Waste Bioconversion through Composting: Microbiome Dynamics and Physicochemical Analysis

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Chapter 8

Conclusion and future prospects

This study highlights the immense potential of composting as a sustainable and efficient technique for managing agricultural residues like RS and FW. Composting offers an environmentally friendly alternative to traditional waste disposal methods such as burning, which contributes significantly to greenhouse gas emissions. Through microbial activity, composting transforms these residues into nutrient-rich compost that improves soil fertility and contributes to sustainable agriculture.

The findings demonstrated the critical role of microbial communities, particularly those derived from ADS and CD, in enhancing the composting process. ADS consistently showed superior performance, promoting greater microbial species richness and diversity than CD. For example, ADS compost exhibited the highest Chao 1 estimate (390.27), Fisher index (57.52), and Shannon index (4.15), indicating a well-balanced and diverse microbial community essential for effective composting. In comparison, CD compost recorded slightly lower values, with a Chao 1 estimate of 372.48, a Shannon index of 3.82, and a read count of 88,249.

Significant microbial taxa such as *Acinetobacter*, *Serratia*, *Bacillus*, *Flavobacteria*, *Pseudomonas*, and *Prevotella* played vital roles in degrading RS and improving nutrient cycling. In mature ADS compost, these key microbial taxa increased significantly: *Acinetobacter* (198.15%), *Serratia* (164.41%), *Bacillus* (98.94%), and *Pseudomonas* (167.51%). Archaea such as *Haloarcula* and *Haloferax* also exhibited higher abundance in ADS compared to CD, increasing by 32.36% and 36.25%, respectively. This increased microbial diversity and activity in ADS resulted in more efficient composting, faster degradation of organic matter, and improved nutrient transformation, evidenced by increased nitrate and phosphate concentrations in the final compost.

However, the study also revealed significant challenges posed by MPs, such as PET and PS, which disrupted microbial processes essential for effective composting. PET and PS MPs led to a 1.14-fold and 1.13-fold decrease in microbial alpha diversity (Chao1 index), respectively, compared to the control (CK), which had a Chao1 value of 951.33. The presence of MPs also caused a decline in key nutrients, with nitrate levels in PET and PS treatments falling to 0.8253 g/kg and 0.7756 g/kg, respectively, compared to 1.0325 g/kg in the CK. Similarly, humic acid content was lower in the MP treatments (PET: 50.26 g/kg; PS: 51.02 g/kg) compared to the CK (55.25 g/kg). The reduced germination indices for PET (37.25%) and PS (32.26%) further indicated compromised compost quality, as compared to the CK (78.68%). This highlights the need for strategies to mitigate the impact of MPs on composting systems.

From an economic perspective, the study analyzed the relationship between the MSP of compost and system productivity. The MSP was calculated to be ₹47.56/kg, and it was found that productivity levels below 1000 kg/week led to negative MSP deviations, reducing profitability. Conversely, higher productivity levels, such as 2000 kg/week, resulted in positive MSP deviations and improved financial outcomes, emphasizing the importance of maintaining or enhancing productivity to ensure the economic sustainability of the composting operation.

Future Prospects:

Development of Tailored Microbial Inoculants: Future research should focus on developing customized microbial inoculants that are optimized for different agricultural residues, with the aim of accelerating organic matter decomposition and improving compost quality. These inoculants should be specifically designed to enhance nutrient cycling and pathogen control, further boosting the composting process's efficiency.

Strategies to Mitigate Microplastic Impact: The negative effects of microplastics on microbial diversity and compost quality underline the need for strategies to mitigate their presence. Future studies should explore biodegradable alternatives to traditional plastics or develop technologies that can degrade microplastics during the composting process. Additionally, filtration systems or pre-sorting techniques could be implemented to reduce microplastic contamination in organic waste streams.

Integration of Biochar Production: The study suggests that integrating biochar production with composting could offer additional benefits. Biochar, produced from agricultural waste through pyrolysis, is a stable carbon-rich material that enhances soil quality, increases water retention, and sequesters carbon. Combining biochar with compost could provide farmers with a valuable soil amendment that improves long-term soil health and productivity while contributing to carbon capture.

Expansion of ADS Utilization: The enhanced performance of ADS in promoting microbial diversity, nutrient cycling, and compost quality suggests that its application should be expanded to other organic waste streams. Future research could explore how ADS can be used more broadly in municipal solid waste composting, livestock manure management, and horticultural waste composting. This would optimize the utilization of ADS and enhance its role in sustainable waste management.

Life Cycle Assessment (LCA): Composting could focus on advanced emission quantification, improving energy efficiency, and integrating diverse organic waste streams. Additionally, incorporating AI-driven monitoring, enhancing nutrient recycling, and assessing long-term soil health impacts would refine the process. Regional studies, social and economic impacts, and comparing composting with emerging waste technologies like anaerobic digestion could also provide a more holistic view of its sustainability and future relevance in waste management.

Composting in Sustainable Agriculture: Future research should also focus on the broader integration of composting into sustainable agricultural practices. By improving soil organic matter, reducing dependence on chemical fertilizers, and enhancing soil health, composting can play a key role in regenerative agriculture. Long-term studies on the impact of compost on crop yields, soil biodiversity, and water retention further demonstrate the benefits of composting as part of a holistic farming approach.