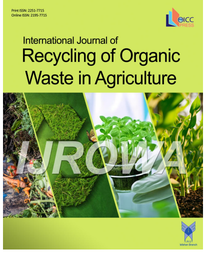

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Comparative characterization of biochar obtained from cow dung and poultry litter

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Abstract:

Purpose: The conversion of animal waste to biochar by pyrolysis remains the most sustainable alternative for proper management of cow dung and poultry litter in addressing soil infertility and environmental problems. Biochar serves multiple purposes, including waste management, organic fertilizer, carbon sequestration, soil improvement, and renewable energy production.

Method: Cow dung and poultry litter feedstocks were pyrolyzed for 1 hour at 400 °C in an oxygen limited reactor to produce biochar. Physico-chemical investigation of the produced biochar includes proximate analysis, microwave plasma atomic emission spectroscopy (MP-AES), scanning electron microscope-energy dispersive X-ray (SEM-EDX), Fourier transform infrared (FTIR) spectroscopy and thermogravimetric analysis (TGA and DTG).

Results: Cow dung biochar (CDB) yield was 41% while poultry litter biochar (PLB) was 60.2% respectively. Poultry litter biochar showed a higher ash content of 53.2%, volatile matter 43.5%, bulk density 0.449 g/mL and electrical conductivity 0.25 g/mL than cow dung biochar. Investigation observed dominant macronutrients: N (28300 mg/kg), K (10560.05 mg/kg), Ca (972.17 mg/kg), Mg (4523.82 mg/kg) and micronutrients Cu (80.71 mg/kg), Zn (90.42 mg/kg), Na (2862.47 mg/kg), Fe (2014.25 mg/kg) in poultry litter biochar than cow dung biochar. SEM-EDX images were black and porous with embedded organic and inorganic components. Functional groups acting as cation adsorbents were identified using FTIR. Mass loss and sample disintegration were evident in TGA and DTG curves as temperature increased.

Conclusion: Animal waste converted to biochar can act as a nutrient rich soil conditioner to address the mineral deficit in fruits and vegetables cultivated in acidic soils. Reusing agricultural waste in this way is a good idea.

Keywords: Environmental problems; Waste management; Pyrolysis; Carbon sequestration; Organic fertilizer

1. Introduction

In recent years, the Benue trough have experienced exponential growth in animal waste as a result of extensive agricultural practices. Animal waste such as manure, carcasses, feathers, and other by-products from livestock and poultry operations are organic materials derived from animals. Animal biochar is produced by pyrolyzing animal wastes, such as dung and droppings, and is a very efficient way to improve soil and manage waste. Because of its many advantages, such as increased soil fertility, carbon storage, and less environmental impact, this approach has attracted a lot of interest lately (Lehmann and Joseph, 2020; Joseph et al., 2021; Awasthi et al., 2020). By stabilizing organic matter, lowering greenhouse gas emissions, and immobilizing hazardous nutrients, biochar greatly reduces the environmental impact of disposing of animal waste and improves waste management effectiveness (Mohan et al., 2021; Wu et al., 2022; Ahmad et al., 2023). In the late 20th and early 21st centuries, research on climate change mitigation and sustainable agriculture methods led to a considerable increase in the scientific community's interest in biochar (Lehmann and Joseph, 2015). Plant growth and crop yields are increased when biochar is applied to soils because it improves soil structure, increases nutrient availability, and improves water retention (Mukherjee and Lal, 2022; Gul et al., 2023). Furthermore, biochar is an important method for sequestering carbon, which lowers greenhouse gas emissions from agricultural soils that are strong contributors to climate change, such as nitrous oxide (N_2O) and methane (CH_4). Its use improves soil resilience against climate-related stressors and reduces greenhouse gas emissions (Cayuela et al., 2020; Verheijen et al., 2019). The characteristics of biochar can differ greatly depending on the type of feedstock and the pyrolysis process, which might result in inconsistent impacts on the growth of plants and soil (Lehmann and Joseph, 2015; Kammann et al., 2015). Large-scale biochar production from animal waste that is both environmentally friendly and efficient requires thorough assessments of the pyrolysis technology, feedstock availability, and environmental effects in order to maximise production procedures and guarantee sustainability (Tian et al., 2022; Abbas et al., 2021; Prabhu et al., 2023). Biochars derived from animal biomass has more nutritional value than biochar made from crop leftovers (Sarfaraz et al., 2020). Thus, the current push is to stop viewing agricultural leftovers as unwanted garbage and instead view them as resource materials that may be used for both financial and environmental advantages. This research seeks to produce biochar from the same amount of cow dung and poultry litter in Makurdi, characterize and compare the different biochars.

2. Material and methods

Sample collection and preparation

Sack bags were used to collect cow dung and poultry litter biomass from Air Force Base Farm in Makurdi Local Government Area of Benue State. The samples were transported to the Ministry of Agriculture, Benue State for identification. Biomass was sorted for impurities and sun-dried for 10 days to get rid of excess moisture. The biomass was pounded with mortar and pestle for size reduction.

Biochar production

Separately, same amount (13350 g) of cow dung and poultry litter was fed into the pyrolysis drum with a height of 587 mm and 585 mm in diameter with a perforated base of 20 mm. The bass drum was fitted with an air tight adapter (height 310 mm; diameter 585 mm) incorporated with a chimney (height 700 mm; diameter 140 mm). Separately the heating was started using a match box, after pyrolysis for one hour the yield of CDB and PLB were collected. The biochar was allowed to cool down to room temperature, and the sample was examined for their physical and chemical characteristics.

Physicochemical properties of biochar

Percentage yield (%) was determined as the absolute weight of the biochar formed during pyrolysis divided by the total weight of the feedstock consumed.

$$\text{Percentage yield}(\%) = \frac{\text{Mass of biochar}}{\text{Mass of feedstock}} \times 100\%$$

The moisture, ash, volatile matter content was determined using standard procedure (AOAC, 2012)

$$\text{Moisture content } (\%) = \frac{W_s - (W_2 - W_1)}{W_s} \times 100\%$$

W_1 = Constant weight of a crucible
W_s = Weight of the crucible with its content 100
W_2 = Weight of the crucible with its content when cooled in a desiccator

$$\text{Ash content}(\%) = \frac{\text{Ash weight} - \text{Crucible weight}}{\text{Biochar weight}} \times 100\%$$

$$\text{Volatile Matter } (\%) = \frac{W_2 - W_3}{W_2 - W_1} \times 100\%$$

W_1 = Weight of pre-heated crucible
W_2 = Weight of pre-heated crucible with the sample
W_3 = Weight of the crucible with the sample after being heated
Weight% fixed carbon = 100 – % moisture + % volatile matter + % ash

$$\text{Bulk density} = \frac{\text{Mass of Sample}}{\text{Volume Occupied}}$$

The standard procedure was used to determine the pH and EC using pH meter (HANNA) and conductivity meter (ROS).

Mineral elemental analysis

The Agilent 4210 MP-AES (Kukwa et al., 2023) was used for mineral element determination in biochar.

Scanning Electron Microscope (SEM)

The morphological characterization was accomplished using SEM instrument (Make: PhenomProX Q150R Netherlands) at an accelerating voltage of 20.00 kv (Kukwa et al., 2023).

Fourier transform infrared spectroscopy (FTIR)

The infrared spectrum was obtained using Agilent Technology Cary 630 FT-IR spectrometer over the infrared region of $4000 - 1000\ \text{cm}^{-1}$ and a resolution of $4\ \text{cm}^{-1}$. The samples were compacted into KBr pellets before scanning.

Thermogravimetric analysis (TGA and DTG)

The thermogravimetric analysis was performed under the flow of nitrogen at a max heat-up rate of 20 °C and maximum operating temperature of 1200 °C while monitoring the biochar on a PerkinElmer TGA 4000, made in the Netherlands, analyzer.

3. Results and discussion

Percentage Yield

Pyrolysis of the different animal feedstock results in the yield of cowdung and poultry litter biochar as presented in Table 1.
Percentage yield of CDB was 41% while a higher percentage yield of 60.20% was indicated in PLB biochar at 400 °C in Table 1. When the same amount of feedstock was used variation in the amount of biochar yield depends on the mineral composition of feedstock regardless of pyrolysis type (Iortyom et al., 2024). The yield of PLB was higher because, during pyrolysis, these inorganic components do

Table 1. Percentage yield of biochars.

Feedstock	Feedstock mass (g)	Biochar yield (g)	Percentage (%) yield
Cow dung	13350	5474	41.0
Poultry litter	13350	8050	60.2

not volatilize but instead add to the mass of the biochar, boosting the yield. Though higher than the 37% reported by Oni et al. (2020), the percentage yield of PLB in this work is within the range of 56 – 62% as reported by Kukwa et al. (2023), Sarfaraz et al. (2020) and Wystalska et al. (2021) with values at 56.38%, 57%, and 62% respectively. In contrast to the 41% yield for CDB in this study, Sarfaraz et al. (2020) and Ghodake et al. (2021) recorded higher char yields of 58% and 57.2% for cow dung. At temperatures < 400 °C both biochars retain carbon and essential nutrients for soil enrichment.

Physical characterization

The biochars were alkaline, with pH ranging from 11.8 – 11.3 for CDB and PLB in Table 2 respectively. This aligns with the work of Sarfaraz et al. (2020) with high alkaline values on animal residue. According to Kukwa et al. (2023), the alkaline characteristic of the biochar can neutralize acidic soils and also influence cation mobility in it. High ash content of 53.2% in PLB was consistent within the range of 55–45% for ash (Chaves et al., 2020) when in excess can lead to potential salt buildup and reduce carbon sequestration efficiency in the soil (Mandal et al., 2023). The high VM of 43.5% agrees with the region of 45 – 40% for VM in PLB according to Zhang et al. (2022) which enhances soil microbial activity. Cow dung biochar with low ash (33.2%) and low volatile matter (32.1%) doesn't agree with the works of Ghodake et al. (2021) and Garba et al. (2019). The moisture content of 2.24% in PLB was similar to that reported by Kukwa et al. (2023). Similarly, other animal manures, like pig manure, have bulk densities of less than 1 g/cm^3 (0.4–0.7 g/cm^3), and their effects on soil aeration and water retention are similar (Blanco-Canqui, 2017). Goat manure biochar exhibits comparable effects on nutrient supply and salinity control as PLB, with EC values of other animal-derived biochars falling below 1 dS/m (Wang et al., 2023).

Mineral analysis

Mineral analysis of the biochars reveal the following elements in Fig. 1.

Fig. 1 presents PLB with a higher macro and micro mineral element concentration than CDB because of the mineral composition of the poultry litter. This makes PLB an ex-

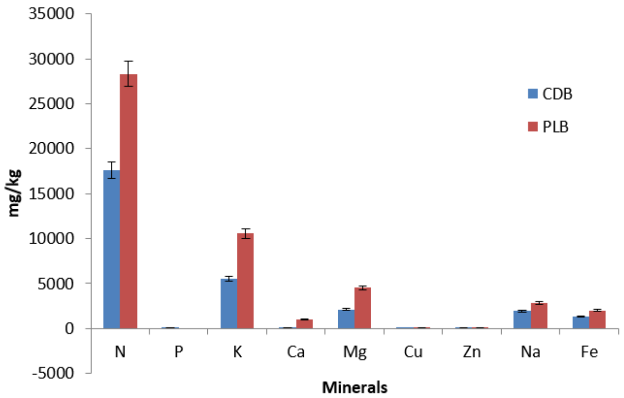

Figure 1. Mineral composition of cow dung and poultry litter biochar. Cow dung biochar consist of macro minerals such as N (17600 mg/kg), P (36.8 mg/kg), K (5554.97 mg/kg), Ca (96.81 mg/kg), Mg (2100.87 mg/kg) and micro elements such as Cu (17.74 mg/kg), Zn (69.17 mg/kg), Na (1933.72 mg/kg), Fe (1317.20 mg/kg). Poultry litter biochar (PLB) consist of N (28300 mg/kg), P (−1.22 mg/kg), K (10560.05 mg/kg), Ca (972.17 mg/kg), Mg (4523.82 mg/kg) and micro elements includes Cu (80.71 mg/kg), Zn (90.42 mg/kg), Na (2862.47 mg/kg), Fe (2014.25 mg/kg).

cellent soil amendment for nutrient deficient soils for rapid growth and crop yield (Sun et al., 2023) hence, reducing need for supplementary fertilizer. Mineral elements in this study were similar with the work of (Sarfaraz et al., 2020) on animal biochar. Phosphorus was not detected in poultry litter biochar in this research but Kukwa et al. (2023) reported a phosphorus concentration of 11.8 mg/kg. Animal biochar offers immediate and significant nutrient enrichment since it has far greater concentrations of macro and micro nutrients than biochars obtained from plants (Ahmad et al., 2023; DChoudhary et al., 2023). But in sensitive areas, plant-derived biochars are more suitable for long-term soil management since they usually present less of a danger of salt and nutrient leakage (Wang et al., 2023).

Scanning electron microscope and energy dispersive X-ray (SEM-EDX)

Fig. 2 (a)-(b) biochar images were heterogeneous, black, porous with embedded organic and inorganic components (Manya et al., 2018). The surface of PLB was smoother with well-defined pores (Chia et al., 2015) compared to CDB. Compared to the higher carbon (88.13%) and lower silicon (1.76%) in PLB, cow dung biochar has a slightly lower carbon concentration (81.5%) but higher silicon 12.27%

Table 2. Physical characterization of produced biochar.

Biochar	%Moisture	%Ash	%Volatile matter (VM)	%Fixed carbon	Bulk density g/mL	pH	Electrical conductivity dS/m
CDB	5.73 ± 1.02	33.2 ± 1.63	32.1 ± 2.89	28.97	0.250 ± 0.0171	11.8 ± 0.808	0.110 ± 0.360
PLB	2.24 ± 0.629	53.2 ± 0.544	43.5 ± 1.42	0.7	0.449 ± 0.0419	11.3 ± 0.351	0.25 ± 0.023

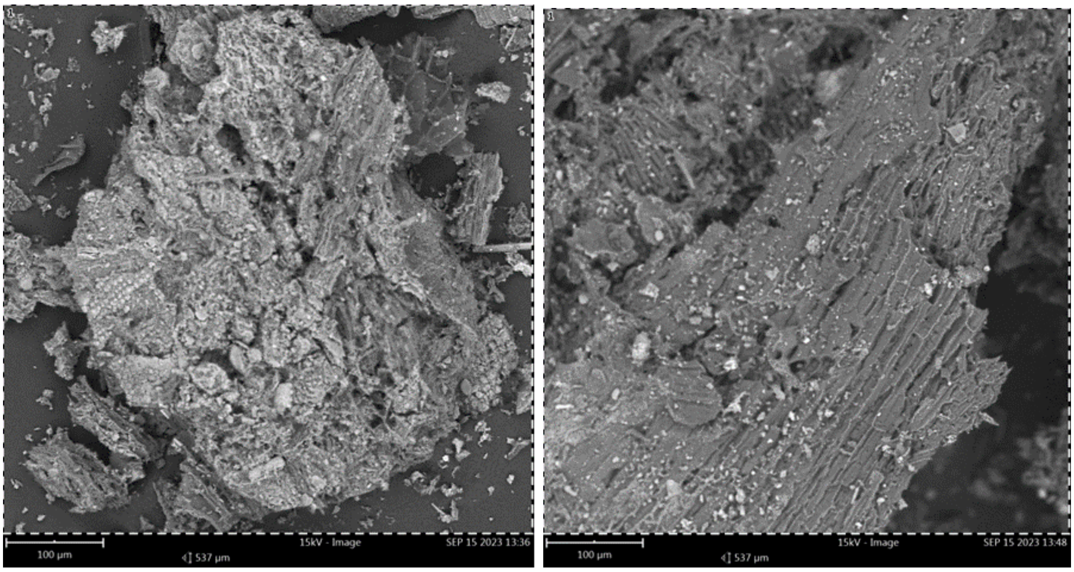

Figure 2. (a) SEM of cow dung biochar (x500); (b) SEM of poultry litter biochar (x500).

(Singh et al., 2010) because cattle eat a lot of grass and fodder while chicken depends on additive feeds. Peaks of macro elements with higher peaks of potassium (3.00%), phosphorus (1.59%) and calcium (1.92%) were observed in PLB while lower peaks of potassium (2.02%), phosphorus (0.34%) and calcium (1.07%) were observed in CDB which was attributed to mineral composition variation.

Fourier transformed infrared of cow dung and poultry litter biochar

Table 3 reveals cow dung and chicken litter biochars with strong bands at 3503.7 cm^{-1} and 3749.7 cm^{-1} which corresponds to the O-H symmetrical and asymmetrical stretching vibrations of H bonded or OH groups as described by Smith and Dent (2021), Coates et al. (2020) and Stuart et al. (2019).

Table 3. FTIR analysis of the produced biochars.

Frequency cm^{-1} CDB	Frequency cm^{-1} PLB	Intensity	Functional group	Reference
	3749.7	Strong	O-H$_{(stretch)}$	Smith and Dent (2021); Coates et al. (2020); Stuart et al. (2019)
3503.7		Strong	O-H$_{(stretch)}$	Kukwa et al. (2023)
	3336.0	Broad	N-H$_{(stretch)}$	Smith and Dent (2021); Coates et al. (2020); Stuart et al. (2019)
3324.08		Broad	N-H$_{(stretch)}$	Hossain et al. (2020); Manya (2012)
	2922.4	Strong	C-H$_{(stretch)}$	Chaves et al. (2020); Chen et al. (2008); Melo et al. (2013)
2243.9		Strong	C≡N$_{(stretch)}$	Gwenzi et al. (2015); Hossain et al. (2020)
2150.7		Variable	C≡C$_{(stretch)}$	Silverstein et al. (2005); Stuart (2004)
	2102.2	Variable	C≡C$_{(stretch)}$	Cao et al. (2019)
	1982.9	Strong	C=O$_{(stretch)}$	Gaskin et al. (2008); Cantrell et al. (2012); Qian et al. (2015)
1979.2		Strong	C=O$_{(stretch)}$	Manya (2012); Hossain et al. (2020)
	1661.8	Weak	C=C$_{(stretch)}$	Gaskin et al. (2008); Cantrell et al. (2012); Qian et al. (2015)
1558.0		Weak	C=C$_{(stretch)}$	Gwenzi et al. (2015); Zhao et al. (2018)
	1408.9	Weak	C-H$_{(bend)}$	Gaskin et al. (2008); Cantrell et al. (2012); Qian et al. (2015)
1401.5		Weak	C-H$_{(bend)}$	Hossain et al. (2020); Yang et al. (2023)
1058.6		Narrow	C-O$_{(stretch)}$	Manya (2012); Zhao et al. (2018); Nguyen and Nguyen (2021)
	1028.7	Narrow	C-O$_{(stretch)}$	Tang et al. (2016)
	872.2	Weak	C-H$_{(bend)}$	Bhatnagar et al. (2010)
790.2		Weak	C-H$_{(bend)}$	Gwenzi et al. (2015); Hossain et al. (2020); Zhao et al. (2018)
	745.5	Weak	C-H$_{(bend)}$	Gaskin et al. (2008); Cantrell et al. (2012); Qian et al. (2015)
	700.7	Weak	C-H$_{(bend)}$	Cantrell et al. (2012); Qian et al. (2015); Gaskin et al. (2008)

In studies according to Kukwa et al. (2023) and Sarfaraz et al. (2020), OH stretching vibration was not found in PLB and CDB but other studies by Wystalska et al. (2021) and Chaves et al. (2020) reveals the presence of O-H functional group in PLB. Different forms of biochar have distinct chemical compositions and structural variations, which account for the difference in wavenumbers. Similar broad peaks indicative of the stretching vibration of 1° N-H (Smith and Dent, 2021; Coates et al., 2020; Stuart et al., 2019), appear with close wavenumbers at 3324.8 cm^{-1} and 3336.0 cm^{-1} for CDB and PLB respectively. Kukwa et al. (2023) reported an N-H band at 3548 cm^{-1} in PLB which was higher than the observed value in this study. The existence of N-H group in CDB was indicated by the wave number at 3324.8 cm^{-1}, which was greater than the 3300 cm^{-1} reported by Hossain et al. (2020). Both values lie within the range of 3200 – 3400 cm^{-1} as reported by Manya (2012) for cow dung biochar. According to Smith and Dent (2021), Coates et al. (2020), Stuart et al. (2019), the dissimilarity in the strong intensity peaks at 2243.9 cm^{-1} and 2922.2 cm^{-1} indicates variances in C≡N and C-H stretching vibrations in cow dung and chicken litter biochar. The C≡N nitrile group corresponds to the same band for cow dung biochar as reported by Hossain et al. (2020), which was marginally higher than the 2240 cm^{-1} frequency for cow dung biochar as reported by Gwenzi et al. (2015). The band at 2922.2 cm^{-1} indicative of aliphatic $C\text{-}H_{(stretch)}$ agrees with the study of Chaves et al. (2020); Chen et al. (2008); Melo et al. (2013) with values within the region of 2920 – 2885 cm^{-1} for poultry litter biochar. The terminal alkynes C≡C in both biochars were represented by stretching vibrations with varied intensities at frequencies of 2150.7 cm^{-1} and 2113.4 cm^{-1} (Silverstein et al., 2005; Stuart, 2004; Cao et al., 2019). Strongly intensified bands at 1979.2 cm^{-1} and 1982.9 cm^{-1} indicate $C{=}O_{(stretch)}$ in both CDB and PLB (Smith and Dent, 2021; Coates et al., 2020; Stuart et al., 2019). Similarly carbonyl absorption band around 1980 cm^{-1} for ketones in CDB fall within the range of 1900 – 2000 cm^{-1} was reported by Hossain et al. (2020) and Manya (2012). The frequency of C=O for PLB reported in this work was higher than the 1796 cm^{-1} and 1600 cm^{-1} band observed in PLB by (Kukwa et al., 2023) and (Chaves et al., 2020). The bands at 1558.0 cm^{-1} and 1661.8 cm^{-1} indicate aromatic $C{=}C_{(stretch)}$ in CDB and PLB with weak peak intensities (Smith and Dent, 2021; Coates et al., 2020; Stuart et al., 2019). The functional groups observed in these biochars were in agreement with earlier research by Sarfaraz et al. (2020) for the biochars of cow dung and poultry litter. But the C=C frequency do not appear in the poultry litter biochar studies according to Kukwa et al. (2023). Similar C-H bending vibrations are indicated by the close wavenumbers of 1401.5 cm^{-1} and 1408.9 cm^{-1} (Smith and Dent, 2021; Coates et al., 2020; Stuart et al., 2019). The weak intensity peaks in cow dung and chicken litter biochar, located at 1401.5 cm^{-1} and 1408.9 cm^{-1} respectively, were ascribed to the bending vibrations of C-H bonds in aliphatic compounds, including methylene ($-CH_2-$) groups (Hossain et al., 2020; Yang et al., 2023). The C-H bending vibrations at 1408.9 cm^{-1} in PLB were found to be in agreement with the research conducted by Qian et al. (2015), Cantrell et al. (2012), and Gaskin et al. (2008). The narrow bands at 1058.6 cm^{-1} and 1028.7 cm^{-1} indicates $C\text{-}O_{(stretch)}$ in CDB and PLB (Manya, 2012; Zhao et al., 2018; Nguyen and Nguyen, 2021; Tang et al., 2016). In both biochars, the wavenumbers 790.2 cm^{-1} and 872.2 cm^{-1} are commonly linked to weakly intensified out-of-plane C-H bending vibrations in aromatic compounds (Bhatnagar et al., 2010; Gwenzi et al., 2015; Hossain et al., 2020; Zhao et al., 2018). In PLB, weak bands at 745.5 cm^{-1} and 700.7 cm^{-1} are suggestive of aromatic C-H out-of-plane bending vibrations. These bands show that similar aromatic structures have been found in PLB on multiple occasions, as shown by studies by Gaskin et al. (2008), Cantrell et al. (2012), and Qian et al. (2015).

Thermogravimetry and derivative thermogravimetric analysis

The thermal properties of biochar were analyzed using TGA and DTG in an inert nitrogen environment, volatile chemicals were thermally decomposed up to 1200 °C at a maximum rate of 20 °C min^{-1}. Figs. 3 (a)-(b) present the TGA analysis of CDB displaying five (5) stages (Hossain et al., 2020; Singh et al., 2015; Zhao et al., 2018; Devi and Saroha, 2014) of mass loss when compared to the four (4) stages (Simbolon et al., 2019; Ro et al., 2013; Singh et al., 2014) of mass loss in PLB.

Kukwa et al. (2023) reported three stages of mass loss in PLB which can be attributed to variation in moisture con-

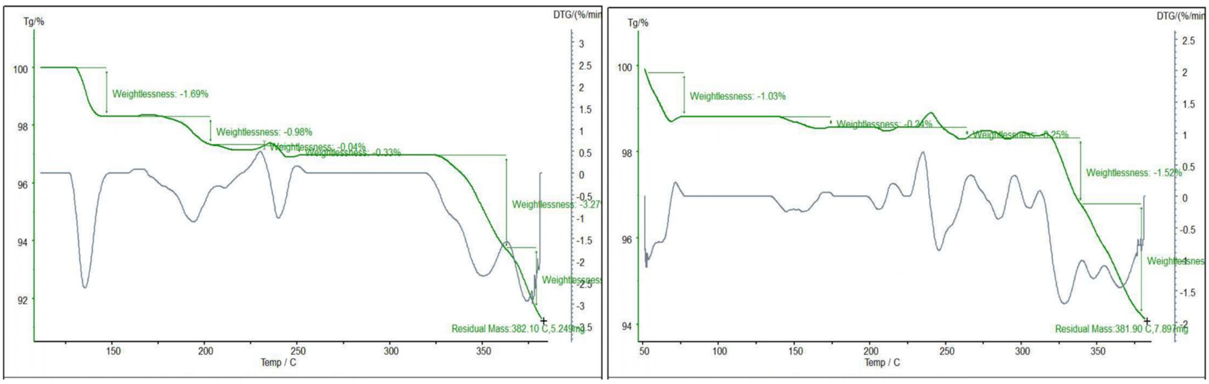

Figure 3. (a) Cow dung biochar thermogravimetry and derivative thermogravimetric analysis; (b) Poultry litter biochar thermogravimetry and derivative thermogravimetric analysis.

tent, temperature, feed compositions and experimental conditions. Cow dung biochar first stage I (203.7 – 152 °C) involves a higher weight loss of −1.69% which represents moisture and light volatiles (Bartocci et al., 2019) which occured at 168.7 °C on the DTG graph within the region of 175 – 150 °C while PLB initial stage I (80.3 – 175.7 °C) displayed at lower weight loss of −1.03% indicating moisture and light volatile (Kukwa et al., 2023; Cantrell et al., 2012; Ro et al., 2013) shown at peak temperature of 137.1 °C on the DTG curve within a temperature range of 175.7 – 80.3 °C. Variations may result from differences in feedstock composition and initial moisture levels. In the second stage II (203.7 – 234.9 °C), a higher weight loss of about −0.98% was associated with the degradation of proteins and lipids (Singh et al., 2015) in CDB seen at a sharp peak on 228.7 °C on the DTG graph within the limit of 234.9 – 225 °C. Conversely, PLB in the second stage II (175.7 – 268.1 °C) showed a lower weight loss of −0.24% representing hemicellulose and cellulose (Cantrell et al., 2012; Ro et al., 2013) occurring at a sharp peak temperature of 238.6 °C on the DTG curve within a temperature range of 250 – 225 °C. Cow dung biochar third stage III (256.2 – 234.9 °C) represents a negligible mass loss of −0.04% of thermally unstable organic compounds (Singh et al., 2015) with an obvious dip on the DTG curve within the range of 234.9 – 250 °C. Poultry litter biochar's tertiary stage III (268.1 – 341.6 °C) weight loss of −0.25% represents partly cellulose and lignin decomposition traced by the fingered peak at 295.2 °C on the DTG curve within a temperature limit of 300 – 275 °C. The observed mass loss of CDB was −0.33% in stage four IV (256.2 – 362.5 °C) involves further decomposition of a more stable organic matter (Devi and Saroha, 2014), with a uniform flat top between 260 – 321.2 °C and a dip at 350 °C on the DTG curve within a region of 362.5 – 325 °C while in PLB a weight loss of −1.52% was observed in the final stage IV (341.6 – 381.9 °C) which was attributed to the breakdown of more stable organic fractions depicted by the peak positioned at 381.90 °C on the DTG plot within the range of 375 – 381.90 °C. This aligns closely with the values reported by Singh et al. (2014), indicating the residual mass of 7.897 mg in thermogram. A notable mass loss of −3.27% was observed in cow dung biochar fifth stage V (382.1–362.5 °C), which was ascribed to the breakdown of leftover organic material and minerals on the DTG peak at 375 °C, which was located within the 382.1–362.5 °C range.

4. Conclusion

Poultry litter biochar was observed with a higher percentage yield, ash value, volatile matter, macro and micro nutrient content when compared to cow dung biochar. The higher potassium and nitrogen levels in PLB makes it more suitable for nutrient intensive crop production while CDB with lower nutrient release, bulk density and electrical conductivity was better for improving long term soil structure and carbon sequestration. Poultry litter biochar risks salinization due to elevated nutrient concentrations whereas CDB lower nutrient content is safer for sustainable application which may require complementary fertilizers. SEM-EDX images reveal the heterogeneous nature of both biochars. FTIR analysis identified the presence of carbonyl, hydroxyl, and amine groups with surface charge that act as cation adsorbent in biochar. Thermal stability of biochars was ascertained through TGA analysis. The challenges of animal waste originating from cattle and poultry farms within Makurdi was managed through thermo-chemical conversion into biochar and further utilizing it for improving the bioavailability of nutrients in the soil for the growth of crops. Further research should explore blending strategies on both biochars to optimize nutrient availability and soil health.

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Authors contributions
Kukwa Erdoo Rose: Administration, Conceptualization, Methodology, Project, Supervision, Writing-review and editing; Iortyom Orseer Barnabas (Corresponding Author): Data, Curation, Analysis, Formal, Methodology, Resources-Writing-original draft; Adah Christie Agbenu: Administration, Project, Supervision, Writing-review and editing.

Availability of data and materials
The data that support the findings of this study are available from the corresponding author, upon reasonable request.

Conflict of interests
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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