] Pathogens found in composting can be viruses, bacteria, protozoa or helminths especially when the components are municipal solids waste and sewage sludge. Thus, along with providing nutrients and beneficial microorganisms, the organic fertilisers may sometimes be seen to spread pathogenic microorganisms into agroecosystems.[56-58] In certain anaerobic composting systems presence of common pathogens such as S*almonella, Clostridium, Campylobacter, Listeria monocytogenes* and *Escherichia coli* were found during early phases.[59,60] It is also suggested that the thermophilic phase of composting is responsible for killing the pathogens.[61]

Fig. 1. Microbial Way of composting.

The enteric pathogen is known to be able to grow even after having diminished below the detectable limits thus representing a health hazard for certain uses of compost. The most critical factor to prevent the regrowth of pathogens is to provide stability. The compost materials appear to be stable when their dryness supports high rates of beneficial microbial work. When this compost material is rewetted, pathogens can repopulate in certain conditions.[62] Therefore, it is always safe to store compost products under dry conditions.[63] Reports show that industrial biowastes composts are safely commercialized as products within 4 to 6 months.[64] Thus, the long-term duration storage for composting should be avoided to prevent the survival and regrowth of pathogens. However, proper management of the thermophilic microbes and mature stages of the composting process remains an important step in controlling the persistence of pathogens.

Plant growth-promoting microorganisms in the rhizosphere

Plants growth in farming soils is affected by various biotic and abiotic factors. The rhizosphere is a thin layer of soil that instantly covers the plant roots where various metabolic activities of roots are observed. The rhizosphere is home to a diverse range of microorganisms, including bacteria,

Table 1. Microbial diversity studies using omics approaches

No.	Molecular Technique	Reported Organisms	Author and year
1.	Metabolomics	Mycorrhizal fungi (AMF), Endophytic fungi	Bernardo L, Carletti P, Badeck FW, et al[49]
2.	16S rDNA gene pyrosequencing	Bacteria	Dal Cortivo C, Ferrari M, Visioli G, et al[50]
3.	high-throughput pyrosequencing of bacterial 16SV1-V3 and fungal ITS2 of the ribosomal DNA operon	Bacteria and fungi	(Hartmann M, Frey B, Mayer J, Mader P, Widmer F[51]
4.	16S rDNA V3 region gene sequence	Rhizospheric Bacteria	(Visioli G, Sanangelantoni AM, Vamerali T, Dal Cortivo C, Blandino M[52]
5.	RT-PCR and pyrosequencing of 16S rDNA gene	Bacteria and archaea	(Pershina E, Valkonen J, Kurki P, et al[53]

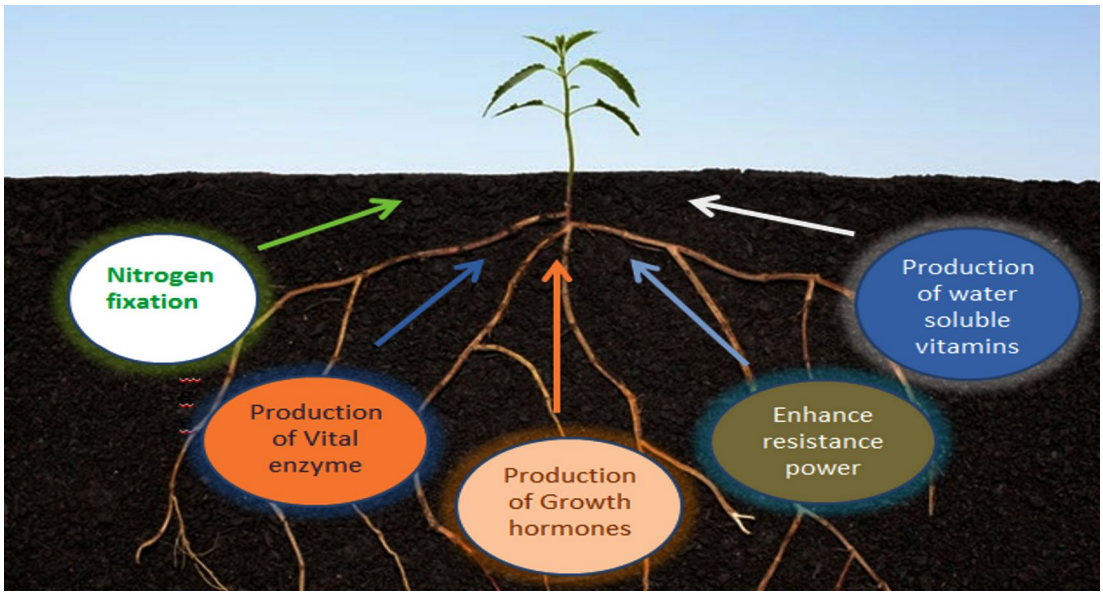

Fig. 2. Mechanism of PGPR.

fungus, protozoa, and algae.[65,66] *Pseudomonas, Azospirillum, Azotobacter, Klebsiella, Enterobacter, Anthrobacter bacillus* and *Serratia* are some microorganisms that have enormous plant growth-inducing capacity.[67] Mechanism of induction of systematic resistance and production of siderophores or antibiotics keep the bacteria to suppress the plant diseases. The use of plant growth-promoting rhizobacteria replaces the use of pesticides, chemical fertilizers and supplements resulting in significant growth in height of the plant, length of root, dry matter production of shoot and root of plants. Potato, radish, sugar beet and sweet potato cultivations are getting benefits out of this.[68]

Many recent studies have also evidenced the detailed mechanism through which plant growth-promoting rhizobacteria (PGPR) greatly revitalizes the soil condition and plant health, and enhances crop yield in agriculture. Apart from the removal of harmful pathogenic microorganisms, plant growth-promoting rhizobacteria provide an appropriate environment for plant nutrition and root growth. This rhizobacteria not only help in nitrogen fixation providing plants with the absorbable form of ammonia but also produce important factors like siderophores, phytohormones such as cytokinins, gibberellins, etc. Phosphate solubilization and mineralization of organic compounds, production of phytohormones (biofertilizers) like IAA, abscisic acid (ABA), ethylene (ET), and auxins, and nitrogen fixation are also some important plant growth-promoting rhizobacterial activities.[69-72] However, the effect of the microbial community of compost on rhizosphere microbial activity needs to be elucidated extensively which could be a very promising subject of research. It can also be effective to use this rhizobacteria as an exogenous inoculum for developing compost.

Microbial content associated with earthworms

Earthworms play a major role in shaping soil structure format and cycling nutrients.[73] They also help in maintaining a healthy soil ecosystem and are known as ecosystem engineers.[74] Vermicomposting effectively reduces organic biomass and generates high-quality fertilizer for plants. Works are being done to study bacterial communities residing in the gut of earthworms that are involved in this decomposition process. Another experiment observed that vermicomposting increases the taxonomic diversity of bacterial communities accompanied by an increase in their functional diversity as well as metabolic capacity and other plant growth promoting factors.[75] Depending on their effects on the soil compartment and microbial communities, earthworms can be categorized into three types of ecological groups. Such as; epigeic earthworms are found on the surface of the soil and feed on organic litter, endogeic earthworms produce horizontal tunnels when they feed on mineral soil and partially decomposed materials and anecic earthworms are the largest species that survive on the nutrients obtained from the microorganisms present in the dead and degrading organic matters and deposit their casts at the entrance of the burrows.[76,77] Activities of microorganisms present in the soil are known to be controlled by earthworms.[78] The relationship between earthworm and soil microorganisms is very complex which is considered as the 'sleeping beauty paradox'.[79] The microorganisms in soil normally stay dormant and get activated in the presence of suitable environmental conditions, earthworms being considered as an important activator. They have a direct and important role in increasing the soil microorganisms through providing digested nutrition products and by dropping down the microbial biomass from their gut in the form of casts.[80,81] According to a report the endogenic A trapezoides had no effect on the numerical form of soil bacterial operational taxonomic units.[82] Another report observed the positive effect of earthworms on the bacterial richness and their diversity which were created by four epi-anaeic species from the genus *Lumbricus*.[83] In the study of vermicomposting methods, the importance of earthworms on soil microbial diversity had been investigated. During the first stage of vermicomposting, the earthworms of epigeic group *Eudrilus* sp. and *E. fetida* increased the bacterial diversity on the substrate.[84] However, the negative effects of earthworms on bacterial richness were explained by the reduced number of bacterial species during the passage through Eisenia's gut and of *L. rubellus* as observed in the casts.[85] The interaction between earthworms and microorganisms during soil nutrient cycling and many other important pollutants leaves us with limited knowledge about

its mechanism. Next-generation sequencing (NGS) could be used profoundly to achieve the solution in the near future.[77]

CONCLUSION

Improper waste management leads to an unsafe environment which ought to be replaced with composting like safer waste management. The world is leading towards a changed natural resource where human impact on and adjustment to the physical environment is inevitable. The composting process can play an important role in achieving this goal as organic fertilizer. The importance of composting will cause less use of industry made chemical fertilizers in favour of natural compost. By decreasing the number of harmful chemicals discharged into the environment through decreasing their usage, it would undoubtedly benefit the environment and human health. Much more awareness of the potential of technology is still needed for farmers to fully contain it. To make plant compost effective against nematodes, compost could be supplemented with bactericides and fungicides. More research is needed to understand materials that need to be composted for a long time and those that are gradually being mineralized. A study is also needed to determine the effect of interaction between various sources of microbial communities assembled in soil; from plant rhizosphere, earthworm cast and mature compost.

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CONFLICT OF INTEREST

The authors declare that there is no conflict of interest

AUTHORS' CONTRIBUTION

KD conceptualized the work. PPR helped in data collection, analysis and interpretation. KD, PPR and SP helped in manuscript preparation, drafting the manuscript and its critical revision. All authors read and approved the final manuscript for publication.

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DATA AVAILABILITY

All datasets generated during the current study are available from the corresponding author on reasonable request.

ETHICS STATEMENT

Not applicable.

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