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MICROBIAL-ASSISTED SOLID WASTE MANAGEMENT-A CIRCULAR ECONOMY APPROACH

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ABSTRACT

The soil contains a significant quantity of microbial life, including a vast range of bacteria, archaea, yeast, fungi, algae, and protozoa. They can thrive in harsh environments like hot springs, deep beneath rocks, and in subfreezing temperatures. However, although these biological communities are considered significant in sustaining a sustainable biosphere, roughly about 90 % of microorganisms significance remains unknown. The majority of the microorganisms that are often found in solid waste are bacteria and fungi. These species are collectively referred to as Solid Waste Microflora. They grow using the elements from the waste as their food. Municipal solid waste should be maintained in a satisfactory state before discharge to decrease biological activity, prevent or postpone the release of toxic substances into the environment, and decrease odor generation. Organic waste composting represents a bio-oxidation sequence, encompassing the mineralization and partial transformation of organic substances. This sequence results in an end-product devoid of pathogens and phytotoxicity, while also inheriting certain humic characteristics. The local microbial population actively mediates the biodegradation and conversion process during composting. Identification of these microorganisms is necessary as they keep the flow of nutrients from one system to another. Composting also aids in waste disposal to a larger level and serves as an organic source of nutrients. To attain the objectives of sustainable waste management, waste generation must be minimized, waste materials must be recovered and recycled, and energy must always be recovered to preserve resources for the future. Recovering energy from abandoned waste has the potential to generate energy for communities, produce energy in industries, and reduce greenhouse gas emissions (GHG) and other toxic air pollutants.

KEYWORDS : Environmental management, Municipal solid waste, Effective microbes,

INTRODUCTION

In India, the annual generation of municipal solid waste (MSW) was estimated to be around 150,000 to 170,000 metric tonnes per day (TPD) in 2020. This amount is projected to increase to 260,000 TPD by 2030(Ministry of Housing and Urban Affairs, Government of India, 2020).

As of 2020, approximately 78% of the total MSW generated in urban areas was collected, while only 28% received some form of treatment. However, the treatment capacity has been increasing steadily, and India has set a target to achieve 100% collection and scientific management of MSW by 2024 (Central Pollution Control Board, India 2021).

India faces substantial waste management challenges as a consequence of growing populations and development. To tackle these difficulties, our country utilized microbial-assisted solid waste treatment methods. There are separate biogas facilities that use microorganisms to create biogas and organic fertilizer via the anaerobic digestion of organic waste. In India, research has emphasized the potential of microbial consortia in enhancing biogas generation and regulating the method of digestion (Yadav *et al.,* 2020).

Global perspectives of Solid waste management

The significance of microbially aided solid waste management has been acknowledged by several Asian nations (Gupta *et al.,* 2021). For instance, China has constructed large-scale biogas places which employ microorganisms to convert organic waste into biogas. These factories not only handle waste but also create environmentally friendly energy. Numerous studies were performed to evaluate the efficacy of microbial consortia in producing biogas from varied organic waste sources (He *et al.,* 2020).

Microbial-assisted solid waste management has attracted interest in the worldwide context because of its potential to reduce trash's environmental effects. The use of microorganisms in waste treatment activities provides multiple advantages, like reduced waste volume, reduced emissions of greenhouse gases, and a generation of beneficial byproducts (Mehta *et al.,* 2019).

"Sustainable Farming with Biofertilizers: A Greener Approach"

Biofertilizers are living microorganisms that enhance soil health and contribute to a sustainable economy. They fix atmospheric nitrogen, solubilize phosphorus, and mobilize essential nutrients, reducing reliance on chemical fertilizers and conserving resources (Kumar *et al.,* 2019). Beneficial microorganisms in biofertilizers improve soil structure, and nutrient cycling, and suppress pathogens, leading to enhanced water retention and aeration (Singh *et al.,* 2019). Moreover, biofertilizers promote sustainable agriculture, reducing chemical runoff, and minimizing environmental impacts while supporting biodiversity conservation (Bhardwaj *et al.,* 2021). Additionally, they offer cost savings for farmers through reduced chemical inputs and potential yield improvements (Dwivedi *et al.,* 2021). Overall, biofertilizers present a nature-friendly and cost-effective solution for enhancing soil productivity and economic prosperity.

Effective Microbial-Assisted Composting: Converting Organic Waste into Nutrient-Rich Compost

A crucial field of exploration in microbial-assisted solid waste management is the utilization of microorganisms in organic waste breakdown and composting processes. Bacteria and fungi play a role in breaking down complex organic molecules, speeding decomposition, and promoting the synthesis of nutrient-rich compost. Several studies indicate that microbial-assisted composting is effective in converting organic waste, such as food waste and agricultural residue, into a beneficial asset for soil amendment and plant nourishment (Smith *et al.,* 2021; Munir *et al.,* 2022).

Further, microbial-assisted approaches show promise in the treatment of an extensive variety of waste streams, including industrial wastewater and sewage sludge. Bioaugmentation, involving the introduction of specific microbial strains, may enhance pollutant breakdown while facilitating the removal of contaminants from wastewater. This technique offers a sustainable and cost-effective alternative to traditional methods of treatment, stressing its industrial potential (Li *et al.,* 2021; Olawuyi *et al.,* 2022).

In addition, recent developments in molecular biology and genetic engineering have revealed insights into microbial communities ability to function and their potential for optimizing waste management procedures. Researchers may develop tailored microbial consortia and optimize process environments to optimize resource recovery and minimize the impact on the environment by investigating the microbial composition and metabolic pathways involved in waste degradation (Gupta *et al.,* 2021; Kim *et al.,* 2022).

Composting in bioreactors decomposes organic waste efficiently, boosting waste management while providing nutrient-rich compost. Microorganisms absorb waste more quickly if conditions in the environment like aeration and moisture are optimized, reducing composting time. The controlled process minimizes smells and prevents microorganisms, making the compost safer to use. It holds more nutrients, improving soil fertility and the production of crops. Bioreactor composting brings about a significant reduction in greenhouse gas emissions when contrasted with the practice of landfilling. Additionally, it redirects organic waste away from landfills, thereby eradicating its environmental repercussions (Ghaley and Kumar, 2017; Cai *et al.,* 2018; Rajagopal *et al.,* 2018; Wang *et al.,* 2019; Ariunbaatar *et al.,* 2020).

Vessel-based reactors have emerged as efficient and controlled systems for composting organic waste, providing several advantages over traditional composting methods. These reactors offer a controlled environment that enhances the composting process, leading to faster decomposition rates, improved odor control, and higher-quality compost production. The design and operation of vessel-based reactors enable precise process management, including temperature regulation, aeration rates and moisture control, which optimize microbial activity and accelerate composting. Recent research and advancements in this field have further strengthened the case for adopting vessel-based reactors in composting practices (Kaur *et al.*, 2021; Nkongolo *et al.*, 2021; Sattar *et al.*, 2021; Cabral *et al.*, 2022; Pan *et al.*, 2022).

Transitioning to a Circular Economy: A Sustainable Solution for Solid Waste Management

The shift from a linear economy to a circular one has captured significant focus as a durable remedy for challenges in managing solid waste. In contrast to the conventional linear approach of "take-make-dispose," the circular economy strives to curtail waste, optimize resource exploitation, and foster a closed-loop framework where resources undergo frequent reuse, recycling, or regeneration. By incorporating circular economy principles, solid waste management methodologies have the potential to curtail environmental effects while concurrently unlocking economic possibilities.

The study stresses the relevance of circular economy solutions in solid waste management (Ritalahti *et al.*, 2020), for example, underlining the potential of waste prevention and reduction evaluations in reducing waste formation at the source. The circular economy can reduce the overall volume of trash produced by adopting approaches such as product design for lifetime, repairability and recyclability.

Further, effective recycling and recovery systems are a vital component of the circular economy in solid waste management.

The development of recycling infrastructure, trash sorting, and collection systems and the promotion of the use of recovered materials may all contribute significantly to resource conservation and waste reduction (Geng *et al.*, 2021).

E-waste, such as ineffective electronic equipment, offers valuable components that may be collected and reused, therefore safeguarding resources and reducing hazards to the environment.In addition to the risk for environmental and public health problems, hazardous waste, such as electronic trash, medical waste, and chemical waste, require specialized treatment. However, harmful waste management tends to be inadequate with limited facilities and resources bound for its proper disposal and treatment (Abualreesh *et al.*, 2019; Wang *et al.*, 2020; An *et al.*, 2021).

Composting food scraps and yard clippings produces nutrient-rich compost, reduces landfill waste, greenhouse gas emissions and enhances soil health. Composting optimization for effective organic waste recycling has been investigated, emphasizing its significance in sustainable waste management (Li *et al.*, 2022).

Recycling and reusing Plastic trash is critical for reducing pollution and conserving resources. They studied the upcycling of mixed plastic waste into environmentally friendly building supplies, demonstrating an opportunity for turning plastic waste into valuable resources (Al-Salem *et al.*, 2020).

Challenges in Managing Growing Solid Waste Volumes: The Role of Microbial Assistance

Source segregation at the point of origin is a significant concern in solid waste management. When different waste streams are not properly split it becomes hard to recover items that are recyclable and effectively handle organic waste. This problem is exacerbated by a lack of awareness, inadequate infrastructureand poor waste disposal behaviors (Kelessidis *et al.*, 2019 and Nizami *et al.*, 2020).

Despite initiatives that promote recycling, various regions possess poor recycling rates. Inadequate infrastructure, insufficient collection processes, and a lack of public understanding and involvement can hinder ineffectual recycling initiatives. This eliminates valuable natural assets and raises the demand for landfills (Medina *et al.*, 2017 and Pariatamby *et al.*, 2019).

Microbial Compost as a Sustainable Alternative to Synthetic Fertilizers: Enhancing Soil Fertility and Crop Yields

The effect of microbial composting on soil organic carbon, nitrogen, and microbial biomass carbon fractions in broad agricultural systems was investigated by Chauhan *et al.*, (2021). The results of this study indicate that microbial compost application raised soil organic carbon content significantly, boosting soil fertility and microbial activity.

The effects of microbial compost on soil organic matter, microbial activity and nutrient availability in agricultural soils were examined by several researchers. Microbial compost application put soil organic matter content, encourages microbial activity, and improved nutrient availability, which enhanced the productivity and fertility of the soil (Gul *et al.,* 2020).

The impact of microbial compost on soil organic matter and fertility in an arid agroecosystem. Microbial compost application significantly increased soil organic matter content and improved soil fertility results such as available nutrients and microbial biomass (Yadav *et al.,* 2021).

Microbial compost can be used as a sustainable alternative to synthesized fertilizers in crop cultivation. The results revealed that adding microbial compost enhanced soil fertility, nutrient availability, and crop yields, implying that it may have the potential to replace synthetic fertilizers (Adekiya *et al.,* 2021)

A cost-benefit study of replacing microbial

Table 1. Composting bio-boosters:

Field used	Name of microorganisms	Reference
Agricultural waste: Composting of rice straw	Commercial effective microbes contain lactic acid bacteria, yeast, and phototrophic bacteria.	Jusoh *et al*., 2013.
Agricultural byproducts: Potential compost inoculants for accelerating the composting process.	*Kocuria, Microbacterium, Acidovorax, Comamonas*.	Chandna *et al*., 2013.
Agricultural waste: Rapid composting of paddy straw.	*Candida tropicalis (y6),Phanerochaete, chrysosporium (vv18),Streptomyces globisporous (c3), Lactobacillus sp.,*	Sharma *et al*., 2014.
Municipal solid waste: Effective degradation of organic fraction of municipal solid waste	*Trichoderma viride, Aspergillusniger Aspergillus flavus*	Awasthi *et al*., 2014.
Municipal solid waste: Composting by enzymatic activities	*Pseudomonas sp., Trichoderma Viride Trichoderma Sp*	Gautam *et al*., 2014.
Municipal solid waste: Co-composting of organic fraction of municipal solid waste mixed with different bulking manure.	*Phanerochaete chrysosporium, Trichoderma viride, Pseudomonas aeruginosa,*	Awasthi *et al*, 2015.
Food waste: Degrades organic acids on the composting	*Dysgonomonas sp., Pseudomonas caeni strain, Aeribacillus pallidus strain, Pseudomonas sp., Lactobacillus salivarius* strain, *Bacillus thuringiensis* strain and *Bacillus cereus strain.*	Song *et al*., 2018.
Municipal solid waste: Fungal consortium on the composting efficiency	*Trametes versicolor Fomes fomentarius*	Voberkova *et al.,* 2017.
Composting of cellulosic agricultural residues.	*Phanerochaete chrysosporium consortium*	Elad *et al.* (2018)
Bioenergy production, specifically for the production of biogas from organic waste materials.	*Thermophilic bacterial strains (e.g., species of Bacillus, Thermus)*	Xu *et al.* (2019)
Co-composting of chicken manure and agricultural waste.	*Pleurotus spp. consortium*	Chen, *et al.* (2019)
Composting of agricultural waste.	*Neurospora crassa* and *Aspergillus niger consortium*	Shah, M.P. and Patel, K. C. (2019)
Composting of grape marc waste.	*Pleurotusostreatus* and *Trichoderma harzianum consortium*	López-González, *et al*., 2020.
Composting of lignocellulosic waste, agricultural residues, and crop residues.	*Trichoderma* and *Aspergillus consortium*	Kumar, *et al.* (2020)
Agricultural waste	*Bacillus cereus, Enterobacteriaceae bacterium, Penicillium sp., Alternaria alternata.*	Dash *et al*., 2022.

compost with chemical fertilizers was conducted. According to the findings, using microbial compost as a replacement for chemical-based fertilizers can be cost-effective, providing farmers with economic benefits while lowering the environmental impact of synthetic fertilizers (Dahiya *et al.,* 2021).

Indian Agricultural Research Institute(IARI) developed the PUSA decomposer that enhances soil health and fertility by hastening the breakdown of agricultural wastes such as rice straw after harvest. Cellulolytic and ligninolytic fungi in the microbial community help break down complex organic matter in crop leftovers, releasing essential nutrients and organic substances into the soil. This process enhances soil structure, nitrogen absorption by plants, and overall soil health by boosting soil microbial activity and nutrient availability

The use of urine as an NPK (nitrogen, phosphorus, and potassium) source for conventional fertilizer replacement is gaining attraction as a sustainable and environmentally friendly means of agricultural nutrient recycling. Urine is a nutrient-rich liquid that contains nearly 80-90% of nitrogen, 50-80% of phosphorus, and a smaller quantity of potassium from humans release. The widespread utilization of urine-derived fertilizers poses challenges: proper handling, treatment, and storage are critical to prevent pathogen-related health risks; social acceptance varies among all communities, requiring effective awareness campaigns; and adequate regulations must be implemented for safe and controlled usage (Rose *et al.,* 2015).

Process of Bioconversion of organic waste into Compost

Composting is characterized as a microbial, biochemical, and aerobic procedure involving the conversion of organic components into a durable and sterilized end-product known as humus (Wei *et al.,* 2017).

In aerobic composting, carbon dioxide, nitrite, and nitrate are generated during the composting by aerobic microorganisms that degrade organic molecules. While metabolizing the nutrients during an anaerobic treatment, the anaerobic microorganisms decrease the organic matter to break them down. When an anaerobic method is applied to land, the final result experiences some minor oxidation as it is a reduction process. Composting municipal solid waste is supported in many nations across the world, and researchers have seen the effects of doing so in their work (Gautam *et al*., 2010).

The activity of microorganisms is influenced by various factors, including the initial pH and C/N ratio of the input materials, particle size distribution, and conditions like aeration and humidity within the compost heap. These elements collectively govern both the composting process and the eventual quality and maturity of the compost produced (Bernal *et al.,* 2009).

Further, immature composts can lead to environmental issues such as water pollution and odor emissions, as well as harmful effects on plant germination and development more generally (Bernal *et al.,* 2009; Wang *et al.,* 2016).

Microbial metabolism in compost production

Microbial metabolism plays an essential role in compost production as it induces organic matter degradation and transformation. Numerous microbes metabolic activities contribute to the breakdown of complex substances, nutrient cycling and the yield of useful compost.

Aerobic Metabolism: Aerobic organisms dominate in the initial stages of composting. To carry out the process of oxidative metabolism, such microbes require oxygen and organic substrates. They utilize pathways like glycolysis and the tricarboxylic acid cycle (TCA cycle) for breaking down readily available chemicals like sugars and simple carbohydrates. This process generates metabolic byproducts such as carbon dioxide and water (Tang *et al.,* 2020; Inês *et al.,* 2021).

Anaerobic Metabolism: As composting evolves, the oxygen supply decreases, enabling anaerobic conditions to form. Anaerobic microorganisms like facultative and obligate anaerobes become active. To metabolize complex organic substances, they employ fermentation and anaerobic respiration. Lactic acid bacteria, for example, develop lactic acid through fermentation, resulting in pH reduction and pathogen suppression during the composting process (Fuentes-Ramrez *et al.,* 2019; Jia *et al.,* 2021).

The process of composting hinges upon intricate interplays among microorganisms and their collaborative metabolic activities. These microbial consortia, composed of fungi, bacteria, and actinobacteria, engage in a complex interweaving of interactions. Notably, fungi play a pivotal role in dismantling stubborn compounds like lignin and cellulose, whereas bacteria and actinobacteria continue the degradation process on the resultant byproducts (Zeng *et al.,* 2020 and Inês *et al.,* 2021).

Microorganisms have enabled feasible and cost-effective responses which would have been impossible via chemical or physical engineering methods. More so, microbial technologies have successfully been applied to a wide range of environmental problems, especially waste management issues (Satyanarayana *et al.*, 2012).

Organic waste composting happens naturally through moist decomposition, however, there is no agreement on the effectiveness of inoculation in this process. Effective Microbial culture is made up of non-dominant and dominant microorganisms, with the former taking the lead (Karnchanawong and Nissaikla, 2014; Manu *et al.*, 2017; Rastogi *et al.*, 2019a and Rastogi *et al.*, 2019b). The addition of efficient microorganisms (EM) to the treatment mixes has increased waste breakdown rates.

Further, these additions can be extracted from microbial communities based on particular degradative functionalities or created using culture mixes such as soil, cow dung, and straw. Because of the proliferating mesophilic and thermophilic bacterial populations, the microbial component of a compost mix influences the temperature profile and ammonia emissions.

Studies on composting have discovered that microbial inoculation also impacts the quality of the compost. An ascending compost heap consistently exhibits a noteworthy reduction in operational duration attributed to the microbial actions inherent in the degradation process (Abdullah *et al.*, 2013). Introducing supplementary inoculants further accelerates the composting period, condensing it to a range of 30–36 days, and concurrently generates compost devoid of pathogens. In a co-composting trial executed by Awasthi *et al.* (2015), the introduction of a mixed microbial culture (*Phanerochaete chrysosporium*, *Trichoderma viride* and *Pseudomonas aeruginosa*) into the feedstock material emerged as an efficacious technique for curtailing the composting timeline.

The reduction in nitrogen loss and the acceleration of mineralization processes were notably pronounced when municipal solid waste (MSW) underwent co-composting alongside sludge and a blend of microbial cultures. This microbial consortium encompassed *Bacillus casei*, *Candida rugopelliculosa*, *Lactobacillus buchneri*, *Trichoderma*, and white-rot fungi, as reported by Awasthi *et al.* (2016). Likewise, Varma and Kalamdhad (2015) delved into carbon decomposition during waste

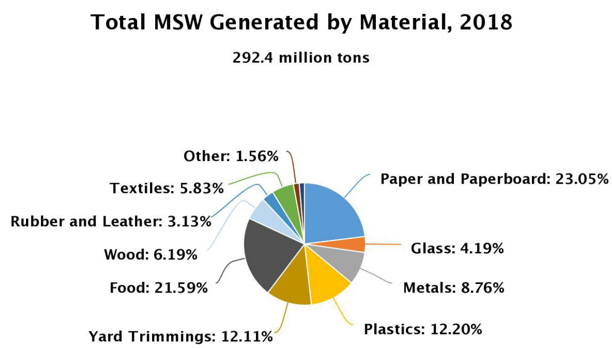

Fig. 2. Total MSW Generated by material, 2018.

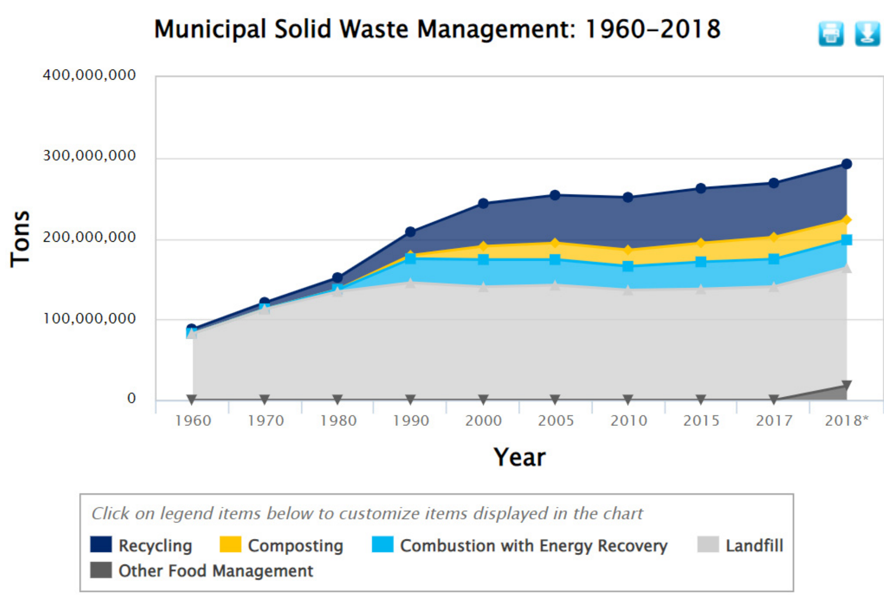

Fig. 1. MSW management 1960-2018 (USEPA 2022)

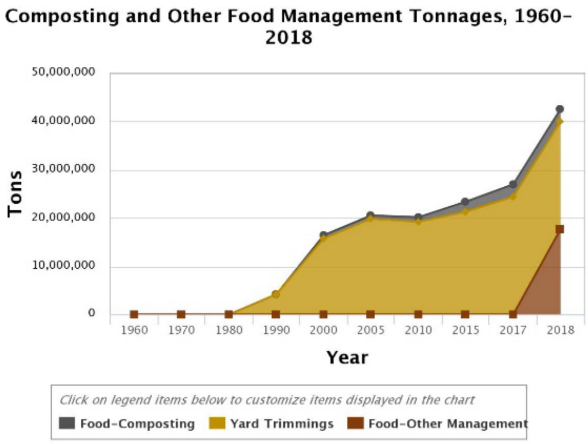

Fig. 3. Composting and other food management tonnages, 1960-2018.

drum composting, discovering that the introduction of the fungus Phanerochaete chrysosporium (white-rot fungus) led to an accelerated waste breakdown rate within a shorter timeframe through inoculation. The effects of co-composting, contingent upon the substrates employed, can vary when employing diverse microbial combinations at different stages. To achieve optimal outcomes in the co-composting of mixed consortia, the approach of introducing an inoculated municipal solid waste (MSW) alongside a consortium comprised of the white-rot fungus Fomes fomentarius, Phanerochaete chrysosporium, and Trametes versicolor yielded the best results, as elucidated by Vobrková et al. (2017).

CONCLUSION

Solid waste management through composting offers a sustainable and environmentally friendly solution for reducing the volume of waste and converting it into valuable compost. Composting involves the controlled decomposition of organic waste by microorganisms, leading to the breakdown of complex organic compounds and the release of essential nutrients. This process not only helps divert organic waste from landfills but also contributes to soil fertility enhancement and reduces the need for synthetic fertilizers. Composting plays a crucial role in promoting circular economy principles by recycling organic waste and closing the nutrient loop. With the advancement of composting technologies and increasing awareness of the importance of sustainable waste management, composting is becoming an integral component of solid waste management strategies worldwide.

Conflict of Interests

The authors declare that they have no conflict of interest.

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