Extended Abstract

Agronomic Evaluation of Waste-Derived Organic Amendments using *Eisenia fetida*–Mediated Vermicomposting

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Degree for which submitted: Doctor of Philosophy

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Abstract of the Thesis

The accumulation of poultry litter, rice straw, pressmud, fish-processing waste, urban pigeon droppings, food waste, and anaerobic-digestion residues creates interconnected environmental and agricultural challenges. Uncontrolled disposal promotes odour generation, greenhouse-gas emissions, nutrient loss, pathogen dissemination, and contamination of soil and water. At the same time, these residues contain recoverable organic carbon, nitrogen, phosphorus, potassium, calcium, magnesium, and micronutrients. This thesis evaluates biological strategies for converting such heterogeneous waste streams into stabilized organic amendments through Eisenia fetida–mediated vermicomposting, with complementary use of biogenic metal-oxide nanomaterials and anaerobic digestion.

The research followed an integrated waste–earthworm–microbe–plant framework. Feedstock composition was optimized by combining nitrogen-rich residues with carbonaceous and structurally supportive materials such as rice straw. Earthworm growth, reproduction, survival, biomass gain, specific growth rate, and feed-conversion ratio were evaluated alongside decomposition, moisture, ash, pH, electrical conductivity, organic carbon, C/N ratio, nutrient recovery, enzymatic activity, microbial quality, and trace-metal safety. Mature products were characterized using Fourier-transform infrared spectroscopy, field-emission scanning electron microscopy coupled with energy-dispersive X-ray spectroscopy, CHNS analysis, X-ray photoelectron spectroscopy where applicable, and ICP–OES. Germination, seedling vigour, chlorophyll response, and pot-growth measurements were used to determine agronomic value.

Across the studies, balanced mixed feedstocks consistently outperformed single-residue treatments. The combined substrates moderate ammonia and salinity stress, improved aeration and moisture retention, enhanced earthworm multiplication, accelerated mineralization and humification, and produced porous, nutrient-rich amendments with lower C/N ratios. However, the work also demonstrated that the treatment yielding the highest nutrient concentration was not always the safest or biologically most effective. Feedstock proportion, pathogen load, nanoparticle dose, and maturation period therefore require simultaneous optimization.

The thesis establishes vermicomposting as a practical platform for recovering nutrients from agricultural, agro-industrial, animal, urban, and digestion-derived wastes. It further shows that carefully optimized biogenic nanomaterials can improve selected conversion and antimicrobial responses, whereas excessive doses can inhibit biological processes. The resulting amendments enhanced seed germination, seedling vigour, and chlorophyll status, supporting their potential use in sustainable agriculture after field validation and quality standardization.

Chapter 1 Introduction

Chapter 1 presents the environmental burden and resource potential of biodegradable organic wastes. Poultry litter and pigeon droppings contain high nutrient loads but may harbour pathogenic or antimicrobial-resistant microorganisms. Fish-processing residues decompose rapidly and create odour

and water-pollution risks. Pressmud and anaerobic digestate contain valuable organic matter and mineral nutrients but may remain bulky, chemically variable, or difficult to handle. Rice straw provides lignocellulosic carbon and structural porosity, yet open-field burning causes air pollution, greenhouse-gas emissions, and nutrient loss.

The chapter explains the biological mechanism of vermicomposting. E. fetida fragments and mixes organic residues, improves aeration, and stimulates microbial and enzymatic activity. These processes accelerate decomposition, mineralization, and humification, thereby reducing unstable organic carbon and the C/N ratio while increasing the relative availability of plant nutrients. The discussion also addresses the need to balance nutrient recovery with earthworm health, microbial safety, metal toxicity, phytotoxicity, and crop response.

The central hypothesis proposes that balanced co-substrates and optimized doses of biogenic nanoparticles can enhance decomposition, nutrient stabilization, and agronomic performance without compromising biological safety. The objectives were to optimize feedstock formulations; quantify physicochemical transformation and nutrient recovery; evaluate earthworm growth and reproduction; assess microbial, toxicological, phytotoxic, and antimicrobial responses; and validate the agricultural performance of the resulting amendments.

Chapter 2 Materials and Methods

Chapter 2 describes the common experimental framework applied across the studies. Organic residues were pre-composted before the introduction of E. fetida to reduce heat, ammonia, and volatile toxicants. Experiments were conducted under controlled moisture and temperature, generally for 60–110 days, with treatment-specific earthworm densities and three replicates. Samples were collected during and after conversion for biological, physicochemical, structural, microbial, toxicological, and agronomic analyses. Earthworm performance was assessed through adult survival, final population, population increase, biomass gain, individual growth rate, cocoon production, specific growth rate, and feed-conversion ratio. Product maturity was evaluated using pH, electrical conductivity, moisture, ash, decomposition, organic carbon, C/N ratio, humification-related changes, and nutrient concentrations. Microbial and enzyme analyses included total viable counts, selective culture-based screening, β-glucosidase, dehydrogenase, and functional nutrient-solubilization tests where relevant. Plant experiments measured germination, mean germination time, root and shoot growth, seedling vigour, and SPAD chlorophyll values.

Chapter 3: Result and discussion

3.1. Poultry Litter and Rice Straw Vermimanure

The first study examined cow dung, rice straw, and poultry litter in different combinations during 110 days of vermimanuring. The mixed FS4 treatment containing cow dung, rice straw, and poultry litter in a 1:1:1 ratio produced the strongest overall performance. It supported 281 ± 14 live earthworms, an average weight of 1.08 ± 0.20 g, a weight gain of 0.88 ± 0.30 g, and the lowest feed-conversion ratio of 1717 ± 186. The FS3 treatment showed the highest decomposition, while FS4 achieved 59 ± 8% ash, 65 ± 6% decomposition, and 42 ± 5% moisture.

Vermimanuring increased nutrient availability and reduced the C/N ratio relative to the initial materials. FS4 contained 1.83 ± 0.06% nitrogen, 1.73 ± 0.03% phosphorus, 3.06 ± 0.11% potassium, 2.41 ± 0.26% magnesium, and a C/N ratio of 13 ± 0.15. FESEM revealed fragmented and porous surfaces, EDX confirmed mineral elements, and FTIR showed transformation of O–H, C–H, C=O, and C–O–C groups associated with decomposition and stabilization. The findings demonstrate that rice straw supplies carbon and structure, while poultry litter supplies nitrogen and minerals, allowing E. fetida to convert both residues into a stable amendment.

Study 3.2 Rice Straw Pressmud and Biogas Slurry Vermimanure

The second study evaluated biogas slurry alone and in combination with rice straw and pressmud for 60 days. The ternary T4 formulation containing 60% biogas slurry, 20% rice straw, and 20% pressmud produced the best combined biological and product-quality response. T4 supported 132 ± 11.1 earthworms and 49 ± 6.0 cocoons, with an average individual weight of 1.74 ± 0.15 g, a specific growth rate of 1.76 ± 0.05, and the lowest feed-conversion ratio of 1014 ± 10. Relative to T1, T4 increased population by 59%, cocoon production by 75%, and weight gain by 122%, while reducing the feed-conversion ratio by 63.7%.

Mature products showed pH values of 7.1–7.8, electrical conductivity of 3.2–6.0 dS m^{-1}, and C/N ratios of approximately 12–15. T4 reached a C/N ratio of 11.62 ± 0.89 and contained 1.67 ± 0.04% nitrogen. Nutrient recovery, ash content, surface porosity, and pellet properties improved in the mixed treatment. Trace metals remained well below the cited permissible soil limits. In the okra assay, T4 produced 96.6% germination, a mean germination time of 12.18 ± 0.30 days, and a seedling vigour index of 2127 ± 132. Pelletization further improved storage, handling, transport, and field-application potential.

Study 3.3 Fish Processing Waste Rice Straw and Biogas Slurry Vermicompost

The third study optimized biogas slurry, fish-processing waste, and rice straw during a 60-day vermicomposting experiment. The ternary Tm formulation containing the three materials in a 1:1:1 ratio produced the strongest overall response. Tm supported a final population of 367 ± 11 earthworms and 141 ± 9 cocoons, with an average weight of 0.18 ± 0.03 g, a specific growth rate of 0.47 ± 0.07%, and the lowest feed-conversion ratio among the earthworm treatments. It also achieved 61% ash, 65% decomposition, a pellet durability index of 89%, and 60% solubility.

CHNS, FTIR, FESEM–EDX, XPS, and ICP–OES analyses confirmed feedstock-dependent maturation, functional-group transformation, greater porosity, and nutrient recovery. Vermicomposted mixtures reached C/N ratios of approximately 9–14, indicating advanced stabilization. In the bitter-gourd experiment, Tm increased germination from 40% in the control to 60%, promoted earlier emergence, reduced mean germination time by approximately 13%, and produced higher SPAD chlorophyll values. These results show that fish waste can be safely integrated with lignocellulosic rice straw and partially stabilized biogas slurry when the substrate ratio is carefully controlled.

Study 3.4 Urban Pigeon Droppings Biogas Slurry and Rice Straw

The fourth study assessed five mixtures containing 0–40% urban pigeon droppings. The balanced Fs-2

formulation containing 60% biogas slurry, 20% rice straw, and 20% pigeon droppings produced the best overall biological response. It achieved 65% decomposition and the highest earthworm population, 96 ± 15, corresponding to a 4.8-fold multiplication from the initial population. Fs-2 also supported the highest total bacterial count of 9.0×10^8 CFU g^{-1} and a yeast-and-mould population of 1.8×10^5 CFU g^{-1}.

Culture-based screening did not detect E. coli or Salmonella in Fs-2 under the conditions used, whereas higher pigeon-dropping proportions reduced microbiological quality. Fs-4 contained the highest nitrogen and phosphorus concentrations and the lowest C/N ratio, but it also showed poorer earthworm performance and greater microbial-safety concerns. β-Glucosidase and dehydrogenase activities were closely associated with bacterial abundance. The study therefore demonstrates that maximum nutrient enrichment cannot be used as the sole criterion for treatment selection; biological performance and microbial safety must be considered together.

Study 3.5 Biogenic CuO ZnO and CuO ZnO Assisted Vermicomposting

The fifth study investigated whether biogenic CuO, ZnO, and CuO–ZnO nanoparticles could improve poultry-litter vermicomposting and the functional quality of the final product. The combined CuO–ZnO treatment produced the highest total earthworm population, 133.0 ± 17.1, and the highest specific growth rate, 1.89 ± 0.15% day^{-1}, while maintaining strong cocoon production. The ZnO-only treatment showed a comparatively weaker earthworm response, indicating that nanoparticle composition and dose influenced biological compatibility.

The nanoparticle-assisted products showed microorganism-dependent antimicrobial activity. ZnO produced the largest inhibition zone against Staphylococcus aureus, 28.0 mm, followed by CuO–ZnO at 26.7 mm. ZnO and CuO–ZnO also inhibited *Escherichia coli*, while CuO showed the strongest response against Aspergillus niger. The amendments were subsequently evaluated using Abelmoschus esculentus to connect compost quality with plant performance. Overall, the work supports the use of carefully optimized biogenic nanoparticles as functional additives, while emphasizing the need for dose-specific earthworm and soil-safety assessment.

Chapter 4 Conclusion and Future Scope

The thesis demonstrates that *E. fetida*–mediated vermicomposting can transform diverse waste streams into stable and agronomically useful organic amendments when feedstock composition is balanced according to carbon availability, nitrogen content, moisture, porosity, salinity, and biological risk. Mixed treatments consistently improved decomposition, earthworm growth, nutrient recovery, structural porosity, and crop response. The strongest formulations were FS4 for poultry litter and rice straw, T4 for rice straw–pressmud–biogas slurry, Tm for fish waste–rice straw–biogas slurry, and Fs-2 for pigeon-dropping co-vermicomposting.

The work also establishes safety as a central optimization criterion. High nutrient concentrations did not necessarily correspond to the best biological or microbiological outcome. Similarly, biogenic metal-oxide nanoparticles enhanced selected conversion, antimicrobial, and agronomic responses only within an appropriate dose range. The combined evidence supports treatment selection based on a multi-parameter

framework comprising decomposition efficiency, earthworm survival and reproduction, maturity, nutrient value, microbial quality, toxicological safety, handling properties, and plant performance.

Future work should validate the optimized products through multi-season and multi-location field trials. Research should quantify nutrient-release kinetics, residual pathogen dynamics, nanoparticle transformation and long-term soil fate, greenhouse-gas emissions, storage stability, pellet performance, and economic feasibility. Standard operating procedures and product-quality specifications will be required before farmer-level production and commercialization. Omics-based investigation of earthworm–microbe interactions may further clarify the mechanisms connecting feedstock chemistry, microbial function, nutrient stabilization, and plant response.

Selected Research Publications Included in the Thesis

- **Kumari, S.,** Singh, R. K., Singh, A., Choubey, A. K., & Srivastava, P. K. (2025). Optimization and evaluation of *Eisenia fetida*-based vermicompost derived from fish processing waste, rice straw, and biogas slurry for sustainable agriculture. *Process Safety and Environmental Protection, 198*, 107225. https://doi.org/10.1016/j.psep.2025.107225
- Srivastava, P. K., Singh, A., **Kumari, S.,** Arora, S., Choubey, A. K., & Sinha, A. S. K. (2023). Production and characterization of sustainable vermimanure derived from poultry litter and rice straw using tiger worm *Eisenia fetida*. *Bioresource Technology, 369*, 128377. https://doi.org/10.1016/j.biortech.2022.128377
- Kumari, S., Srivastava, P. K., Choubey, A. K., Pathak, P., & Sharma, C. (2026). Environmental feasibility of pigeon droppings management through co-vermicomposting with biogas slurry and rice straw. *International Journal of Environmental Research*. Manuscript submitted for publication.
- **Kumari, S.,** Kumar, A., Singh, S., Hirani, H., & Srivastava, P. K. (2026). Biogenic Fe–Zn–Mn oxide nanocomposite-assisted food-waste anaerobic digestion: Biogas enhancement, digestate valorization, and agronomic benefits. *Energy*, 142883. https://doi.org/10.1016/j.energy.2026.142883
- Kumari, S., Gupta, S., Pandey, P., Choubey, A. K., & Srivastava, P. K. (2026). Antimicrobial activity and plant-growth performance of biogenic CuO-, ZnO-, and CuO–ZnO nanoparticle-assisted poultry-litter vermicompost. *Journal of Environmental Management*. Manuscript submitted for publication.