

Microbes as Requisite Additives for Organic Waste Management: A Brief Review

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Abstract

Owing to the changes in human lifestyle and resource deterioration impelled by rapid population growth and unsustainable industrialization, waste management has emerged as an extensive contrivance for human welfare and environmental prosperity. Unmanaged waste impacts both rich and poor hurting their economy and environment development. The organic waste, being the largest component of MSW in developing countries, can be developed into a valuable resource by utilizing microorganisms. Brief repository about the exertion of microbes for sustainable degradation of organic waste was presented in this article describing the ways how organic waste can be transformed in marketable asset generating remarkable profits.



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Introduction

The current waste management practices face challenges owing to a huge generation of Greenhouse gases (GHGs) that has contributed to changes in consumption patterns and growth in resource squandering mainly caused by the rapid industrialization, urbanization and population growth.^{1, 2} The old saying "Waste not, want not" rings so true today as global leaders and local communities alike progressively call for a fix for the so called "throwaway culture". Waste management is a universal issue that is not only linked to individuals and households in a broader way but also affects human well-being and environmental prosperity.³


As the waste is openly dumped or burned (about 90%) in under developed countries due to lack of sustainable waste management policy, it is underprivileged and most vulnerable populations that are disproportionately affected.⁴

It is not only the underdeveloped countries that are affected by unmanaged waste, developed countries that are chief contributors of solid waste mess are severely impacted too. Poorly managed waste is seriously deteriorating the health of world's ocean, transmitting diseases, clogging drains and causing floods thereby hinders economic growth, hurts the environment and human welfare⁵

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The rate of waste generation is swelling progressively as almost 201 billion tonnes of municipal solid waste (MSW) is produced annually worldwide with 33% of it is not managed in environmental friendly manner (World Bank's 'what a waste 2.0' report 2018). It is estimated that due to rapid urbanization and population pressure, global waste will increase by 70% to about 340 billion tonnes annually. India contributes around 50 million tonnes of MSW every year.⁶

The organic waste being the largest component of MSW in developing countries consists of farmyard wastes, food and agro industrial wastes.⁷ Organic wastes abundant in organic fraction, can be transformed into renewable biogas and compost under controlled conditions by microorganisms.⁸ Microorganisms having impressive metabolic ability are widely distributed on the biosphere, growing in wide range of environmental conditions. Their nutritional versatility can be exploited for biodegradation of organic waste. Microorganisms are considered as the principle agents which can clean and alter the complex lipophilic organic molecules which are considered recalcitrant to simple water soluble products. Microorganisms that carry out biodegradation of organic waste include *Acinethobacter*, *Actinobacter*, *Alcaligenes*, *Anthrobacter*, *Bacillus*, *Flavobacterium*, *Mycobacterium*, *Pencillium*, *Pseudomonas*, *Xanthobacter*, *Nocardia*, *Serratia* etc. Mankind has encountered several problems in maintaining the quality of environment, and microorganism can be an invaluable in finding solutions for several problems.

The greatest advantage of utilizing microbes for organic matter degradation is that these techniques are practicable and economical which would have been unfeasible employing physical/ chemical methods⁹

Techniques like bioremediation and biotransformation are used in microbial degradation to bind the innate proficiency of microbial metabolism to breakdown, transmute or accrue environmental pollutants. In the recent years the utilization of microorganisms for organic matter degradation has grown tremendously over the years. This expeditious increase in such research has been facilitated by the omics approach (genomic, metagenomic, proteomic, bioinformatic) that has provide high throughput analysis of environmentally relevant microorganisms.¹⁰ This has enormously helped the scientific community to get new insights about the biodegradative pathways of microbes; and their ability to adapt in fluctuating environmental settings.

The objective of this review is to prompt the application or role of microorganisms in management of organic waste. It is emerging as an area of interest for the researchers across the globe to find the solutions to environmental threats posed by solid waste.

Principles of Microbial Degradation

Microorganisms utilize carbon, hydrogen, oxygen and nitrogen and the organic contaminants for their growth.¹¹ Two categories of transformations exist.

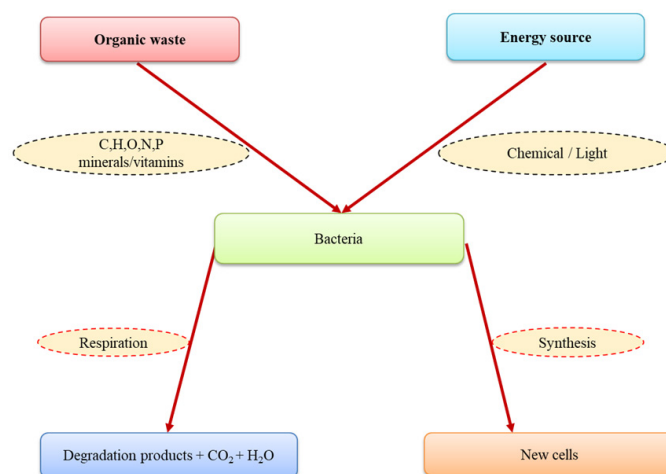


Fig.1: Growth and cometabolism: utilization of waste by microbes

- The first step in microbial degradation is growth linked as microbes utilize the organic compound such as carbon and energy to support growth and the development process.
- The second step involves the microbes utilizing respirational carbon in order to maintain their cell viability. Comatabolism is another phenomenon that involves the simultaneous degradation of two compounds also falls in second category.¹² Comatabolism is an essential exertion that has been utilized for organic waste degradation for more than twenty years. Such as approach is being used to degrade the hazardous solvents (PCE, TCE and MTBE) as these have harmful effects on the environment.¹³ Such compounds are comatabolically degraded by bacteria (Fig. 1)

Factors Affecting Microbial Degradation

Microorganisms can reduce various organic wastes owing to their metabolic machinery and capability to acclimatize to hostile environs. However their efficacy hinge on several dynamics including the chemical nature and concentration of wastes, their accessibility to microorganisms and the physicochemical characteristics of the environment.¹⁴

Biological factors

Microbial transmutation is executed by numerous biotic factors that impact the rate of organic waste degradation via organism enzyme inhibition activities and proliferation rate.¹⁵ Competition among the organisms for limited carbon sources prompts enzymatic inhibition causing antagonistic or predatory interactions. Similarly, degradation capability of organisms is facilitated by environmental contaminant concentration and catalyst activity that ultimately impact the rate of organic waste degradation. Factors like enzyme specificity, affinity and contaminant availability affect the rate of metabolism. To prevent the exponential and uncontrolled growth of microbes, proper and apt concentration of oxygen and nutrients should be supplemented by adequate conditions of temperature, pH and moisture content.¹⁵ Temperature is an imperative feature that affect the metabolic action of organisms as for each 10°C decline in temperature, the degree of organic matter

degradation decrease roughly to about one half. Similarly, pH of 6.5 to 8.5 is an important indicator for organic matter degradation in most terrestrial systems. The degree of pollutant metabolism is influenced by moisture too as it affects the nature and concentration of available material in aquatic systems.¹⁶

Environmental Factors

The adsorption and absorption of organic compound is highly influenced by the soil type and its OM content. These processes are not only vital to diminish the accessibility of the contaminant to varied type of microorganisms but also impact the metabolism rate of contaminant that is proportionally declined (Environmental Response Division, 1998). The oxidizing property of the soil gives the measure of electron density as Eh value >50mV indicates oxygen facilitated conditions while Eh value <50mV indicates reducing and anaerobic conditions¹⁷

The desired degradation of the waste depends on the degradation reactions to which the compounds of interest will be subjected involving metabolism pathway and the mode of process. The modes of these degradation processes are classified as aerobic and anaerobic (Fig.2.)

- Aerobic transformation of organic waste occurs in presence of oxygen where the molecular oxygen serves as electron receptor. This process utilizes microbes such as bacteria and fungi that transform carbon into energy and produces carbon dioxide, water and humus as waste products.
- Anaerobic degradation reactions of organic waste take place in absence of molecular oxygen involving anaerobic respiration and fermentation. Such degradation starts with hydrolysis of input material process initiated by bacteria in order to halt down insoluble organic polymers such as carbohydrates and make them accessible for bacteria. Carbohydrates and amino acids formed in hydrolysis process are converted into CO₂, NH₃ and organic acids by acidogenic bacteria. The resulting organic acids are transformed into acetic acid as well as additional ammonia, H₂O and CO₂. Finally methanogens transform these products to CH₄ and CO₂.

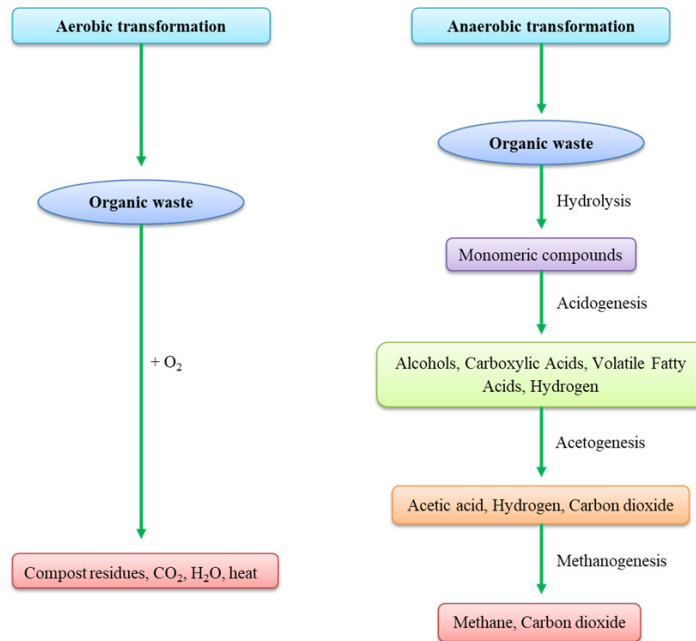


Fig.2: Aerobic and anaerobic degradation of organic waste by microbes

Aerobic Degradation of Organic Waste

Under aerobic conditions, composting process is done by the exothermic reaction, producing energy in the form of heat that ultimately raises the temperature prompting degradation of organic waste (thermic phase) producing CO₂ & H₂O. Such microbially driven process generates stabilized

organic matter with high humic acid content (Fig.3). Composting, as an option for organic waste transformation, lessens the phytotoxicity and expands the hygienic prominence of non-stabilized OM¹⁸ that is beneficial to soils and plants^{5, 19} (Fig.3). The process of composting involves four phases (Fig. 4).

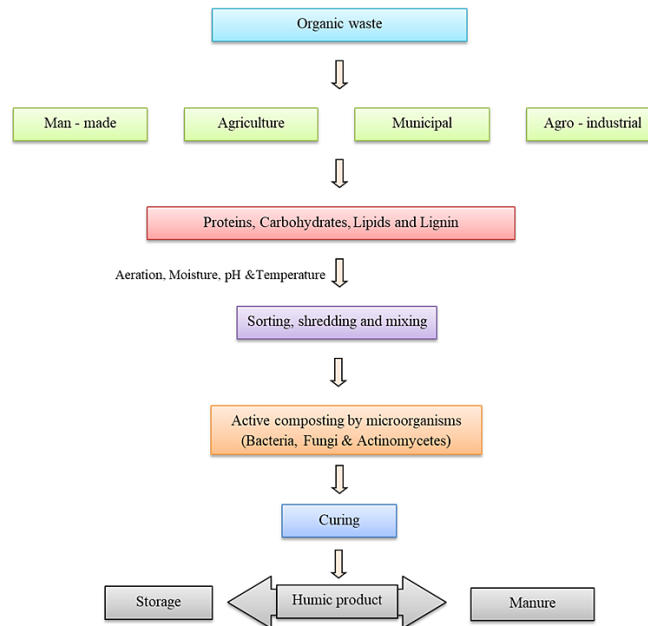


Fig.3: Composting process of organic waste

Mesophilic Phase (25-40°C)

In Mesophilic phase of organic waste degradation, sugars and proteins that are energy rich compounds are transformed by bacteria and fungi. These decomposers compete with each other for readily accessible substratum. As specific growth rates of bacteria surpass in magnitude as compared to fungi, these act as catalysts paving the ways for the mechanical transformation of organic waste.²⁰

Thermophilic Phase (35 – 65°C)

The advantage of with standing high temperatures enhances the capability of thermophilic bacteria that out-compete the Mesophilic microbiota as high temperatures inactivate the degradation action of Mesophilic bacteria. The rate of degradation by thermophilic bacteria is boosted and accelerated up to a temperature of about 62°C. About 40% of the solid portions of organic waste are degraded entirely through the bacterial medium.²¹ A temperature between 50 to 65°C is highly optimized temperature for the genus *Bacillus*. At about 65°C and greater, thermophilic process is overtaken by *Bacillus stearothermophilus*. However, the most suitable temperature where all the pathogens and harmful bacteria in waste stream are eliminated and thermophilic enzyme is activated to shorten the fermentation time is 70-80°C. During the thermophilic

mode of organic waste degradation, complex organic waste is digested, resulting in high quality fertilizer, free of odour and pathogens.

Cooling Phase (Second Mesophilic Phase)

When the substrates available for the thermophilic bacteria are reduced or halted owing to their activity, temperature decrease occurs. Such process is enhanced by number of microorganisms (*Cellulomonas*, *Clostridium* and *Nocardia*, *Aspergillus*, *Fusarium* and *Paecilomyces*) that cause starch and cellulose degradation (Ryckeboer *et al.* 2003).

Maturation and Curing Phase

The eminence of substrate diminishes during the maturation phase thereby entirely altering the microbial community composition. Owing to competitive advantage, fungi to bacteria ratio upsurges due to diminishing water potential and lesser substrate accessibility. Compounds (lignin-humus complexes) that are not further degradable become highly dominant. In curing phase of organic waste degradation, physico-chemical parameters are not altered but microbial community changes do still occur.²² Organisms (Mycobacteria and Verrucomicrobia) tangled in macromolecule degradation begin to preponderate.

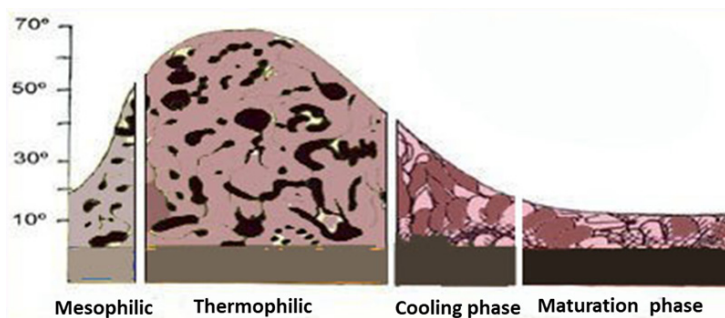


Fig.4: Phases of composting process

Anaerobic Degradation

Anaerobic process for organic waste degradation is a reduction process involving a series of biochemical reactions (Fig.5) occurring under anoxic conditions.²³ Such a process involves four different steps (Fig.6), hydrolysis, Acidogenesis, Acetogenesis and Methanogenesis. The rate limiting step in anaerobic digestion is hydrolysis which causes failure under enacted kinetic process,²³ resulting in washing out of microorganisms.²⁴ There

are diverse views regarding the rate limiting step in anaerobic degradation of organic waste. For complex organic substrate, most of the investigation has reported that hydrolysis process is a rate limiting step.^{22, 25, 26} For the easily biodegradable substrates, Methanogenesis is the rate limiting step.²⁷ Various factors such as physiology, nutritional needs, growth kinetics and sensitivity to environment, influence the anaerobic degradation of organic waste. A delicate balance between acid forming and methane forming

microorganisms can sometimes be an obstacle, prompting reactor instability and low methane production.²⁸ The separation of microorganisms is

based on differences in growth kinetics accomplished through membrane separation, kinetics and pH control.^{29, 30}

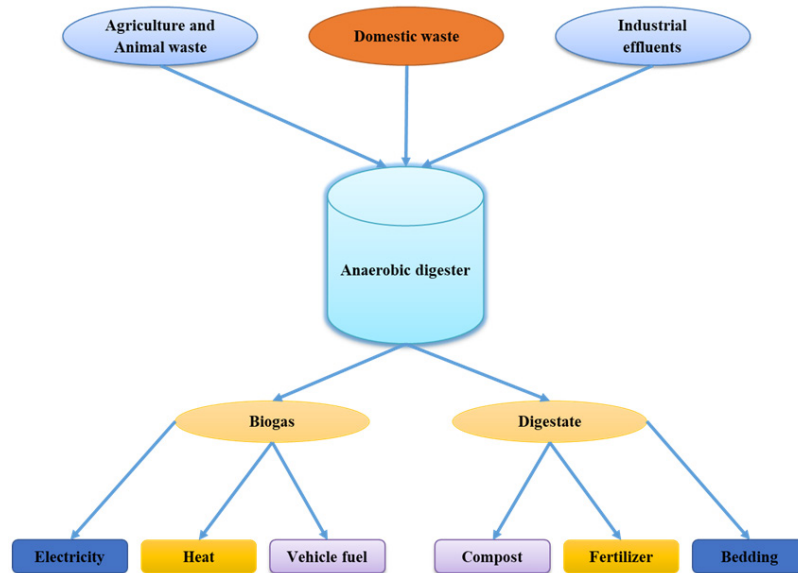


Fig.5: General process of anaerobic digestion of organic waste

Hydrolysis

Hydrolysis is an enzyme facilitated alteration where greater molecular mass (lipids, polysaccharides, proteins, and nucleic acids) are transformed into simpler molecules. This process of organic waste is mediated by anaerobes (Bacteriodes, Clostridia) and facultative bacteria (Streptococci).³¹ The microorganisms secrete different extracellular enzymes that break down the complex compounds in order to take them up into the cell for use as a cradle of energy and nutrition. Different enzymes produced by microorganisms prompt degradation of varied types of organic waste materials. The decomposition rate of organic waste is controlled by the nature of the substrate for example the degradation of cellulose and hemicellulose is slower in comparison to proteins during the hydrolysis process.²⁴

Acidogenesis

During the Acidogenesis phase, monomeric compounds are taken up by the cells for the process of fermentation under the influence of electron donors accompanied by the bacteria (*Clostridium*, *Streptococcus* and *Lactobacillus*) generating lactate, Butyrate, Propionate and ethanol, plus CO₂ and molecular hydrogen.³² Process of fermentation

can be accompanied through Stickland coupled deamination and deamination of a single amino acid in the occurrence of a H₂- scavenging partner.³³

Acetogenesis

Acetogenesis is accomplished by the oxidation of fermentation products to produce acetate, formate, hydrogen and carbon dioxide. Acetogenic process involving Acetogenic bacteria can be thermodynamically unstable requiring a syntrophic association between acetogen and hydrogen.³⁴ Such syntrophism is obligatory and biochemical energetics involved in such association has been investigated.³⁴

The process of Acetogenesis forms the substrate for the Methanogenesis process, however, due to the competition among/between few anaerobes and methanogens, sharing the substrate can diminish the proficiency of methane production.²² These include bacteria like *Desulfotomaculum*, *Desulfobulbus*, *Deferribacter*, *hydrogenogenic Carboxydocella* and *Thermosinus*³⁵ that outcompete methanogens owing to inhibition of numerous microbiota³⁶ and lowering partial pressure.³⁷

Methanogenesis

Anaerobic degradation of organic waste in the Methanogenesis process involves the generation of methane accomplished by Archaea belonging to the phylum Euryarchaeota.³⁸ In anaerobic reactors, methane forming organisms commonly found include Methanobacterials, Methanococcales, Methanomicrobials and Methanosarcinales. These organisms most frequently utilize hydrogen as an electron donor, however formate or secondary alcohols can also be an option^{39, 40}

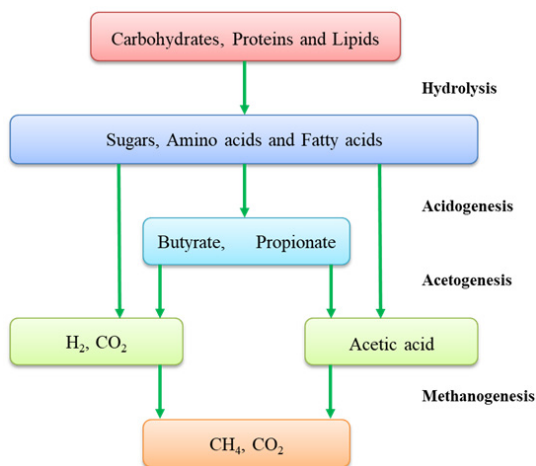


Fig.6: Phases of anaerobic digestion

Conclusion

Organic waste should be seen as a treasured entity and not as a cradle of environmental effluence that can simply be put into landfills or incinerators, but can be transmuted into marketable harvests generating sufficient employment and profits. For degradation of organic waste, priorities like sustainable processing of organic waste and its utility as a resource can be optimized by harnessing innovative technologies (Fig.7). This will improve the quality of life by being in line with the principles of sustainable development closely linked with poverty alleviation goals. Furthermore, microbes are proven to augment the degradation process that provide an alternative solution to waste management, as chemical and thermal methods are not favoured in terms of cost, energy consumption and environmental prosperity. The most reliable strategy for degradation of organic waste is the biodegradation by eco-friendly microbes. this has been widely accepted as an environmentally sound and economically feasible resource for treatment

of solid waste and effluents. Hence microbes are prerequisite for clean environment.

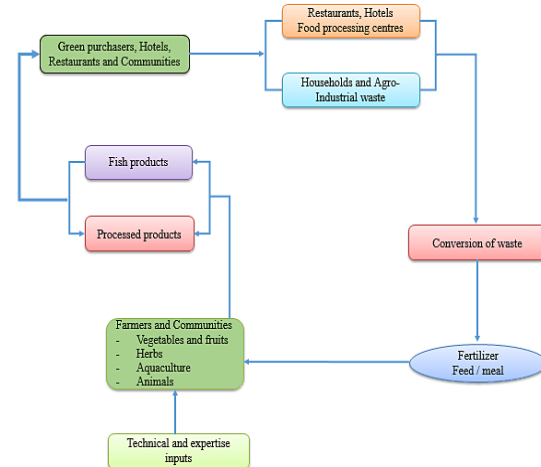


Fig. 7: Flowchart of a green and productive community

Declarations

Authors declare that there is no conflict of interest in this study

Authors' contributions

Shahnawaz Hassan and Sabreena led the development and design of the manuscript. The authors read and approve the final manuscript.

Data Availability Statement (DAS)

Data sharing is not applicable to this article as no new data were created or analysed in this study.

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Conflict of Interest

The authors do not have any conflict of interest.

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