ID: 754

Bio-Transformation of Agricultural and Municipal Waste into High-Value Resources: Advances, Challenges, and Future Prospects

Abdol Ghaffar Ebadi[1]*, Usman Mir Khan[2], Muhammad Yasir Naeem[3], Umar Murad Khan[4], Yaira Rakhmetova[5], Ali Murad Khan[6]

[1]Researcher and Faculty member, Jouybar branch, Islamic Azad University, Jouybar, Iran
[2]National Institute of Food Science and Technology, University of Agriculture, Faisalabad, 38000, Pakistan
[3]Department of Agronomy, Animals, Food, Natural Resources and the Environment (DAFNAE), University of Padua, Italy
[4]Faculty of Veterinary Medicine, Selcuk University, Konya, Türkiye,
[5]Department of Biotechnology, Faculty of Biology and Biotechnology, Al Farabi Kazakh National University, Almaty, Kazakhstan
[6]Faculty of Bio-Sciences, University of Veterinary and Animal Sciences, Lahore, Pakistan
*Presenter Author's Email: Dr_ebadi2000@yahoo.com

Abstract

Biotransformation technologies are one of the most promising fields in sustainable waste management, where farm and municipal waste is transformed into high-value bioproducts. This review explores the latest advances in microbial, enzymatic, and thermochemical processes that facilitate conversion of biomass and organic residues into bioenergy, bioplastics, biofertilizers, and bio-based chemicals. Scalable technologies such as anaerobic digestion, composting, fermentation, and gasification are emphasized with emphasis on process optimization and energy efficiency. The application of genetically engineered microbes and synthetic biology in enhancing conversion efficiency and product selectivity is examined. In addition, decentralized biorefineries are proposed as an economic model for circular bioeconomies to incorporate into local waste systems. The paper also examines key challenges that must be addressed, including heterogeneity of feedstock, microbial contamination, economic barriers, and policy uncertainty. Socio-economic and environmental impacts are evaluated using sustainability metrics and case studies from elsewhere. Future research directions stress the need for hybrid technologies, integrated systems, and real-time monitoring technologies in order to maximize the use of resources with the maximum possible efficiency and minimum possible environmental effects.

Keywords: *Anaerobic digestion, Bio-based products, Biorefineries, Biotransformation, Organic waste, Sustainable waste management*