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Circular Waste Management Through Bokashi and Trichoderma Composting of Market Fruit and Vegetable Wastes

Luzviminda S Quitos[1]*, Reigh Albert T Ponce[1], Mishaelle Q Reyes[2] & Maribel P Mananguit[3]

[1]Department of Environmental Science, College of Science, Central Luzon State University, Science City of Muñoz, Nueva Ecija, Philippines
[2]Center for Environmental Research, Nueva Ecija University of Science ang Technology, Cabanatuan City, Nueva Ecija, Philippines
[3]Soils Laboratory, Bureau of Soils and Water Management, Baguio City, Philippines

*Corresponding author: Luzviminda S. Quitos, Department of Environmental Science, College of Science, Central Luzon State University, Science City of Muñoz, Nueva Ecija, Philippines.

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Abstract

Market waste management remains a pressing environmental and socio-economic challenge, particularly in developing countries where open dumping and landfilling remain the dominant methods of disposal. Fruit and vegetable residues constitute a major portion of municipal solid waste and, when unmanaged, contribute to methane emissions, foul odors, pest infestations, and contamination of surface and groundwater. To address this challenge, this study investigates the potential of integrating bokashi fermentation and Trichoderma-assisted composting as a dual microbial strategy for converting biodegradable market waste into high-quality organic fertilizer. Four treatments with varying ratios of bokashi, Trichoderma, and market waste were tested to determine their effects on decomposition rate, temperature trends, nutrient availability, and fertilizer yield. The composting process was closely monitored, and the resulting organic fertilizers were analyzed for macronutrients and organic matter content. The fertilizers were applied to mustard greens (Brassica juncea), and soil health was evaluated before and after application. Results revealed that Treatment 3 (10% bokashi, 30% Trichoderma, 60% waste) produced the highest fertilizer yield and nutrient content, while Treatment 1 (30% bokashi, 10% Trichoderma) promoted superior mustard growth. The synergy between bokashi and Trichoderma accelerated decomposition, reduced greenhouse gas emissions, and improved soil properties. This study demonstrates the viability of bokashi–Trichoderma composting as a scalable, low-cost, and environmentally sustainable waste management strategy. It further emphasizes its role in mitigating pollution, enhancing soil fertility, and reducing dependence on synthetic fertilizers. Recommendations for policy support, infrastructure development, and community adoption are also proposed to promote large-scale implementation.

Keywords: Bokashi Composting, Trichoderma, Market Waste Management, Sustainable Agriculture, Organic Fertilizer, Environmental Impact, Circular Economy.

Introduction

Solid waste management has become one of the most urgent environmental concerns worldwide, especially in rapidly urbanizing regions where population growth and increased consumerism have led to a surge in municipal solid waste generation. According to the World Bank, the world generates approximately 2.24 billion tons of solid waste annually, and this number is expected to rise to 3.88 billion tons by 2050 if no interventions are made. A major portion of this waste—originating from homes, public markets, restaurants, and food processing facilities—is biodegradable and primarily composed of fruit and vegetable residues. When improperly managed, this organic waste contributes to environmental degradation, climate change, and public health issues.

In many developing countries, including the Philippines, the predominant method of waste disposal is open dumping or landfilling. Landfills act as ecological reactors where biochemical decomposition processes occur under both aerobic and anaerobic conditions. However, the decomposition of organic waste in landfills under oxygen-deprived conditions produces methane (CH_4), a greenhouse gas that is 28–34 times more potent than carbon dioxide (CO_2) over a 100-year period. In addition to greenhouse gas emissions, unmanaged organic waste produces leachate, a toxic liquid that can contaminate soil and groundwater, threatening ecosystems and human health.

From a sustainability perspective, the mismanagement of biodegradable waste represents a missed opportunity for resource recovery. Instead of being treated as waste, fruit and vegetable residues can be transformed into valuable products such as organic fertilizers, soil conditioners, and bioenergy feedstocks. This aligns with the concept of the circular economy, which emphasizes the reuse, recycling, and regeneration of materials to minimize waste and environmental impacts. Composting, in particular, is a simple, low-cost, and resource-efficient method for converting organic waste into nutrient-rich compost that enhances soil fertility and supports sustainable agriculture.

Composting as a Sustainable Solution

Traditional composting methods, such as windrow or pit composting, rely on aerobic microbial activity to decompose organic matter. While effective, these methods can be slow, require large areas of land, and may generate unpleasant odors if not properly managed. To address these limitations, innovative composting techniques have emerged, including bokashi fermentation and the use of microbial inoculants such as Trichoderma, which offer faster decomposition rates, reduced odor, enhanced nutrient retention, and improved microbial diversity in the final product.

Bokashi is an anaerobic fermentation process that uses microorganisms, typically lactic acid bacteria and yeast, to partially decompose organic material in airtight containers. Unlike traditional composting, bokashi preserves most of the nutrients by preventing volatilization and leaching. Moreover, it suppresses foul odors and pest infestations, making it suitable for urban and household settings. After fermentation, bokashi material can be incorporated into soil to complete the decomposition process, enriching the soil with nutrients and beneficial microbes. Trichoderma, on the other hand, is a genus of beneficial fungi widely recognized for its ability to accelerate the breakdown of complex organic compounds such as cellulose and lignin. It is also known to enhance nutrient cycling, suppress soil-borne pathogens, and promote plant growth through the production of enzymes and growth-stimulating metabolites. The integration of Trichoderma in composting systems has been shown to improve the efficiency and quality of compost, making it a valuable bio-inoculant in sustainable agriculture.

Global and Philippine Context of Waste Management

The Philippines generates approximately 21 million metric tons of waste annually, 52% of which is biodegradable. Public markets are among the largest contributors of organic waste due to the sale and processing of fruits and vegetables. Despite the enactment of Republic Act 9003 (Ecological Solid Waste Management Act of 2000), which mandates waste segregation and recycling, the implementation of sustainable waste management practices remains limited in many local government units (LGUs). Challenges include insufficient infrastructure, lack of funding, limited technical capacity, and low public participation.

Composting has been identified as one of the most practical strategies for reducing biodegradable waste at the source. However, many LGUs lack standardized composting systems and rely on traditional methods that are time-consuming and inefficient. Integrating bokashi and Trichoderma into composting practices could provide a scalable, efficient, and eco-friendly solution that can be implemented in households, barangays, public markets, and agricultural communities.

Alignment With Sustainable Development Goals (SDGs)

This study directly supports several United Nations Sustainable Development Goals:

- **SDG 2:** Zero Hunger – By producing organic fertilizer, the study promotes sustainable agriculture and enhances crop productivity.
- **SDG 12:** Responsible Consumption and Production – It transforms waste into a resource, reducing landfill burden and encouraging circular economy practices.
- **SDG 13:** Climate Action – It mitigates greenhouse gas emissions by diverting organic waste from landfills and promoting carbon sequestration in soils.
- **SDG 15:** Life on Land – It improves soil health, biodiversity, and ecosystem resilience through organic matter restoration.

By integrating these global sustainability frameworks, the study contributes to environmental protection, food security, and long-term ecological balance.

Rationale of The Study

The necessity of this study is driven by the urgent need for sustainable, low-cost, and locally adaptable waste management solutions. While bokashi and Trichoderma have separately been proven effective in composting and plant growth promotion, limited research exists on the combined use of these technologies in market waste management. There is a gap in literature concerning the synergistic impact of these microbial inoculants on decomposition efficiency, nutrient availability, and plant productivity. Furthermore, most previous studies have focused on laboratory-scale experiments, with few exploring real-world implementations in community-level waste streams.

Therefore, this research investigates the use of bokashi and Trichoderma in varying combinations to determine their effectiveness in converting fruit and vegetable waste into high-quality organic fertilizer. It aims to identify the best treatment for decomposition, nutrient content, fertilizer yield, and plant performance. Additionally, the study examines its potential as a sustainable waste management model that can be scaled for community adoption.

Objectives of the Study

This study aims to harness the synergy of bokashi and Trichoderma in composting market waste as a sustainable waste management strategy. Specifically, it seeks to:

1. Evaluate the decomposition efficiency and temperature trends of different bokashi–Trichoderma combinations.
2. Analyze the nutrient content and yield of the resulting organic fertilizer.
3. Assess the impact of the fertilizers on mustard green growth and soil health.
4. Determine the most effective treatment for both fertilizer production and plant performance.
5. Highlight the environmental benefits and policy implications of bokashi–Trichoderma composting for sustainable waste management.

Background and Literature Review

The growing concern over environmental degradation, climate change, and resource depletion has intensified global interest in sustainable waste management strategies. Biodegradable waste, particularly from markets and households, represents both an environmental liability and a valuable resource. When unmanaged, it contributes to pollution and greenhouse gas emissions; when properly utilized, it becomes an important input for sustainable agriculture and soil restoration. This section discusses the science behind organic waste composting, the roles of bokashi and Trichoderma, and the broader environmental and agricultural implications of transforming waste into fertilizer.

Organic Waste Management: Global and Local Challenges

Globally, organic waste accounts for approximately 44% of total municipal solid waste. In low- and middle-income countries, this proportion can exceed 60%, with fruit and vegetable waste being the most prevalent. The predominant waste disposal method in many countries is landfilling, which presents several challenges:

- Generation of methane (CH_4) from anaerobic decomposition
- Leachate production leading to water pollution
- Odor and pest problems
- High land usage and long-term maintenance costs
- Loss of potentially valuable resources

In the Philippines, the issue is particularly critical. According to the National Solid Waste Management Commission, the country produces more than 21 million metric tons of waste annually, and this number continues to climb due to urbanization and economic growth. Public markets are among the major contributors of organic waste, especially in urban centers. Despite the existence of Republic Act 9003 (Ecological Solid Waste Management Act), many local government units still struggle with implementation due to lack of infrastructure, funding, and public participation.

Opportunity: Instead of viewing market waste as a burden, it can be converted into a resource for soil fertility, local livelihood, and environmental sustainability.

Composting: A Circular Economy Approach

Composting transforms organic waste into nutrient-rich humus through controlled decomposition. It is recognized globally as one of the most effective and environmentally friendly waste management strategies. Composting supports the concept of the circular economy, in which waste is reintegrated into productive systems rather than discarded.

Benefits of composting:

- Diverts waste from landfills
- Reduces methane emissions
- Enhances soil structure, fertility, and water retention
- Suppresses plant diseases through beneficial microbes
- Decreases reliance on synthetic fertilizers
- Promotes carbon sequestration in soils

However, traditional aerobic composting methods can be slow and require high labor and land area. Without proper management, they can also produce odor, attract pests, or lose nutrients through volatilization and leaching. For these reasons, innovative techniques such as bokashi fermentation and microbial inoculants have gained attention.

Bokashi Composting: Anaerobic Fermentation for Waste Stabilization

Bokashi, derived from the Japanese term "fermented organic matter," is an anaerobic composting technique that uses effective microorganisms (EM) to break down organic waste inside an airtight container. It typically includes lactic acid bacteria, yeasts, and phototrophic bacteria, which ferment rather than fully decompose the material.

Key advantages of Bokashi:

- Minimal odor (unlike aerobic composting)
- Prevents nutrient loss due to limited volatilization
- Suppresses pathogens and pests
- Faster process (10–14 days pre-fermentation)
- Suitable for urban and indoor settings
- Enhances microbial diversity in soil when buried

Several studies have demonstrated that bokashi improves soil biological activity, increases nutrient availability, and promotes plant growth. For example, Kim et al. (2019) found that bokashi-amended soils showed higher microbial biomass and improved plant nutrient uptake. However, bokashi by itself does not fully decompose organic matter; it must be followed by soil incorporation or further composting.

Trichoderma: A Powerful Decomposer and Biocontrol Agent

Trichoderma is a genus of filamentous fungi found naturally in soils. It is widely used in agriculture due to its ability to:

- Decompose complex organic compounds such as cellulose, hemicellulose, and lignin
- Produce enzymes (cellulases, xylanases, proteases) that accelerate composting
- Suppress soil-borne pathogens (e.g., Fusarium, Pythium, Rhizoctonia)
- Promote plant growth through hormonal stimulation (auxins, gibberellins)
- Enhance nutrient availability and root development

Research by [1,2] showed that Trichoderma not only speeds up the composting process but also results in compost with higher microbial activity and nutrient content. Additionally, it improves plant resistance to abiotic stress such as drought and salinity. In the Philippines, Trichoderma harzianum has been promoted by the Department of Agriculture as a biofertilizer and biocontrol agent, making it locally available and cost-effective.

Synergistic Potential of Bokashi and Trichoderma

While both bokashi and Trichoderma have individually demonstrated benefits in composting and plant growth, limited research has explored their combined use. Bokashi fermentation preserves nutrients and establishes beneficial microbes in the early stages of decomposition, while Trichoderma further breaks down complex materials during aerobic curing or soil application.

Potential Synergy:

- Bokashi initiates fermentation, lowers pH, suppresses harmful microbes.
- Trichoderma completes decomposition, increases nutrient mineralization.
- Combined system may reduce total composting time.
- End product may contain a diverse microbial community beneficial to soil health.
- Potential to produce superior organic fertilizer compared to traditional compost.

This dual approach offers a more holistic, efficient, and sustainable composting method aligned with circular economy principles.

Comparison with Chemical Fertilizers

The overuse of chemical fertilizers in modern agriculture has led to numerous environmental and health issues:

- Soil acidification and degradation
- Loss of beneficial soil microorganisms
- Water pollution through nutrient runoff (eutrophication)
- Heavy metal accumulation in crops
- High cost and dependence on imported inputs
- Contribution to greenhouse gas emissions during manufacturing

Organic fertilizers derived from compost provide a safer and more sustainable alternative. They release nutrients slowly, improve soil structure, increase water retention, and support microbial diversity. Compost-based fertilizers are essential in regenerative agriculture and soil health management.

Bokashi and Trichoderma-enriched composts offer added value by enhancing nutrient availability and biological activity, potentially outperforming both traditional compost and chemical fertilizers in long-term soil productivity.

Materials and Methods

Sampling Location

The study was conducted at the Central Luzon State University (CLSU) Ramon Magsaysay-Center for Agricultural Resources and Environment Studies (RM-CARES), located in the Science City of Muñoz, Nueva Ecija. Market waste, comprising fruit and vegetable residues, was sourced from the local wet market, while mustard greens were cultivated at the CLSU Nanotechnology R&D facility.

Composting of Market Waste

The composting process utilized sealed bins arranged in a bedding style with alternating layers of bokashi, Trichoderma, and market waste. Four treatments were designed:

1. Treatment 1: 60% market waste, 30% bokashi, 10% Trichoderma
2. Treatment 2: 60% market waste, 20% bokashi, 20% Trichoderma
3. Treatment 3: 60% market waste, 10% bokashi, 30% Trichoderma
4. Treatment 4: 100% market waste (control)

Organic Fertilizer Collection

The organic fertilizer was harvested after 25 days, once temperature trends stabilized, indicating the completion of active decomposition. Compost was sieved to separate undecomposed materials, which were returned to the bins. The dried fertilizer was analyzed for physical properties, including texture and odor.

Mustard Green Cultivation

Mustard green seeds were pre-soaked for optimal germination, transplanted to pots containing 160 g of organic fertilizer, and grown under controlled conditions. Baseline soil nutrient levels were assessed using a Soil Test Kit (STK) prior to planting, and post-harvest soil samples were analyzed for changes in nitrogen (N), phosphorus (P), and potassium (K) levels.

Fertilizer Analysis

Samples of the dried organic fertilizer were submitted to the Department of Agriculture-Bureau of Soils and Water Management for nutrient analysis. Parameters included total nitrogen, phosphorus, potassium, organic matter content, and trace elements such as zinc and copper.

Results and Discussion

Temperature Dynamics

All bokashi–Trichoderma treatments exhibited higher microbial activity compared to the control. Peak composting temperatures ranged between 37–42°C, facilitating pathogen suppression and efficient nutrient transformation. Bokashi fermentation reduced odor and methane formation, while Trichoderma enhanced aerobic decomposition during curing.

Organic Fertilizer Production

The production of organic fertilizer varied substantially among the treatments, reflecting the influence of bokashi and Trichoderma ratios on microbial activity and decomposition efficiency. Among all treatments, Treatment 3 (10% bokashi, 30% Trichoderma, 60% waste) achieved the highest yield at 0.67 kg, followed by Treatment 2 (0.64 kg) and Treatment 1 (0.38 kg). The control treatment (Treatment 4), which lacked microbial inoculants, yielded negligible fertilizer, underscoring the essential role of microbial additives in accelerating biodegradation.

The superior performance of bokashi- and Trichoderma-enriched treatments can be attributed to synergistic microbial dynamics. Bokashi fermentation introduces lactic acid bacteria and yeast that initiate anaerobic breakdown and nutrient preservation (Higa & Parr, 1994; Kim et al., 2019). Meanwhile, Trichoderma species enhance cellulose and lignin degradation through the secretion of cellulolytic and ligninolytic enzymes [2,1]. Their combined use not only expedites decomposition but also improves the stability and maturity of the composted material.

Similar findings were reported by Singh et al. (2021), who observed increased compost yield and faster decomposition rates when microbial inoculants were integrated into organic waste management systems.

The marked reduction in residual waste across Treatments 1–3 demonstrates the efficiency of this dual microbial approach in diverting biodegradable waste from landfills. Converting market waste into nutrient-dense organic fertilizer supports circular waste management and contributes to climate mitigation by reducing methane emissions from uncontrolled decomposition (Awasthi et al., 2015). Furthermore, the increased fertilizer yield observed in this study aligns with previous research showing that microbial co-composting systems enhance both mass loss and nutrient recovery (Lazcano et al., 2019).

Table 2: Organic Fertilizer Yield and Remaining Waste

Treatment	Harvested Fertilizer (kg)	Remaining Waste (kg)
Treatment 1	0.38	1.79
Treatment 2	0.64	1.48
Treatment 3	0.67	1.32
Treatment 4 (Control)	0.00	2.50

Nutrient Analysis

A comparative evaluation of the experimental treatments against the Philippine National Standard for organic fertilizers [3] demonstrated that Treatment 3 consistently exhibited superior macronutrient composition. Specifically, it recorded 2.09% total nitrogen (N), 1.15% total phosphorus (P), and 1.61% total potassium (K)—values that surpass those observed in Treatments 1 and 2. The elevated nitrogen concentration enhances vegetative growth and chlorophyll synthesis, while phosphorus contributes to robust root development and energy transfer mechanisms. The higher potassium level in Treatment 3 supports enzyme activation and osmotic regulation, both of which are vital for stress tolerance and yield improvement.

In terms of organic matter (OM) content, all treatments exceeded the 40% minimum threshold stipulated by the national standard, confirming their compliance with quality specifications. Organic matter levels ranged from 24.98% in Treatment 2 to 44.60% and 43.75% in Treatments 1 and 3, respectively. High OM content plays a critical role in improving soil aggregation, water-holding capacity, and microbial habitat diversity. Moreover, micronutrient analysis revealed that essential trace elements such as manganese (Mn) and iron (Fe) were abundant in all formulations [4][5]. These elements are crucial for photosynthetic efficiency, chlorophyll formation, and enzymatic activation in plants. The synergistic presence of macro- and micronutrients contributes to a well-balanced fertilizer formulation capable of sustaining plant vigor and productivity over multiple cropping cycles.

Overall, the superior nutrient profile of Treatment 3 underscores its potential as a sustainable biofertilizer alternative to chemical inputs. By enriching soil nutrient pools and enhancing nutrient-use efficiency, its application can reduce reliance on synthetic fertilizers, thereby mitigating nutrient leaching and agricultural runoff—a primary cause of eutrophication in nearby aquatic ecosystems. In addition, the slow-release characteristics of organic-based fertilizers ensure steady nutrient availability, minimizing volatilization and environmental losses associated with conventional agrochemicals.

Table 3: Nutrient Composition of Organic Fertilizer

Parameter	Treatment 1	Treatment 2	Treatment 3
Total Nitrogen (%)	1.54	1.79	2.09
Total Phosphorus (%)	1.10	1.14	1.15
Total Potassium (%)	1.46	1.38	1.61
Organic Matter (%)	44.60	24.98	43.75

Post-harvest soil analysis revealed significant improvements in soil fertility indicators, particularly in treatments enriched with bokashi and Trichoderma. Both Treatment 1 (30 % bokashi + 10 % Trichoderma) and Treatment 3 (10 % bokashi + 30 % Trichoderma) showed remarkable increases in available macronutrients, organic matter, and microbial activity compared with the control soil.

Quantitatively, total nitrogen (N) increased from 0.07 % to 0.12–0.15 %, while available phosphorus (P) rose from 10.8 mg kg^{-1} to 18.5–21.3 mg kg^{-1}. Exchangeable potassium (K) improved from 65.2 mg kg^{-1} to 112.7–126.4 mg kg^{-1}, reflecting a 65–90 % enhancement in soil nutrient status after compost application. These nutrient increments were sufficient to support vigorous mustard growth without the addition of chemical fertilizers [3,4].

The improved fertility resulted from the synergistic biochemical processes promoted by bokashi microorganisms and Trichoderma fungi. Bokashi inoculants—comprising lactic acid bacteria, yeasts, and photosynthetic microbes—accelerate organic matter decomposition and humus formation under semi-anaerobic conditions, preventing nutrient volatilization and odor emissions [5]. In parallel, Trichoderma enhances mineralization by secreting cellulases and phosphatases, releasing plant-available nutrients from complex residues and promoting beneficial microbial consortia [6]. The resulting enrichment in microbial biomass and enzymatic activity improves rhizosphere nutrient cycling and uptake efficiency.

The compost's organic-matter content (24.98–44.60 %) further enhanced soil aggregation, porosity, and water-holding capacity, while elevating the cation-exchange capacity (CEC) and buffering ability of the soil. Post-harvest pH remained within 6.4–6.7, favorable for microbial proliferation and nutrient solubility. Trace elements such as manganese (Mn) and iron (Fe)—essential cofactors in photosynthesis and enzyme systems—were present in sufficient quantities, reinforcing plant metabolic efficiency [7,8].

Biologically, Trichoderma colonization of the rhizosphere suppressed soil-borne pathogens while releasing growth-promoting hormones (auxins, gibberellins) and siderophores that enhanced root vigor and micronutrient uptake. The continuous addition of organic matter promoted carbon sequestration through humus stabilization, improving soil resilience and mitigating greenhouse-gas emissions [9]. Over successive applications, these processes enhance soil organic carbon (SOC) stocks, reduce erosion, and sustain long-term soil productivity.

From an environmental standpoint, improved nutrient retention minimizes leaching and runoff, mitigating eutrophication of nearby water bodies. The substitution of synthetic fertilizers with biologically enriched composts aligns with the Philippine National Standard for Organic Fertilizers [10] and supports sustainable waste management and regenerative agriculture [11]. Collectively, the bokashi–Trichoderma system demonstrates how circular-economy composting can restore soil fertility, enhance microbial ecology, and advance environmentally responsible agricultural practices [12].

Conclusion

1. Biodegradable market wastes are viable raw materials for producing high-quality organic fertilizers.
2. Bokashi and Trichoderma accelerate decomposition and enhance the nutrient profile of compost while preventing greenhouse gas emissions.
3. Treatment 3 (10% bokashi, 30% Trichoderma) is optimal for fertilizer yield, while Treatment 1 (30% bokashi, 10% Trichoderma) supports superior plant growth.
4. The process reduces landfill dependency, mitigates methane emissions, and enhances soil health, contributing to broader environmental benefits.
5. A localized waste management plan incorporating these methods can significantly reduce waste, promote sustainable agriculture, and foster environmental resilience.

Recommendations

1. Scaling Implementation: Encourage municipalities to adopt bokashi and Trichoderma composting systems at community and industrial scales.
2. Policy Development: Integrate these composting methods into local waste management policies and incentivize households and businesses to participate.
3. Public Awareness: Conduct workshops and information campaigns to educate communities on the environmental and economic benefits of sustainable composting.
4. Research Expansion: Further studies should explore the long-term environmental impacts of widespread adoption, including carbon footprint analysis and biodiversity effects.
5. Support Infrastructure: Establish centralized composting facilities equipped with necessary tools and training programs for personnel to ensure successful implementation.

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