RESEARCH PAPER

Conversion Of Kitchen And Agricultural Wastes Into Nutrient-Rich Vermicompost Using Eisenia Fetida: Seasonal And Biological Insights For Sustainable Agriculture

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Abstract

Vermicomposting is a biological process involving specific earthworm species (commonly eisenia fetida) and microorganisms to decompose biodegradable organic materials (such as crop residues, vegetable peels, animal manure, and dry leaves) into a nutrient-rich soil amendment called vermicompost. Current study focused on the utilization of kitchen and agricultural waste through vermicomposting using the exotic earthworms eisenia fetida. The efficiency of vermicomposting was evaluated through physicochemical, biological, microbial, enzymatic, and agronomic parameters under different treatments and seasons. The results indicated that mixed kitchen and agricultural waste (t3) exhibited higher waste reduction, nutrient enrichment and improved physicochemical properties. Total organic carbon decreased while total kjeldahl nitrogen, phosphorus and potassium increased, resulting in a reduced c/n ratio. Earthworms eisenia fetida performance showed maximum biomass gain, cocoon production, and survival in mixed kitchen and agricultural waste (t3), with optimum activity at 70% moisture. Application of vermicompost improved germination, root and shoot growth and biomass of triticum aestivum, with best results in mixed waste treatment. The study indicates that vermicomposting produces nutrient-rich and safe biofertilizer for sustainable waste management and crop productivity.

Keywords: Na

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1. Introduction

Vermicomposting is a novel and environmentally friendly method of managing agricultural waste. It uses the biological activity of specific earthworm species, most notably *Eisenia fetida*, also known as the red wiggler, to turn a variety of organic waste into vermicompost, a premium soil amendment[1].The accumulation of crop residues, straw, animal manures, and other organic byproducts has become a serious environmental concern as agricultural production increases worldwide. Conventional disposal techniques, like burning or careless dumping, not only result in the loss of valuable organic matter but also pollute the air and soil, which in turn causes greenhouse gas emissions[2].Vermicomposting, on the other hand, provides a workable, affordable, and environmentally responsible solution by speeding up the breakdown of organic matter and simultaneously creating a stabilized, nutrient-rich compost that improves soil fertility and health.

Earthworms and a wide variety of other microorganisms work together to drive the synergistic vermicomposting process. By actively breaking down, aerating, and consuming decaying organic materials, earthworms such as *Eisenia fetida* increase microbial activity and facilitate the quick biochemical conversion of waste[3].Earthworms break down complex organic matter into fine, granular casts that are rich in secondary nutrients and micronutrients that increase plant availability as well as essential plant nutrients like potassium, phosphorus, and nitrogen. This process produces vermicompost with advantageous structural, chemical, and biological qualities for use in agriculture in addition to lowering the volume and toxicity of raw waste materials.

The efficiency and durability of *Eisenia fetida* earthworms are a major benefit of vermicomposting with this species. Under ideal circumstances, populations of *Eisenia fetida* can double in a few weeks. It also has a high rate of reproduction and can flourish on a broad range of organic substrates[4]. Vermicomposting operations can be made flexible and scalable in a variety of agroecological contexts due to the species' notable tolerance for changes in temperature, moisture content, and substrate composition. Research consistently shows that, when compared to raw or conventionally composted materials, vermicompost produced by *Eisenia fetida* has much higher concentrations of available nutrients, lower levels of phytotoxic substances, and increased populations of beneficial soil microorganisms.More broadly, using *Eisenia fetida* for vermicomposting promotes integrated organic waste management techniques and helps create a circular agricultural economy. Farmers may lessen their dependency on chemical fertilizers, which are expensive and raise questions about sustainability in the long run, while simultaneously increasing crop yields and soil quality by turning low-value agricultural waste into valuable organic fertilizer[5]. Thus, vermicomposting's widespread use supports the modern objectives of resource efficiency, environmental preservation, and sustainable agriculture. In this context this study utilized *Eisenia fetida*earthworm to convert kitchen and agricultural waste into high quality vermicompost.

2. Materials And Methods

2.1 Waste Collection, Pre-Composting, and Vermicomposting Setup

Kitchen and agricultural waste were collected from Baharpur, Uttar Pradesh (India). Kitchen waste included fruit, vegetable peels, leftover pulses, tea leaves, coffee groundsand other household food residues, rich in nitrogen for earthworm growth and microbial activity. Agricultural waste included crop residues such as wheat straw, paddy husk, maize stalks, fallen leaves and other plant-derived materials, rich in carbon, providing a balanced carbon-to-nitrogen ratio. For pre-composting the collected kitchen and agricultural wastes were shredded into smaller pieces (2–5 cm) and arranged in shallow heaps or windrows under a shaded and ventilated area to enhance microbial action and prevent direct sunlight exposure. Adequate moisture was maintained by sprinkling water periodically. For vermicomposting, it was done in wooden bins. The bins were rectangular in shape, with dimensions approximately 90 cm in length, 60 cm in width, and 45 cm in height, which allowed sufficient space for free movement of the earthworms, and it was mixed with pre-composted agricultural residues, partially decomposed cow dung, and moist shredded straw or leaves, forming a soft, porous substrate for earthworms to burrow and feed.Each bin inoculated approximately 100–120 adult earthworm *Eisenia fetida* per kilogram of pre-composted substrate.

2.2 Experimental Design and Waste Treatments

The experiment was done in three setups: first being kitchen waste (T1), second agricultural waste (T2) and then both kitchen and agricultural waste were mixed (T3).

2.3 Seasonal Conditions

The experimental work was systematically planned to span multiple crop-growing seasons, namely Rabi (winter crops), Kharif (monsoon crops), and Zaid (summer crops). This seasonal coverage was essential for assessing how natural variations in temperature, humidity, and rainfall influence the activity, survival, and reproductive efficiency of the earthworm *Eisenia fetida.*

2.4 Earthworm Growth, Survival, Reproduction, and Moisture Optimization

Biomass gain and progression over time, cocoon production and hatchability, survival rate, and effect of moisture on biomass gain were monitored for the earthworm *Eisenia fetida*.A representative sample of worms from each treatment was carefully removed, gently washed to remove adhering substrate, and weighed using a digital balance with an accuracy of ±0.01 g. Initial biomass measurements were recorded at the time of inoculation, and subsequent measurements were taken every 15 days.Biomass gain was calculated as the difference between the final and initial weights of the worms and expressed as a percentage increase.

2.5 Physicochemical Analysis of Waste During Vermicomposting

The kitchen and agricultural waste were monitored for changes in physicochemical parameters including pH and electrical conductivity (EC), total organic carbon (TOC), total Kjeldahl nitrogen (TKN), C/N ratio, and availability of phosphorus (P) and potassium (K).TOC was determined using the wet oxidation method, where vermicompost samples were digested with a mixture of potassium dichromate ($K_2Cr_2O_7$) and concentrated sulfuric acid (H_2SO_4), followed by titration with ferrous ammonium sulfate. TKN was determined using the conventional Kjeldahl digestion method, where compost samples were digested with concentrated sulfuric acid in the presence of a catalyst, followed by distillation and titration of the liberated ammonia. For determining available phosphorous Olsen's Method was followed whereas potassium as determined using flame photometry.

2.6 Assessment of Compost Maturity and Stability

For determining the compost maturity and stability, the following parameters were monitored: C/N ratio as maturity index, germination index, and stabilization indicators.

2.7 Microbial Population, Diversity, and Enzymatic Activity

The microbial population in the vermicompost was assessed through standard serial dilution and plating techniques.Bacteria were enumerated using nutrient agar, incubated at 28–30°C for 24–48 hours, and colony-forming units (CFU) were counted. Fungal populations were determined by plating on potato dextrose agar (PDA) supplemented with antibiotics to suppress bacterial growth and incubating at 25°C for 3–5 days. For determining the conversion of waste into vermicomposting enzymatic activity (cellulase, urease, phosphatase) were determined.

2.8 Vermiwash Analysis

Vermiwash collected during vermicomposting was analyzed for nutrient composition; additionally, its physicochemical parameters (pH, electrical conductivity(EC), nitrogen, phosphorus, potassium, and organic carbon content) were also characterized.

2.9 Heavy Metal Content and Safety Evaluation of Vermicompost

Heavy metals including (Pb, Cd, Cr, Ni, Zn, Cu) were monitored in vermicompost to evaluate its suitability for usage in fields.

2.10 Agronomic Evaluation: *Triticum aestivum* (Wheat) Bioassay

To check the effect of vermicompost on the growth of wheat plant, germination percentage, root and shoot length, and seedling biomass were monitored after treatment.

3. Results

3.1 Earthworm Growth, Survival, Reproduction, and Moisture Optimization

Optimization studies are critical for maximizing the efficiency of vermicomposting by identifying ideal environmental and substrate conditions for *Eisenia fetida*. These studies focus on key factors temperature, moisture, pH, and particle size that significantly influence earthworm activity, waste decomposition, and compost quality.The effect of varying moisture content showed that biomass gain, cocoon production, and survival increased with moisture, peaking at 70% (198 ± 6.0% biomass gain, 5.5 ± 0.4 cocoon production per worm, 96.3 ± 1.5% survival rate), indicating an optimal environment for earthworm activity. These results highlight that maintaining optimal substrate moisture is critical for maximizing earthworm growth, reproductive performance, and survival, which are essential for efficient vermicomposting and high-quality vermicompost production.

3.2 Waste Reduction and Compost Yield

As shown in figure mixed waste (T3) showed the highest waste reduction (45.0 ± 1.6%), followed by kitchen waste (T1) (42.0 ± 1.5%) and agricultural waste (T2) (35.0 ± 1.4%). Compost conversion efficiency was highest in T2 (65.0 ± 2.0%), while T3 (55.0 ± 1.8%) and T1 (58.0 ± 1.7%) were lower. The control showed minimal waste reduction (26.0 ± 1.2%), indicating the role of*Eisenia fetida* in substrate degradation and compost production.

Mixed waste (T3) showed the most favorable compost characteristics with blackish-brown color, crumbly texture, earthy odor, lowest C/N ratio (10.2), and highest germination index (90.2 ± 3.5%). Kitchen waste (T1) also showed mature compost with C/N ratio (11.6) and germination index (84.5 ± 3.1%).Agricultural waste (T2) showed higher C/N ratio (17.5) and lower germination index (76.8 ± 2.9%), while the control showed least maturity with higher C/N ratio (29.1) and germination index (65.4 ± 2.5%).

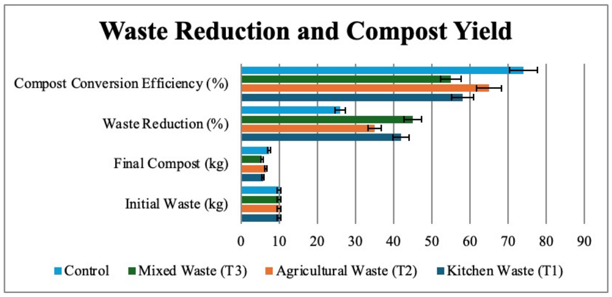

Figure 3.1 Graphical Representations of Substrate Reduction and Compost Yield After 60 Days

3.3 Physicochemical Transformation of Kitchen and Agricultural Waste During Vermicomposting

The physicochemical properties of vermicompost are important indicators of its maturity, stability, and suitability as an organic fertilizer.These parameters not only reflect the degree of decomposition of the organic matter but also determine the nutrient quality and agronomic potential of the final compost.The pH values stabilized near neutrality (7.0–7.3) compared to the slightly acidic initial substrate (6.8). Electrical conductivity (EC) increased in all vermicompost treatments, highest in T3 (2.62 dS/m), indicating enhanced soluble salt and mineral availability within acceptable limits. Total organic carbon (TOC) decreased from 38.2% to 20.2–24.8%, reflecting organic matter mineralization by microbial and earthworm activity. Total Kjeldahl nitrogen (TKN) increased, particularly in T3 (1.98%) and T1 (1.85%), reducing the C/N ratio to 10.2–17.5:1. Available phosphorus and potassium were enriched, with maximum P (35.5 mg/kg) and K (435 mg/kg) in T3, while the control maintained a higher C/N ratio (29.1:1) and lower nutrient availability.

3.4 Earthworm Growth, Survival and Reproduction

Mixed waste (T3) exhibited the highest biomass gain (198 ± 5.9%), cocoon production (5.5 ± 0.4), and survival (96.2 ± 1.2%) whereas Kitchen waste (T1) showed moderate growth (185 ± 6.2%) and cocoon production (4.8 ± 0.3), while agricultural waste (T2) showed lower growth (130 ± 4.7%) and cocoon production (3.1 ± 0.2), with lower survival (88.4 ± 2.1%).These findings indicate that mixed waste promotes growth, reproduction, and survival, while the control confirms the effects are due to earthworm*Eisenia fetida.*

3.5 Seasonal Influence on Waste Vermicompost Quality

Seasonal variations significantly influence vermicomposting efficiency and compost quality, as environmental factors like temperature, humidity, and rainfall affect earthworm activity and microbial processes.Seasonal variations showed pH slightly alkaline across Rabi (7.0 ± 0.1), Kharif, and Zaid (7.3 ± 0.2). Electrical conductivity (EC) was highest in Kharif (2.45 ± 0.10 dS/m). Total organic carbon (TOC) was higher in Rabi (22.4 ± 1.0%) and Zaid (21.0 ± 0.8%) than Kharif (20.2 ± 0.9%). Total Kjeldahl nitrogen (TKN), phosphorus, and potassium were highest in Kharif (1.98 ± 0.08%, 35.5 ± 1.4 mg/kg, 435 ± 17 mg/kg), while Rabi and Zaid showed moderate nutrient content.Overall, these results demonstrate that seasonal conditions, particularly moisture and temperature, significantly influence the nutrient dynamics of vermicompost, with monsoon-produced compost exhibiting the highest fertility and potential for improving soil nutrient status.

3.6 Microbial Population, Diversity, and Enzymatic Activity

Microbial analysis showed higher bacterial, fungal, and actinomycete populations in vermicompost than the initial substrate and control. Mixed waste (T3) recorded the highest counts (64.8 ± 2.4 $\times 10^6$ CFU g^{-1} bacterial count, 13.6 ± 0.6 $\times 10^6$ CFU g^{-1} fungal count, 20.5 ± 0.9 $\times 10^6$ CFU g^{-1} actinomycete count), followed by kitchen waste (T1) and agricultural waste (T2).The control showed lower microbial counts, confirming the role of earthworm*Eisenia fetida*in enhancing microbial activity.

Enzymatic activity showedthat vermicomposting enhanced key enzymes involved organic matter decomposition and nutrient cycling. Mixed waste (T3) exhibited the highest activity: cellulase (92.6 ± 3.5 µg glucose/g/hr), β-glucosidase (63.2 ± 2.4 µg pNP/g/hr), laccase (20.4 ± 0.8 U/g), dehydrogenase (46.8 ± 2.0 µg TPF/g/hr), urease (40.6 ± 1.7 µg NH_4-N/g/hr), and phosphatase (81.2 ± 3.0 µg pNP/g/hr) as displayed in table 3.1Kitchen waste (T1) showed moderate activity, while agricultural waste (T2) showed lower activity. The control showed the lowest enzyme activities, confirming the role of earthworm*Eisenia fetida* in enhancing microbial enzymatic processes.

Table 3.1 Enzymatic Activities in Vermicompost

Enzyme	T1: Kitche	T2: Agricultur	T3: Mixe	Contr ol

	n Waste	al Waste	d Wast e	
Cellulase (µg glucose/g/hr)	84.5 ± 3.1	71.2 ± 2.8	92.6 ± 3.5	48.5 ± 2.0
β-Glucosidase (µg pNP/g/hr)	56.4 ± 2.1	48.7 ± 1.9	63.2 ± 2.4	32.6 ± 1.5
Laccase (U/g)	18.2 ± 0.7	14.6 ± 0.6	20.4 ± 0.8	9.8 ± 0.4
Dehydrogenase (µg TPF/g/hr)	42.5 ± 1.9	35.2 ± 1.5	46.8 ± 2.0	20.5 ± 1.0
Urease (µg NH_4-N/g/hr)	38.4 ± 1.5	30.8 ± 1.3	40.6 ± 1.7	22.2 ± 0.9
Phosphatase (µg pNP/g/hr)	75.6 ± 2.8	62.4 ± 2.4	81.2 ± 3.0	40.8 ± 1.8

3.7Vermiwash / Leachate Characteristics

The physicochemical characteristics of leachate (vermiwash) collected during vermicomposting of different substrates were analyzed. The pH of all treatments remained near neutral, ranging from 7.0 ± 0.1 in mixed waste (T3) to 7.3 ± 0.2 in agricultural waste (T2), indicating that the vermiwash is suitable for use as a biofertilizer without causing soil acidity or alkalinity issues. Electrical conductivity (EC), an indicator of soluble salts, was highest in T3 (2.30 ± 0.09 dS/m), reflecting greater mineralization and nutrient content, while the control had the lowest EC (1.45 ± 0.05 dS/m). Nutrient analysis showed that mixed waste (T3) leachate contained the highest levels of total nitrogen (240 ± 15 mg/L), available phosphorus (48 ± 3 mg/L), and potassium (350 ± 16 mg/L), followed by kitchen waste (T1) and agricultural waste (T2) as shown in figure 3.2 The control leachate exhibited the lowest nutrient concentrations, confirming minimal microbial and earthworm activity. These results highlight that vermiwash from mixed substrates is nutrient-rich and can serve as an effective organic liquid fertilizer, enhancing plant growth and soil fertility while demonstrating the importance of substrate composition in maximizing nutrient release during vermicomposting.

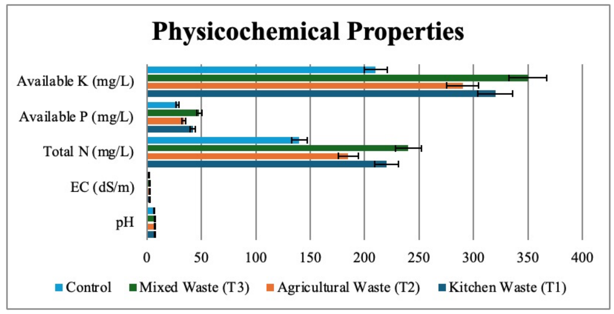

Figure 3.2 Graphical Representations of Physicochemical Properties of Leachate (Vermiwash) Collected During Vermicomposting

3.8 Heavy Metal Content and Safety Evaluation

The results indicate as shown in figure 3.3 that all heavy metal concentrations in the vermicompost samples remained well below the recommended safe limits, confirming their suitability for agricultural application. Among the treatments, kitchen waste vermicompost (T1) recorded the highest levels of Cu (22.5 ± 0.8 mg/kg) and Zn (45.2 ± 1.5 mg/kg), followed by mixed waste vermicompost (T3) with Cu (20.8 ± 0.9 mg/kg) and Zn (42.8 ± 1.4 mg/kg). Agricultural waste vermicompost (T2) showed comparatively lower values for both Cu (18.4 ± 0.7 mg/kg) and Zn (38.5 ± 1.2 mg/kg). Lead (Pb) and cadmium (Cd) concentrations were also within safe thresholds across all treatments, with the highest Pb observed in T1 (2.8 ± 0.1 mg/kg) and the lowest in control soil (2.0 ± 0.1 mg/kg). Cd levels were slightly higher in vermicompost treatments (0.36–0.45 mg/kg) compared to the control (0.30 ± 0.02 mg/kg), yet still well below the FAO/WHO limit of 3 mg/kg. Overall, the findings demonstrate that vermicomposting effectively stabilizes organic waste while maintaining heavy metal concentrations at environmentally safe levels, making it a sustainable practice for soil fertility enhancement without posing toxicity risks.

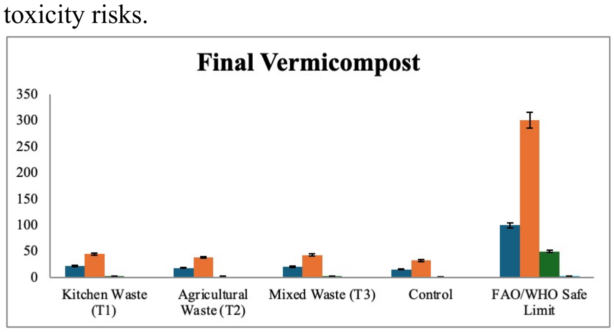

Figure 3.3 Graphical Representations of Heavy Metal Content (mg/kg) in Final Vermicompost

3.9 Agronomic Performance: *Triticum aestivum* (Wheat) Bioassay

The impact of vermicompost applications on seed germination and early growth of *Triticum aestivum* over a 30-day period showed that all vermicompost treatments enhanced germination andgrowth of wheat compared to the control, as indicated in table 3.2. Mixed vermicompost (T3) recorded the highest germination rate (92 ± 3%), shoot length (18.6 ± 0.7 cm), root length (9.2 ± 0.4 cm), and biomass (5.2 ± 0.3 g).Kitchen waste vermicompost (T1) showed germination (84 ± 3%) with shoot and root length (16.8 ± 0.6 cm and 8.5 ± 0.4 cm), while agricultural waste (T2) showed moderate germination (78 ± 2%) and shoot length (15.2 ± 0.5 cm). The control showed the lowest germination (68 ± 2%) and growth parameters indicating the need of vermicompost in seed germination.

Table 3.2 Effect of Vermicompost on Germination and Plant Growth

Treatment	Germination (%)	Shoot Length (cm)	Root Length (cm)	Biomass (g)
Control (Soil only)	68 ± 2	12.5 ± 0.5	6.2 ± 0.3	2.8 ± 0.2
T1 (Soil + Kitchen VC)	84 ± 3	16.8 ± 0.6	8.5 ± 0.4	4.6 ± 0.3
T2 (Soil + Agricultural VC)	78 ± 2	15.2 ± 0.5	7.4 ± 0.3	4.0 ± 0.3
T3 (Soil + Mixed VC)	92 ± 3	18.6 ± 0.7	9.2 ± 0.4	5.2 ± 0.3

4. Conclusion and Discussion

The present study on vermicomposting of kitchen waste, agricultural residues, and mixed substrates using *Eisenia fetida* provides significant insights into the transformations occurring during the bioconversion process and demonstrates the critical role of both physicochemical changes and biological interactions in achieving nutrient-rich and mature compost.

The reduction in total organic carbon (TOC) from 38.2% in the initial substrate to as low as 20.2% in mixed waste reflects efficient mineralization of organic matter, facilitated by earthworm activity and microbial metabolism, while the corresponding increase in total Kjeldahl nitrogen (TKN), highest in mixed waste at 1.98%, indicates enrichment of available nitrogen due to enhanced microbial transformation and mucus secretions from earthworms that stimulate microbial proliferation[6].Kitchen waste alone also supported substantial growth (185 ± 6.2%) and reproduction (4.8 ± 0.3 cocoons per worm), though slightly less than mixed waste, suggesting that while highly degradable, it may lack certain structural or micronutrient components that agricultural residues contribute. In contrast, agricultural waste produced the lowest biomass gain (130 ± 4.7%) and cocoon production (3.1 ± 0.2), likely due to its high lignocellulosic content, which is less digestible and slows nutrient release, thereby reducing worm productivity [7]The findings also highlight that vermicompost derived from mixed wastes can serve not only as a nutrient-rich organic fertilizer but also as a biologically active amendment containing beneficial microbial communities that enhance soil fertility and suppress pathogens, thereby offering a sustainable alternative to chemical fertilizers and contributing to eco-friendly agricultural practices [8][9]. In conclusion, the combined evidence from microbial diversity indices, bioassay outcomes, and heavy metal evaluations validates the agronomic efficacy and ecological safety of vermicompost, reinforcing its role as a sustainable alternative to chemical fertilizers and a cornerstone of organic waste management strategies [10][11].

DECLARATIONS:

Conflicts of interest: There is no any conflict of interest associated with this study

Consent to participate: There is consent to participate.

Consent for publication: There is consent for the publication of this paper.

Authors' contributions: Author equally contributed the work.

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