Use of Vegetable Peel Waste for Biofertilizer Production

Shefali Singh
Department of Biosciences and ICEIR-3, Faculty of Science, Integral University, Kursi road, Lucknow, 226026, Uttar Pradesh, India
Shifa Suhail
Department of Biosciences and ICEIR-3, Faculty of Science, Integral University, Kursi road, Lucknow, 226026, Uttar Pradesh, India
Smita Rai
Department of Biosciences and ICEIR-3, Faculty of Science, Integral University, Kursi road, Lucknow, 226026, Uttar Pradesh, India
ReenaVishvakarma
Department of Bioengineering, Faculty of Science, Integral University, Kursi road, Lucknow, 226026, Uttar Pradesh, India
Poonam Sharma
Department of Bioengineering, Faculty of Science, Integral University, Kursi road, Lucknow, 226026, Uttar Pradesh, India
Swati Sharma
Department of Biosciences and ICEIR-3, Faculty of Science, Integral University, Kursi road, Lucknow, 226026, Uttar Pradesh, India
sw_sh@rediffmail.com

Abstract

The fast-growing production of waste from agricultural activities and food processing operations especially concerning vegetable peels has created significant environmental concerns. The wastes from agricultural activities contain rich nutrient levels and bioactive materials which allow their transformation into biofertilizers. This study aims to evaluate the effectiveness of using vegetable peel waste as an ingredient for biofertilizer production through enrichment culture methods. This study examines the specific peel varieties and microbial strains used in processing methods while measuring their effects on soil fertility and crop production. Utilizing peel waste according to circular economy principles helps push sustainable agriculture forward while reducing landfill waste and promoting environmental health.

Keywords: Biofertilizer, vegetable peel, sustainable agriculture, food waste management

I. INTRODUCTION

Population growth and changes in diet (UNISEF., 2021) serve as mainstays in the food supply, therefore worsening food scarcity and insecurity[1] as these phenomena are threatening human life. The emergence of sustainable agriculture has sparked new interest in biologically-based substitutes for chemical fertilizers. Biofertilizerswill serve as one, as they contain beneficial microorganisms that will improve soil health and therefore allow plants to be more easily cultivated[2].Additionally, the disposal of organic waste particularly from vegetable

peel waste is an environmental problem that is important to address. Excessive disposable of organic waste from household, retailing, and food processing vehicles is observed through vegetable peels of bananas, potatoes, carrots, cucumbers, and other vegetables which can potentially impact land and water bodies, if not handled correctly[3].These waste products could be direct targets of composting (using a fermentation process with effective microbial inoculants *Trichoderma*, *Azotobacter*, or *Bacillus*) to generate potentially rich biological fertilizers. Although there are benefits, microbial contamination and standardization of the process are some issues. However, with appropriate management and technological enhancement, vegetable peel biofertilizers are a feasible and sustainable alternative to modern agriculture and environmental issues.

II.COMPOSITION OF VEGETABLE PEELS

Vegetable peels, often considered as kitchen waste, are in fact a rich source of essential nutrients and bioactive compounds that contribute significantly to soil fertility and plant health when recycled or composted. Common peels such as those from banana, potato, carrot, onion, and tomato possess a valuable nutritional profile.

II.I.MACRONUTRIENTS

Vegetable peels are abundant in macronutrients like Nitrogen (N), Phosphorus (P), and Potassium (K)collectively known as NPK. These are critical for plant growth:

- Nitrogen aids in leaf and stem development.
- Phosphorus supports root growth and flowering.
- Potassium enhances overall plant vigor and disease resistance.

II.II.MICRONUTRIENTS

In addition to macronutrients, peels also contain trace elements such as Iron (Fe), Zinc (Zn), Manganese (Mn), and Magnesium (Mg). These micronutrients play vital roles in enzymatic functions, chlorophyll synthesis, and metabolic processes in plants.

II.III.BIOACTIVE COMPOUNDS

Peels are rich in phenolic compounds and antioxidants, which have antimicrobial properties and contribute to the health of the soil microbiome. These compounds can enhance the soil's ability to support beneficial microbes and suppress pathogens.

II.IV.ORGANIC MATTER

High in organic matter, vegetable peels improve soil texture, water retention, and aeration. They provide a carbon source for soil microorganisms, thereby enhancing microbial activity, which is crucial for nutrient cycling and soil fertility.

III. BIOFERTILIZER PRODUCTION METHODS AND ROLE OF MICROBIAL INOCULANT

Biofertilizers are natural substances containing living microorganisms, alternative to chemical fertilizer, promotes to plant growth and yield.

III.I.SOLID-STATE COMPOSTING- It is a biological process which converts organic wastes into useful compost. Vegetables peels are rich in carbon source (e.g., dry leaves) and also inoculated beneficial microbes such as *Trichodermahazianum* and *Bacillus subtilis* which promotes decomposition and nutrient release.

III.II.LIQUID FERMENTATION- Also called as submerged fermentation, It is a wet compost where vegetable peels are cut down in liquid media along with microorganisms.

III.III.VERMICOMPOSTING- Incorporating earthworms (e.g., *Lumbricusterrestris*) that breakdown organic matter into nutrient rich compost.

Vegetable peels (e.g., tomato, potato, cucurbits etc.) uses as a waste make biofertilizer, microbial inoculants play an important role in converting the waste into rich nutrient components.

TABLE I: BIOFERTILIZER PRODUCTION TECHNIQUES AND THE FUNCTIONAL ROLE OF MICROBIAL INOCULANTS IN SUSTAINABLE AGRICULTURE

Biofertilizer Type	***Production Method***	***Microbial Inoculant Used***	***Role of Microbial Inoculant***	***References***
Nitrogen-fixing Biofertilizers	Sterilized broth media fermentation in bioreactors	*Rhizobium*, *Azotobacter*, *Azospirillum*, *Anabaena*	Converts atmospheric nitrogen into a plant-usable form (ammonia)	[4]
Phosphate-solubilizing Biofertilizers	For submerged or solid-state fermentation utilizing rock phosphate substrates	*Bacillus*, *Pseudomonas*, *Aspergillus*	Converts insoluble phosphates into soluble phosphates for plant uptake	[5]
Potassium-solubilizing Biofertilizers	Utilizing mica or feldspar-based substrates fermentation	*Bacillus mucilaginosus*, *Frateuriaauranti a*	Activates and release potassium from soil minerals	[6]
Mycorrhizal Biofertilizers	Grown in pot-based systems with	*Glomus* spp. (AM fungi)	Increase nutrient and water uptake by	[7]

	host plants or on root organ cultures		forming symbiotic associations with root nodules	
Zinc-solubilizing Biofertilizers	Utilising zinc oxide or zinc carbonate as substrates for cultivation	*Bacillus*, *Pseudomonas* spp.	Transform insoluble zinc compounds to soluble forms accessible to plants	[8]
Cyanobacterial Biofertilizers	Grown in open tanks or raceway ponds under the sunlight	*Nostoc*, *Anabaena*, *Oscillatoria*	Fixation of nitrogen improves soil texture, and add organic matter	[9]
Compost-based Biofertilizers	Enrichment of compost with specific microbial strains	Consortia of beneficial bacteria and fungi	Increase decomposition, nutrient content, and microbial diversity of compost	[10]

IV. BENEFITS OF PEEL-BASED BIOFERTILIZERS

TABLE II: SUSTAINABLE BENEFITS OF UTILIZING PEEL-BASED BIOFERTILIZERS DERIVED FROM VEGETABLE AND FRUIT WASTE

Benefit Category	***Description***	***References***
Nutrient Enrichment	Provides essential macronutrients (N, P, K) and micronutrients (Fe, Zn, Mn, Mg) for plant growth.	[11]
Soil Fertility Improvement	Enhances organic matter content, improving soil structure, aeration, and water retention.	[12]
Cost-Effective	Utilizes kitchen and agricultural waste, reducing the cost of chemical fertilizers.	[13]
Eco-Friendly	Reduces waste disposal issues and lowers	[14]

	environmental pollution.	
Stimulates Microbial Activity	Supplies organic substrates that promote the growth of beneficial soil microbes.	
Enhances Plant Growth	Improves seed germination, root development, and overall plant vigor.	[15]
Pest and Disease Resistance	Contains bioactive compounds like phenolics and antioxidants that can suppress pathogens.	[16]
Sustainable Resource Use	Encourages circular economy practices by recycling biodegradable waste.	[17]

V. SCIENTIFIC EVIDENCE AND CASE STUDIES

An increasing amount of scientific studies shows the evidence behind peel-based biofertilizers, representing a more sustainable input in agriculture. Several studies have shown that vegetable peels, such as banana, potato, carrot, onion, and tomato peels, can be considered abundant sources of the most essential nutrients for plants as macronutrients and micronutrients[18]. Khanyilefound that bananas and potato peel additions to the soil greatly impacted the nutrient status as well as microbial biomass in soils due to the high levels of potassium, phosphorus, and nitrogen in peel biofertilizers[19]. Inaddition,Hidayatifound that seed extracts of tomato and carrot peels enhanced germination rates and seedling growth of mung bean seeds[20]. The authors credited the improvements to bioactive compounds in the peels such as phenolics and anti-oxidants that increase the metabolic and hormonal activity of plants. Similarly, Chinnaduraiobserved the increase of beneficial microbial species (such as *Azotobacter* and *Bacillus* species) in composts containing onion and banana peels[21]. The study also determined that not only the peels enhance beneficial microbial species, but also produced organic acids and sugars that promote microbial growth for nutrient cycling processes in soils[22]. Field trials also showed significant evidence.

VI. CHALLENGES AND FUTURE PROSPECTS

Despite the astonishing benefits of peel-derived biofertilizers, various limitations restrict their use. One of the most relevant issues is the lack of standardized processing protocols for peel types which lead to variability in nutrient content and efficacy. Additionally, raw peels can attract pests or create offensive odors, which diminishes the chance of sustainable use in large agricultural operations without proper management practices and sufficiently maturing or composting them. The awareness of the scientific principles and evidence regarding the long- term benefits of biofertilizers and the marketing for plant health borne from organic waste is still low among farmers and agricultural resource professionals. Organic waste is an unregulated commodity which causes lack

of control options for quality and may reduce a commercial interest in the product as well as farmer faith in the product itself. Notwithstanding, the future value of peel-derived biofertilizers is encouraging. The trend toward sustainability and interest in the valorization of waste is becoming a pathway to convert organic residues into value-added products. Advances in microbial technologies and fermentation technology will offer optimizations to the efficacy of timing peel-derived biofertilizer applications as well as control on shelf-life of these products. Ultimately, research opportunities may be possible with peel formulations containing a specific microbial inoculum combination to address soil conditions and nutrient deficiencies that persist.

VII. CONCLUSION

The innovative approach of converting vegetable peel waste into biofertilizers provides a sustainable solution for managing organic waste. This method generates a cost-effective alternative to chemical fertilizers that boosts both soil health and plant growth. Implementing this practice supports both circular economy progress and sustainable farming methods especially in areas where resources are scarce.

Consent for publication

None declare

Conflict of interest

None declare

Acknowledgement

The authors would like to express my sincere gratitude and thanks to Integral University for providing DST- FIST (SR/FST/LS-1/2017/13(C) sponsored department of Biosciences and Integral University for providing research facilities.

References

[1]. Vågsholm I, Arzoomand NS, Boqvist S: Food Security, Safety, and Sustainability—Getting the Trade-Offs Right. *Front Sustain Food Syst* 2020, 4.

[2]. Chen J, Lü S, Zhang Z, Zhao X, Li X, Ning P, Liu M: Environmentally friendly fertilizers: A review of materials used and their effects on the environment. *Science of The Total Environment* 2018, 613–614:829–839.

[3]. Haldar D, Shabbirahmed AM, Singhania RR, Chen C-W, Dong C-D, Ponnusamy VK, Patel AK: Understanding the management of household food waste and its engineering for sustainable valorization- A state-of-the-art

review. *Bioresource Technology* 2022, 358:127390.

[4]. Suthar H, Hingurao K, Vaghashiya J, Parmar J: Fermentation: A Process for Biofertilizer Production. In *Microorganisms for Green Revolution: Volume 1: Microbes for Sustainable Crop Production*. Edited by Panpatte DG, Jhala YK, Vyas RV, Shelat HN. Springer; 2017:229–252.

[5]. Bagga D, Chauhan S, Bhavanam A, G. N. N, Meena SS, Mohanty A: Recent Advancements in Fermentation Strategies for Mass Production and Formulation of Biofertilizers: Towards Waste Valorization. *J Soil Sci Plant Nutr* 2024, 24:5868–5897.

[6]. Ghosh S, Banerjee ,Sonali, Prajapati ,Jyoti, Mukherjee ,Abhishek, and Bhattacharyya P: Appraisal of Mica-Based Potassium Mobilizing Bacterial Biofertilizers: Revolutionizing Soil Fertility and Plant Growth Employing Multi-Machine Learning Models. *Communications in Soil Science and Plant Analysis* [date unknown], 0:1–23.

[7]. Wong WS, Zhong HT, Cross AT, Yong JWH: Plant Biostimulants in Vermicomposts. In *The Chemical Biology of Plant Biostimulants*. . John Wiley & Sons, Ltd; 2020:155–180.

[8]. Sehrawat A, Sindhu SS: Zinc-Solubilizing Microorganisms: Contributions in Nutrient Availability and Implications for Crop Productivity in Sustainable Agriculture. In *Plant Holobiome Engineering for Climate-Smart Agriculture*. Edited by Sayyed RZ, Ilyas N. Springer Nature; 2024:183–213.

[9]. Jose S: Cyanobacteria-microalgae consortia as bio- inoculants for enhancing soil fertility and plant growth. 2024,

[10]. Sharma A, Kuthiala T, Thakur K, Thatai KS, Singh G, Kumar P, Arya SK: Kitchen waste: sustainable bioconversion to value-added product and economic challenges. *Biomass Conv Bioref* 2025, 15:1749–1770.

[11]. Abd-Elsalam KA, Hashim AF, Abdelkhalek TE, Hassan RK: Encapsulation of Soil Nutrients for Plant Growth and Development. In *Biopolymeric Nanoparticles for Agricultural Applications*. Edited by Abd-Elsalam KA, Hashim AF, Ahmed FK, Thomas S. Springer Nature Switzerland; 2024:145–174.

[12]. Xing Y, Wang X, Mustafa A: Exploring the link between soil health and crop productivity. *Ecotoxicology and Environmental Safety* 2025, 289:117703.

[13]. Sharma A, Kuthiala T, Thakur K, Thatai KS, Singh G, Kumar P, Arya SK: Kitchen waste: sustainable bioconversion to value-added product and economic challenges. *Biomass Conv Bioref* 2025, 15:1749–1770.

[14]. Kanagaraj J, Senthilvelan T, Panda RC, Kavitha S: Eco-friendly waste management strategies for greener environment towards sustainable development in leather industry: a comprehensive review. *Journal of Cleaner Production* 2015, 89:1–17.

[15]. Riseh RS, Vazvani MG, Vatankhah M, Kennedy JF: Chitosan coating of seeds improves the germination and growth performance of plants: A Rreview. *International Journal of Biological Macromolecules* 2024, 278:134750.

[16]. Khanday AH, Badroo IA, Wagay NA, Rafiq S: Role of Phenolic Compounds in Disease Resistance to Plants. In *Plant Phenolics in Biotic Stress Management*. Edited by Lone R, Khan S, Mohammed Al-Sadi A. Springer Nature; 2024:455–479.

[17]. Islam NF, Gogoi B, Saikia R, Yousaf B, Narayan M, Sarma H: Encouraging circular economy and sustainable environmental practices by addressing waste management and biomass energy production. *Regional Sustainability* 2024, 5:100174.

[18]. Howeidi MAR, Manea AI, Slomy AK: Effect of Bio-Fertilizer and Banana Peel Extract on the Vegetative Traits and Yield of Carrot Plants. *IOP Conf Ser: Earth Environ Sci* 2023, 1158:042035.

[19]. Khanyile N, Dlamini N, Masenya A, Madlala NC, Shezi S: Preparation of Biofertilizers from Banana Peels: Their Impact on Soil and Crop Enhancement. *Agriculture* 2024, 14:1894.

[20]. Hidayati N: THE EFFECT OF BANANA PEEL LIQUID ORGANIC FERTILIZER (LOF) AND GROWING MEDIA ON PRODUCTION OF MUNG BEAN (Vigna radiata L.). 2025,

[21]. Chinnadurai, d., udhayaraja, d., & ramya, a. (2024).Production of Inulinase by Bacillus sp –recycling of agro waste using Banana peel, Garlic and Corn cob. *APSR* 2024, 26.

[22]. Kiruba N, J. M., & Saeid, A. (2022).An Insight into Microbial Inoculants for Bioconversion of Waste Biomass into Sustainable “Bio-Organic” Fertilizers: A Bibliometric Analysis and Systematic Literature Review.