

Comparative Characterization of Swine Dung Vermicompost Using Two Earthworm Species

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Abstract: Despite the increasing use of earthworms for swine dung management, limited information exists on the comparative functional group composition and heavy metal reduction in vermicomposts produced by *Eisenia fetida* and *Eudrilus eugeniae*. This study characterized vermicompost from swine dung produced by *Eisenia fetida* and *Eudrilus eugeniae*. Pre-composted swine dung was vermicomposted for three months using 200 mature earthworms per 10 kg of substrate, with three replicates per species in a completely randomized design. The vermicomposts were analyzed for physicochemical properties and functional groups using Fourier transform infrared spectroscopy (FTIR). FTIR revealed the presence of $-CH_2$, $-CH_3$, $-COO^-$, $-C-O$, and $-C-O-C$ functional groups, indicating enrichment in organic acids and aliphatic compounds. Pb and Cd concentrations decreased substantially, from 32.0 and 0.07 ppm in raw dung to 7.0 and 0.004 ppm for *E. fetida*, and 7.0 and 0.008 ppm for *E. eugeniae*, respectively. These results demonstrate effective heavy metal reduction and functional group enhancement, suggesting that the produced vermicomposts may be suitable for agricultural use, subject to regulatory standards.

Keywords: characterisation; FTIR; heavy metal; swine dung; vermicompost

1. Introduction

This spike in global increase comes with its associated waste generation. Globally, municipal solid and livestock waste account for approximately 2.01 and 9.26 billion tonnes per annum, respectively (Nattassha et al., 2020; Velasco-Muñoz et al., 2022; Aborisade et al., 2026). Therefore, waste management is a critical component of sustainable environmental protection, particularly given the increasing generation of municipal, agricultural, and animal waste. Adopting an efficient means of waste management, organic waste management, a vital technology, emphasizes the importance of biological treatment processes that stabilize organic matter while enabling resource recovery. One of the most widely used approaches is composting, which involves aerobic decomposition of organic residues into a stable, humus-like product that enhances soil fertility, improves soil structure, and supports microbial activity (Epstein, 2017). Compost application has been shown to increase soil organic carbon, nutrient availability, and crop productivity, making it particularly valuable in sustainable agriculture and land restoration programs (Lucchetta et al., 2023).

In developing countries such as Nigeria, swine production has led to a corresponding

increase in swine dung generation, necessitating sustainable utilization strategies. Swine dung, being an abundant animal waste contributing 775 million metric tons of waste per year to total animal waste biomass, is a rich source of nitrogen, phosphorus, and potassium (Machete & Chabo, 2020). The daily swine dung production is largely influenced by animal age, body weight, feeding regime, and water intake. Data from Dourmad et al. (2009) reported that swine total manure production is about 361 - 402 kg of manure per pig annually, translating to 0.383 - 382 tons of waste per pig per year. The nutritional composition of swine dung ranges from 1.55 - 2.12 kg N, 0.49 - 0.52 kg P, and 1.30-1.53 kg K per 383 kg of manure per pig. The trace mineral content of swine dung ranges from 8.70 - 9.14 mg kg^{-1} Cu and 65.5 - 70.8 mg kg^{-1} , per 383 kg of manure per pig. On a dry matter basis, the average manure composition ranges from 18.7-57.1 g kg^{-1} N, 5.4- 15.9 g kg^{-1} P, 13.5 - 43.1 g kg^{-1} K. This makes it an important source of both macro and micronutrients needed for plants' optimum plant growth and yield in the soil.

The principles of reduce, reuse, recycle, and recover have been adopted by Koul et al., (2022) Mengqi et al., (2023) for nutrient imbalance management, for which composting and vermicomposting are key drivers of such pivotal innovations. For more than six decades,



composting has been the go-to fertilizer technology for small-scale and organic farmers with little augmentation with conventional fertilizers (Panday et al., 2024). Vermiculture, an emerging technology engineered by earthworms and microbes, has been credited with not only improving the nutritional composition of the organic residues but also greatly reducing the concentration of heavy metal content (Poornima et al., 2024)

Vermicomposting involves the breakdown of animal and plant biomasses into their mineral and organic acid constituents, aided by earthworms and microorganisms (Mupambwa & Mnkeni, 2018). Producing mature vermicompost from swine dung, rich in plant nutrients, would not only improve soil nutrition but also ensure the formation of essential functional groups that enhance soils' capacity to retain basic cations. Soils richer in acidic functional groups like carboxyl, enol, phenolic OH, and quinones have been implicated to retain basic cations like Ca^{++} , Mg^{++} , K^+ etc at the exchange sites of soils (Sharma et al., 2025), which will help minimize leaching and improve the nutritional status of the soil, (Bender & van der Heijden, 2015). Having an ample knowledge of the organic acids produced by a microbial biotransformational process that could ensure reduced leaching and increased nutrient holding capacity for plant uptake becomes very important

Humic substances (HS), including humic acids, fulvic acids, and humin, are vital fractions of soil organic matter (SOM) with high charge that influence soil exchange sites and significantly regulate soil fertility, nutrient retention, and carbon sequestration (Maffia et al., 2025). Adopting a procedure that can at best reveal the fingerprints of these functional groups in vermicompost, it becomes essential for appropriate functional group speciation. Fourier transform infrared spectroscopy (FTIR) is a well-established technology for functional group characterization and has enormous potential for soil nutrient evaluation owing to its sensitivity and rapid analytical capabilities.

FTIR is a sophisticated technology with notable capacity for detecting specific absorption bands corresponding to functional groups such as hydroxyls, carboxyls, carbonyls, and aromatic structures (Osunde et al., 2024). The functional fingerprints of humic substances with associated wavelength include O-H group (around 3450-

3300 cm^{-1}), C-H stretching of aliphatic groups (2940-2900 cm^{-1}), and C=O stretching of carbonyl and carboxyl groups (1720-1620 cm^{-1}) (Zhou et al., 2019). Other fingerprints included the aromatic C=C skeletal vibrations (1620-1580 cm^{-1}), and polysaccharide-related C-O and C-O-C stretching (1170-950 cm^{-1}) (Zhou et al., 2019).

Over the years, there have been a series of studies characterizing vermicomposts from different sources, but none have compared vermicompost properties produced by different species of earthworm. Therefore, this research intends to investigate the effect of earthworm type on the physicochemical properties and functional groups present in the different vermicomposts. The objectives of this research are to evaluate the physicochemical parameters and characterize the functional groups in the produced vermicomposts

2. Materials and Methods

Collection of materials for the vermicomposting

Swine dung was collected at the swine unit section of the Teaching and Research Farm, Obafemi Awolowo University, Ile-Ife, Osun State, Nigeria. The species used were *Eisenia fetida* (*E. fetida*) and *Eudrilus eugeniae* (*E. eugeniae*) obtained from the Soil Chemistry unit of the Department of Soil Science and Land Resources Management, Obafemi Awolowo University, Ile-Ife, Nigeria.

Production of vermicompost

Freshly collected swine dung was first pre-composted for 15 days so that the heat generated can destroy part of the inherent pathogens in the swine dung (Usmani et al., 2017). The experimental design was a randomized complete block design (CRD), and vermicomposting was carried out in 30 L perforated plastic pots in triplicate. The pots were lined with polyethylene mesh to prevent earthworms from escaping. The pre-composted swine dung was further subjected to vermicomposting for three months. The moisture content of the vermicompost was maintained at 75% using a moisture meter, and the temperature was kept at 28 °C. Two hundred mature exotic species were used to decompose the pre-composted swine dung at a rate of 200 count/10 kg of swine dung in the perforated plastic pot.

Determination of physicochemical parameters of vermicompost

Determination of pH

One gram (1g) of vermicompost was weighed into pH cups, and 10 ml of distilled water was added to give a ratio of 1:10 compost suspension. The solution was stirred and allowed to equilibrate for 30 minutes (Thomas, 1996). A digital pH meter (WalkLab portable pH meter), standardized with buffers (4.00 and 7.00), was used to take the readings.

Determination of Electrical Conductivity

A vermicompost/water extraction in the ratio 1:10 was prepared by weighing 1 g of air-dried vermicompost into a cup and adding 10 ml of deionized water. The suspension was mechanically shaken (using a Stuart flask shaker at the Department of Soil Science and Land Resources Management, OAU) at 15 revolutions per minute (rpm) for 1 hour, then allowed to settle for at least 30 minutes. The Jenway 3540 conductivity meter was calibrated with the KCl reference solution to determine its cell constant, following the manufacturer's instructions (0.7456 g of KCl was weighed into a 1000-ml volumetric flask containing 500 ml of distilled water, then made up to volume). The conductivity cell was thoroughly rinsed, and the electrical conductivity of 0.01 M KCl was measured at the same room temperature as the vermicompost suspensions. The supernatant was drawn into the conductivity pipette, and the value indicated on the conductivity meter was recorded (Jones, 1999).

Determination of exchangeable bases

Ten grams of air-dried and sieved vermicompost was weighed into each 250-ml conical flask, 100 ml of 1 N Ammonium Acetate solution (at pH 7) was added to each flask, swirled for 30 minutes and filtered using Whatman No. 1 filter paper, the filtrates were analysed for Sodium (Na) and Potassium (K) using digital flame photometer while Calcium and Magnesium contents were determined using Accusys 211 Atomic Absorption Spectrophotometer.

Determination of organic carbon

The combined chromic acid digestion method (Nelson & Sommers, 1982) and the

colorimetric method (Nelson & Sommers, 2018; Sims & Haby, 1972) were used to determine organic carbon in vermicompost. One gram of air-dried, ground sample (vermicompost and swine dung) was weighed into a 150-ml conical flask; 10 ml of 1 N $K_2Cr_2O_7$ solution was added, followed by 10 ml of concentrated H_2SO_4 solution. It was swirled for a few seconds, allowed to stand for 30 minutes, and then brought to 50 ml with distilled water. The solution was then centrifuged at 1000 g for 5 minutes and decanted. The amount of reduced Cr^{3+} in the supernatant was determined colorimetrically at 600nm wavelength using an Auto Analyzer (SEAL analytical AA3).

Micronutrients and heavy metal characterization of vermicompost

Micronutrients (Cu, Zn, Fe and Mn) and heavy metals (Pb, Cd and Cr) in vermicompost were determined by ICP-OES after wet acid digestion. Air-dried, <2 mm samples (0.5 g) were digested with 10 mL concentrated HNO_3 and 5 mL H_2O_2 in a microwave digestion system. The clear digest was diluted to 50 mL with deionized water. Samples, blanks, and standards were analyzed on an ICP-OES (Thermo Scientific iCAP 7000 series ICP-OES (with iTEVA/Qtegra software)) at element-specific wavelengths. Concentrations were expressed on a dry-weight basis ($mg\ kg^{-1}$).

Fourier Transform Infrared Spectroscopy (FTIR) Determination

Two milligrams (2 mg) of finely ground vermicompost were mixed with 400 mg of KBr and compressed under vacuum for 10 min. The FT-IR spectra were then recorded on KBr pellets between 4000 and 400 cm^{-1} , at a rate of 16 $nm\ s^{-1}$, using a Shimadzu FTIR spectrophotometer, with precautions taken to avoid moisture uptake; both vermicomposted samples and KBr were dried at 105 °C for 72 hours before making the pellets (Meissl et al., 2008; Ravindran et al., 2008). Estimated humate maturity index (HMI), humate ratio (HR), and humic acid-like index (HA-like) adapted from Zhou et al. (2019) were determined using the formulae

$$HMI = \frac{A_{1620-1650}}{A_{2920} + A_{2850}}$$

$$HR = \frac{A_{1720} + A_{1620-1650}}{A_{2920}}$$

$$HA - like = \frac{A_{1720} + A_{1620-1650}}{A_{2920}}$$

3. Results and Discussion

Table 1 and Figure 1 present the FTIR spectra and functional groups of raw swine dung. The presence of a strong band at 3445 cm^{-1} corresponds to hydroxyl groups (-OH).

The dung also displayed C-H stretching peaks at 2924 and 2854 cm^{-1} , characteristic of lipids, fatty acids, and aliphatic compounds. Notably, the bands at 2001 and 1872 cm^{-1} are indicative of aromatic or conjugated organic compounds. An important peak at 1631.8 cm^{-1} reflects proteins and the N-H group, as well as contributions from aromatic C=C bonds.

Table 1. Major absorption bands observed in raw swine dung

| Wavenumber (cm^{-1}) | Vibration type | Functional group(s) |
|---------------------------------|--|---|
| 3444.86 | $\nu(\text{O-H})$ broad, H-bonded | Alcohols, phenols, carboxylic acids |
| 3857.15 and 3697.67 | $\nu(\text{O-H})$ sharp, free | Free hydroxyl groups |
| 2924.21 | $\nu_{\text{as}}(\text{C-H})$ | Alkanes (CH_2 , CH_3) |
| 2854.48 | $\nu_{\text{s}}(\text{C-H})$ | Alkanes (CH_2 , CH_3) |
| 2131.34 and 2001.32 | $\nu(\text{C}\equiv\text{C})$ or $\nu(\text{C}\equiv\text{N})$ | Alkynes/nitriles |
| 1872.04 and 1796.28 | $\nu(\text{C=O})$ anhydride (as/sym) or cyclic ketone | Carbonyl compounds |
| 1611.83 | $\nu(\text{C=C})$ aromatic/alkene | Aromatic rings/alkenes |
| 1324.94 | $\nu(\text{C-N})$ / $\delta(\text{O-H})$ in-plane | Amines or phenols |
| 1031.29, 1008.88 | $\nu(\text{C-O})$ | Alcohols, ethers, esters |
| 914.29, 777.34 | $\gamma(\text{=C-H})$ out-of-plane | Aromatics/alkenes |
| 694.16, 648.10 | $\gamma(\text{C-H})$ aromatic substitution | Aromatic compounds |
| 531.06, 469.72, 420.97 | $\nu(\text{M-O})$ / skeletal modes | Possible inorganic components |

The OH group present connotes a higher water content of the material, available as free moisture and as water bound to organic matter. Studies by [Smidt & Meissl \(2007\)](#) reported that OH bands are highly reliable indicators of water, alcohols, and carbohydrate hydroxyls in organic residues like manure and compost. The spectra data on the raw swine dung revealed that it is a chemically heterogeneous, moisture-rich, and biologically reactive organic material

composed of both labile and non-labile organic fractions. The high moisture content and an abundance of easily degradable organic substrates underscore the domination of -OH and aliphatic C-H functional groups, resulting in its unstable and microbially active ecosphere, laden with odor and gas emission associated with fresh manure ([Dadrasnia et al., 2021](#)). On the other hand, there is a pool with a profile of more resistant carbon- and nitrogen-containing compounds,

indicative of aromatic C=C structures and N-H functional groups, highlighting that not all of the organic matter present is mineralized. This dichotomy suggests that while a considerable segment of the material supports rapid microbial metabolism and nutrient release, the complementary component promotes slower decomposition and longer-term carbon stabilization, potentially serving as a precursor to humic substance formation.

A holistic evaluation of the raw swine dung spectra showed that it is a nutrient-rich but immature organic amendment, characterized by high microbial utilization and limited stability, which underscores the need for stabilization (e.g., composting) before agronomic application to reduce environmental losses and improve nutrient-use efficiency (Matiz-Villamil et al., 2023).

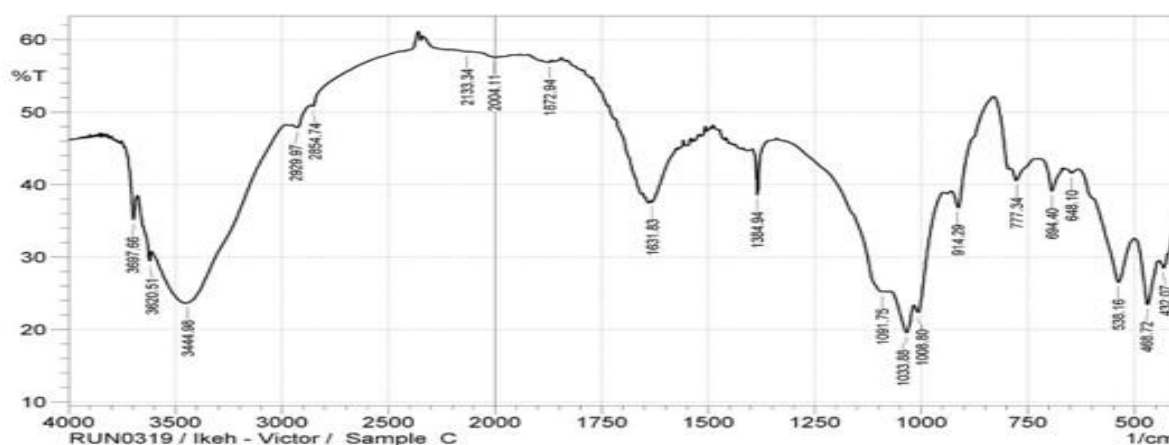


Figure 1. Major absorption bands observed in raw swine dung

Table 2 and Table 4, and Figure 2 highlight the FTIR spectra and functional groups present in vermicompost produced by *E. fetida*. The C-H stretching bands at 2921 cm^{-1} correspond to the asymmetric and symmetric stretching vibrations of methylene (CH_2) and methyl (CH_3) groups, which are absent in raw swine dung. The symmetric stretching vibration of aliphatic $-\text{CH}_2/-\text{CH}_3$ at band 2851 cm^{-1} was also observed. Notably, the asymmetric stretching of carboxylates ($-\text{COO}^-$) at band 1647 cm^{-1} is evident. Phenolic and ether linkages appear at 1236 cm^{-1} , indicating aromatic C-O stretching in phenols and ethers, and contributions from tertiary amides (C-N stretching + N-H bending). The 1037-1001 cm^{-1} region corresponds to C-O and C-O-C vibrations, typical of polysaccharides, ethers, and alcohols.

The presence of alkane carbon in vermicompost indicates the transformation of aliphatic residues (waxes, lipids, proteins) present in swine dung into a more stable

organic structure. This fingerprint also shows a high degree of maturity and stability. The presence of this fingerprint in organic matter or residues was reported by Purakayastha et al. (2015). The decrease in alkyl carbon intensity relative to raw swine dung suggests biodegradation of labile aliphatics, leading to the formation of aromatic and carboxyl units in humic substances. The strong carboxylates and aromatic groups indicate the presence of highly degraded proteins and lipids, resulting in the formation of humate. Carboxylates observed in vermicompost produced from *E. fetida* suggest the presence of stable organic acids that enhance soil fertility (Pathma & Sakthivel, 2012). The presence of amine and amide groups are closely linked with lignin derivatives, polyphenols, humic, and fulvic acids, as reported by Derkacheva & Sukhov (2008) and Pang et al. (2021). These phenolic and ether characteristics of vermicompost degraded by *E. fetida* embodied advanced humification, aromatic stabilization, and the

formation of recalcitrant humates, which are chemically stable, nutrient-retentive, and beneficial for long-term soil fertility (Maffia et al., 2024; Poornima et al., 2024). The presence of alcohol, hydroxyl, and ether groups likely suggests composites of labile carbohydrates that have been degraded by microbes and *E. fetida*, as reported by Nikonenko et al. (2000) and Wiercigroch et

al. (2017). They also suggest partial degradation of labile carbohydrates and microbial polymerization into stable humic substances (Maffia et al., 2025). Finally, the presence of phosphate and silicate bands indicates enrichment in essential minerals that can support crop growth and soil fertility (Uhuegbue et al., 2024).

Table 2. Major absorption bands present in swine dung vermicompost decomposed with *Eisenia fetida*

| Wavenumber (cm ⁻¹) | Vibration type | Functional group(s) |
|--------------------------------|--|---|
| 3412 (broad) | v(O-H), H-bonded | Phenolic/alcoholic O-H; H-bonded water |
| 2921 | v _{as} (C-H) | Aliphatic CH ₂ /CH ₃ |
| 2851 | v _s (C-H) | Aliphatic CH ₂ /CH ₃ |
| 2173, 2031 (weak) | Overtone/comboination | CO ₂ , urea traces/comboination bands |
| 1647 | v _{as} (COO ⁻) / aromatic v(C=C) / H-bonded v(C=O) | Carboxylates in humic substances; aromatic skeleton |
| 1541 | Amide II: δ(N-H)+v(C-N) | Proteins/peptides |
| 1455 | δ _{as} (CH ₃ /CH ₂) and v _s (COO ⁻) | Aliphatic bending; symmetric carboxylate |
| 1385 | δ _{sym} (CH ₃) / v _s (COO ⁻) | Carboxylate symmetric stretch; methyl bend |
| 1236 | v(C-O) phenolic/ether; Amide III (weak) | Ar-O, C-O in humic/fulvic acids |
| 1037, 1001 | v(C-O), v(C-O-C), v(P-O) | Polysaccharide-derived ethers; phosphate; Si-O |
| 912 | γ(=C-H) out-of-plane | Aromatic substitution (lignin-derived) |
| 781 | Aromatic C-H oop bend | Aromatic substitution |
| 698, 601 | Ring bends and lattice modes | Aromatics; silicate/carbonate residues |
| 534 | v(M-O) | Metal-O (Ca/Mg/Fe) humate salts |
| 470, 420 | v(Si-O-Si) bend / lattice | Silicates, metal oxides |

Table 3 and Table 4, and Figure 3 present FTIR spectra and functional groups available in vermicompost produced by *E. eugeniae*. The broad absorption around 3400-3440 cm⁻¹ with a peak of 3237.9 cm⁻¹ corresponds to O-H stretching vibrations of phenolic, alcoholic groups, and structural water molecules. The 2924 and 2854 cm⁻¹ bands represent the asymmetric and symmetric stretching of aliphatic C-H, respectively. A notable and important band at 1647 cm⁻¹ which typifies the asymmetric

stretching of carboxylate (COO⁻), conjugated double bond stretching in aromatic rings (C=C), and hydrogen-bonded carbonyl (C=O) vibrations. The 1516 cm⁻¹ band of secondary amide vibration δ(N-H) bending + v(C-N) stretching is typical of proteins, peptides, and residual nitrogen-containing compounds.

This typical broadness indicates extensive hydrogen bonding, which is unique to humic substances and bound water. The hydroxyl groups in mature vermicompost produced by *E. eugeniae*

indicates the dominance of hydrogen-bonded hydroxyl groups in humic/fulvic acids, which suggests advanced humification, structural stability, moisture retention capacity, and high agronomic quality of the vermicompost (Maffia et al., 2025; Poornima et al., 2024). The presence

of carboxyl, alkene carbon and carbonyl carbon suggests the formation of humic substance (humic acids, fulvic acids) (Hay & Myneni, 2007), and stable aromatic and carboxylate-rich structures (Mesgar et al., 2024; Shrestha et al., 2015).

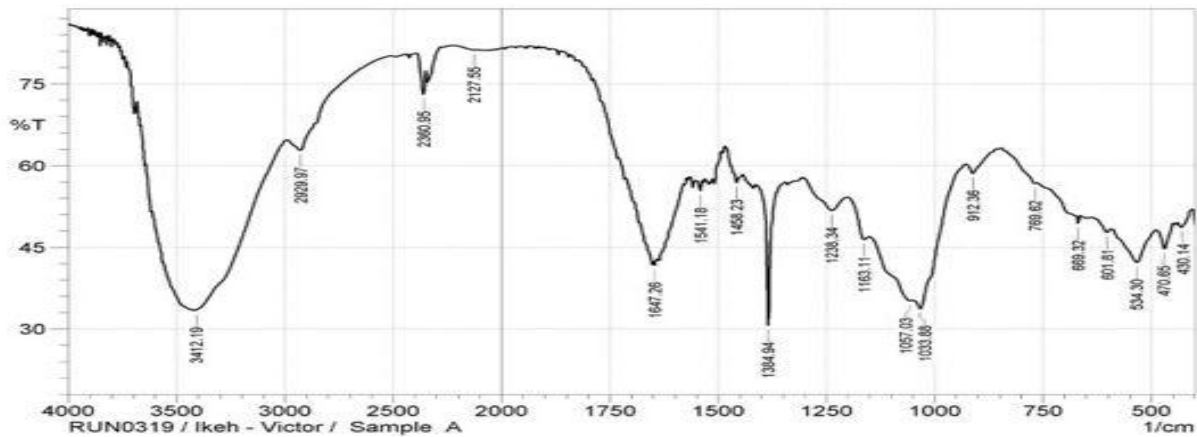


Figure 2. FTIR spectra of swine dung vermicompost produced with *Eisenia fetida*

The carboxyl group also interacts with Ca^{2+} , Mg^{2+} , Fe^{3+} , etc., forming metal-humate salts, thus increasing the cation exchange capacity (CEC) and enhancing the nutrient-holding ability of vermicompost (Paramisparam et al., 2021). The abundance of carboxyl and aromatic carbonyl groups might also contribute to the pH buffering capacity (He et al., 2022), chelation of micronutrients,

improving plant availability, and long-term carbon sequestration and soil organic matter stabilization (Leporino et al., 2025). The secondary amide present in mature vermicompost *E. eugeniae* suggests residual N-containing structures (trace peptides or aromatic N-heterocycles) with low intensity, highlighting successful protein mineralization and incorporation into humic-bound forms.

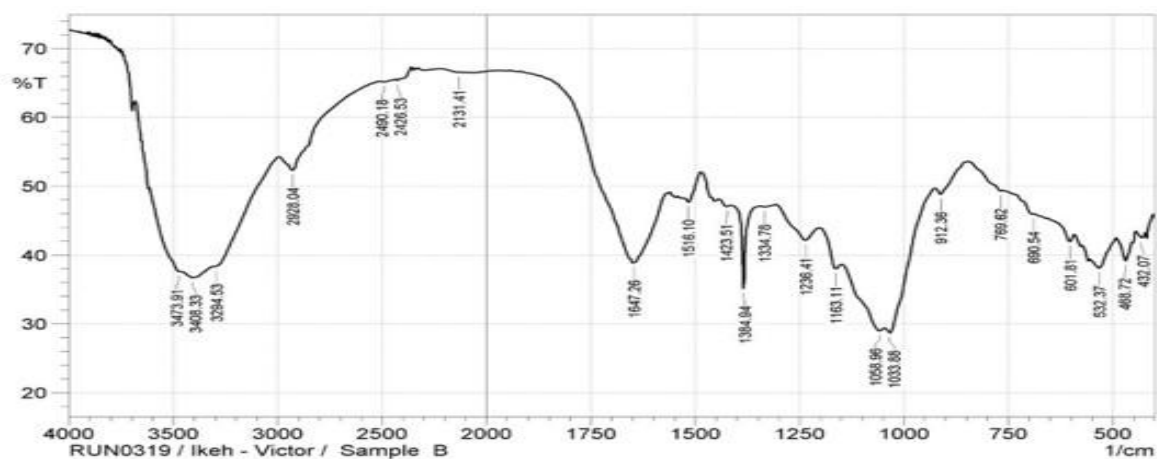


Figure 3. FTIR spectra of swine dung vermicompost produced with *Eudrilus eugeniae*

The humification parameters, as shown in **Table 4**, highlighted the humate maturity index (HMI), humate ratio (HR), and HA-like index in swine dung, phosphate-enriched vermicomposts derived from *Eudrilus eugeniae* and *Eisenia fetida*. Raw swine dung recorded the lowest values for HMI, HR and HA-like index of 0.40,

0.65, and 1.13, respectively. Phosphate-enriched vermicompost derived from *Eudrilus eugeniae* had HMI, HR and HA-like index of 0.61, 0.92, and 1.81, while phosphate-enriched vermicompost derived from *Eisenia fetida* had HMI, HR and HA-like index of 0.72, 1.10 and 2.13, respectively.

Table 3. Major absorption bands present in swine dung vermicompost decomposed with *Eudrilus eugeniae*

| Wavenumber (cm ⁻¹) | Vibration type | Functional group(s) |
|--------------------------------|---|--|
| 3437.9 | v(O-H) broad, H-bonded | Phenolic/alcoholic O-H; structural water |
| 2924.1 | v _{as} (C-H) | Aliphatic CH ₂ /CH ₃ |
| 2854.5 | v _s (C-H) | Aliphatic CH ₂ /CH ₃ |
| 2131.4, 2068.2, 2036.5 | combination/overtone region | Weak overtones, trace nitrile/CO ₂ artifacts |
| 1647.3 | v _{as} (COO ⁻) / aromatic v(C=C) / H-bonded C=O | Carboxylate (-COO ⁻) in humates; aromatic C=O contribution |
| 1516.0 | Amide II: δ(N-H) + v(C-N) | Proteins/peptides (if present) |
| 1453.5 | δ(CH ₂ /CH ₃) and v _s (COO ⁻) | Aliphatic bending; symmetric carboxylate |
| 1384.0 | δ _{sym} (CH ₃) / v _s (COO ⁻) | Methyl bending; symmetric carboxylate stretch |
| 1324.8 | Amide III / phenolic O-H bend | Phenolic O-H; N-containing residues |
| 1268.4, 1186.1 | v(C-O), v(C-O-C), v(P=O) | Aryl-O, ether links in humic substances; phosphates overlap |
| 1036.9, 1000.9 | v(C-O), v(C-O-C), v(P-O), v(Si-O) | Ether/acidic C-O in humics; phosphate and silicate overlap |
| 912.4, 780.8 | out-of-plane =C-H / aromatic C-H bend | Substituted aromatic rings (lignin-derived) |
| 698.6, 609.5 | ring bends / lattice modes | Aromatic ring modes; mineral lattice vibrations |
| 534.3 | v(M-O) | Metal-O (Ca, Mg, Fe) humate complexes |
| 482.7, 420.1 | v(Si-O-Si) bend / lattice vibrations | Silicates, metal oxides (ash) |

Table 4. Estimated humate parameters of swine dung and vermicompost produced

| Sample | HMI | HR | HA-like Index |
|---------------------------------|------|------|---------------|
| Swine dung | 0.4 | 0.65 | 1.13 |
| <i>E. eugeniae</i> vermicompost | 0.61 | 0.92 | 1.81 |
| <i>E. fetida</i> vermicompost | 0.72 | 1.1 | 2.13 |

Note: HMI = Humate maturity index (HMI), HR= Humate ratio (HR), and HA-like = Humic acid-like

The progression in the rates of HMI, HR, and the HA-like index from raw swine dung to vermicomposted materials indicates substantial

transformation and stabilization of organic matter during vermicomposting. Higher HMI and HR values reflect enhanced conversion of labile

organic fractions into stable humic substances, while the elevated HA-like index suggests increased synthesis of humic acid-like compounds. The superior performance observed in the *E. fetida* treatment may be attributed to species-specific differences in feeding behavior,

gut microbial interactions, and decomposition efficiency (Bhat et al., 2015; Singh et al., 2018). These findings confirm that vermicomposting significantly improves compost maturity and quality, with *E. fetida* more effective at promoting humification than *E. eugeniae*.

Table 5. Physicochemical properties of the swine dung, *E. fetida* vermicompost and *E. eugeniae* vermicompost

| Parameters | pH (H ₂ O) | EC (DS/m) | OC (%) | Ca | Mg | Na | K | Fe | Mn | Pb | Zn | Cd | Cr | Cu |
|------------------------------------|--------------------------|--------------|-----------|------|-----|------|------|------|----|----|----|-------|----|----|
| | | | | | | | | | | | | | | |
| Swine dung | 7.02 | 8.97 | 16.23 | 158 | 214 | 0.61 | 1.21 | 13.9 | 30 | 32 | 13 | 0.07 | 2 | 3 |
| <i>E. fetida</i> vermicompost | 6.98 | 3.04 | 13.46 | 93.5 | 154 | 0.09 | 0.54 | 10.4 | 30 | 1 | 7 | 0.008 | 1 | 3 |
| <i>E. eugeniae</i> vermicompost | 6.74 | 3.19 | 13.46 | 98.5 | 100 | 0.09 | 0.44 | 11.4 | 20 | 2 | 7 | 0.004 | 2 | 2 |

Table 5 presents the physicochemical properties and heavy metal concentrations of raw swine dung and vermicomposts produced by *Eisenia fetida* and *Eisenia eugeniae*. The pH of both vermicomposts was slightly acidic. Electrical conductivity (EC) values were measured at 3.04 ds/m for *E. fetida* and 3.19 ds m⁻¹ for *E. eugeniae*. Organic carbon (OC) decreased from 16.23% in raw swine dung to 13.46% in both vermicomposts. Exchangeable bases showed calcium levels decreased from 158 cmol kg⁻¹ in swine dung to 93.5 cmol kg⁻¹ and 98.5 cmol kg⁻¹ in the vermicomposts. In contrast, magnesium decreased by 28% and 53% in *E. fetida* and *E. eugeniae* vermicomposts, respectively. Sodium and potassium also declined by 85%, 55%, and 63.6% in the respective vermicomposts. Zinc concentrations decreased from 13 ppm in raw dung to 7 ppm in both vermicomposts. Lead and cadmium concentrations were reduced by 96.9%, 93.8% (*E. fetida*) and 88.6%, 94.3% (*E. eugeniae*).

The slightly acidic pH of both vermicomposts likely results from microbial activity during decomposition and the production of organic acids, reflecting

normal vermicomposting processes. The reduced EC indicates a decline in soluble salts, creating a more favorable environment for plant growth, as high salt concentrations can inhibit seedling development (Safdar et al., 2019). The decrease in organic carbon demonstrates microbial mineralization of labile organic matter, transforming raw dung into a more stabilized product that can improve soil structure, water retention, and nutrient availability (Suthar, 2009). Reductions in exchangeable calcium, magnesium, sodium, and potassium suggest that both earthworm activity and microbial processes influence nutrient immobilization and assimilation. For magnesium, the higher reduction in *E. eugeniae* vermicompost may reflect its physiological demand for enzymatic and metabolic functions, implying potential implications for soil Mg management. Declines in sodium and potassium further suggest that vermicomposting can help mitigate soil sodicity. Micronutrient analyses indicate that zinc levels decreased due to biological uptake and incorporation into enzyme cofactors and cellular structures (Oyege & Balaji Bhaskar, 2023). Similarly, the substantial reductions in

lead and cadmium concentrations demonstrate the earthworms' ability to tolerate, bioaccumulate, or immobilize heavy metals, reducing potential toxicity in the final vermicompost (Cheng & Wong, 2002). Overall, these findings indicate that vermicomposting with *E. fetida* and *E. eugeniae* not only stabilizes organic matter and improves soil fertility characteristics but also reduces the concentrations of potentially toxic heavy metals, producing a nutrient-rich, safe, and agronomically valuable organic amendment.

4. Limitations and Future Directions

This study provides valuable insight into the transformation of swine dung through vermicomposting; however, these limitations are hereby acknowledged. First, the study was conducted under controlled conditions using a single feedstock (swine dung), which may limit the generalisability of the findings to other organic wastes or field conditions where environmental variability is greater. In addition, the analytical focus was largely based on physicochemical properties, FTIR characterization, and selected heavy metals; thus, other important indicators of compost quality, like microbial community dynamics, enzyme activities, and plant bioassays, were not evaluated. Finally, temporal monitoring of the vermicomposting process was limited, restricting detailed understanding of transformation kinetics.

Future research should therefore explore multi-feedstock systems and conduct field-scale trials to enhance the applicability of findings under diverse environmental conditions. Comparative studies involving a wider range of earthworm species, including *Eisenia fetida* and *Eudrilus eugeniae*, as well as others, would further clarify species-specific efficiencies. Incorporating advanced analytical approaches, such as molecular microbial profiling and kinetic modeling, could deepen the understanding of decomposition mechanisms. Integrated plant growth trials and ecotoxicological

assessments, while benchmarking heavy metal concentrations against recognized standards (e.g., WHO/FAO or national guidelines) to substantiate agronomic safety, will be crucial. Such efforts will strengthen the scientific basis for optimizing vermicomposting as a sustainable waste-management and soil-fertility strategy.

5. Conclusion

Vermiculture represents an effective approach for converting raw swine dung into a stable, nutrient-rich organic amendment. FTIR analysis of vermicomposts produced by *Eisenia fetida* and *Eisenia eugeniae* indicates advanced organic matter transformation, characterized by the degradation of labile aliphatics and proteins and the enrichment of stable aromatic, carboxylate, and humic structures. These transformations enhance chemical stability, moisture retention, and humification, supporting the agronomic value of the vermicompost. Physicochemical analyses reveal reductions in soluble salts, exchangeable bases, and heavy metals, alongside retention of essential macronutrients and micronutrients. While both earthworm species effectively stabilized the raw dung, comparative differences were observed: *E. eugeniae* vermicompost exhibited slightly greater reductions in magnesium and labile organic fractions, suggesting species-specific efficiencies in nutrient assimilation and organic matter mineralization. Although heavy metal concentrations were substantially reduced, claims regarding vermicompost safety should be interpreted in the context of regulatory limits for soil amendments (e.g., FAO, EU, or local standards), as absolute thresholds were not directly assessed in this study. Overall, vermicompost from *E. fetida* and *E. eugeniae* provides a chemically stable, nutrient-enriched organic fertilizer and soil conditioner, with potential for improving soil structure, fertility, and crop productivity.

Future research should focus on evaluating nutrient and heavy metal

bioaccumulation in plants grown on these vermicomposts to further substantiate their safety and agronomic value.

Declaration of Generative AI and AI-Assisted Technologies in the Writing Process

We declare the use of generative AI in the manuscript preparation process upon submission of the paper. “During the preparation of this work, the author(s) used ChatGPT to proofread. After using this tool, the author(s) reviewed and edited the content as needed and take(s) full responsibility for the content of the publication.”

Authorship Contribution Statement

Osunde O.M.: conceptualization, validation, formal analysis, writing – original draft, review and editing; Ikeh V.C: conceptualization, methodology, software, validation, formal analysis, writing – original draft; Adesanwo O.O: conceptualization, methodology, writing – review & editing.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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