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ORIGINAL RESEARCH

Reclamation of poultry litter for the production of biochar

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Abstract

Purpose: Poor management of chicken litter by the poultry industry has caused many environmental issues. Biochar's unique characteristics make poultry litter-to-biochar conversion an intriguing management option thus, could be utilized as an organic fertilizer for plant nutrients. In this research, poultry litter was converted into biochar, which offers a range of possible applications, including analyzing key nutrients, improving air and water quality, conditioning soil, and neutralizing acidic soils.

Method: Fresh poultry litter was pyrolyzed for 20 minutes at a temperature of 500 ^{o}C in an oxygen-restricted muffle furnace to produce biochar. The biochar was examined chemically and physically using a variety of techniques. These included microwave plasma atomic emission spectroscopy (MP-AES), the scanning electron microscope (SEM), the Fourier transform infrared (FTIR) spectroscopy, and thermo gravimetric analysis (TGA and DTG).

Results: The pyrolysis output was 56.38%, 32.20% ash, 2.00% moisture, 0.60 kg/m^3 bulk density, pH 9.65, and 0.00314 d*S*/m EC. The mineral elemental analysis gave 621.73 mg/kg calcium, 63.65 mg/kg potassium, 48.94 mg/kg magnesium, 13.14 mg/kg sodium, and 11.85 mg/kg phosphorus. FTIR showed the presence of functional groups which could act as cation adsorbents. SEM pictures showed the sample's amorphous, non-uniform surface. TGA and DTG curves showed mass loss and sample breakdown as the temperature climbed.

Conclusion: Poultry litter converted to biochar can act as a nutrient-rich soil conditioner to address mineral deficits in fruits and vegetables grown in acidic soils. This is a good way to recycle agricultural trash.

Keywords: Pyrolysis, Chicken wastes, Soil conditioner, Pollution, Environment, Management

Introduction

The poultry industry is one of the world's largest and fastest-growing agro-based sectors. Poultry meat is in high demand, owing to its widespread acceptance in most cultures and comparatively low cholesterol content. The poultry business is, however, currently dealing with some environmental issues (Bolan et al. 2010). One of the most serious issues is the accumulation of large amounts of waste, particularly manure, and litter, as a result of intensive production (Bolan et al. 2010).

Improper management and treatment of poultry litter result in environmental hazards and economic losses. Some of these issues include volatilization of ammonia, nutrients leaching, higher rate of nitrogen mineralization, excessive phosphorus contamination of surface water and damage to crops (Schilke-Gartley and Sims 1993; Steiner et al. 2010; Wang et al. 2015; Liang et al. 2014). Improper dumping of poultry

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wastes could also result in environmental pollution leading to greenhouse gas emissions, bad odour and other unpleasant outcomes (Sánchez et al. 2015; Mukherjee and Lal 2013; Zhang et al. 2016).

The conversion of poultry waste into biochar is one of the most promising strategies among the various methods of managing poultry waste (Akanni and Benson 2014; Nair et al. 2017; Antonangelo and Zhang 2020; Sikder and Joardar 2019). This is due to biochar's unique beneficial characteristics, which could be used to solve environmental pollution problems by utilizing it as an organic fertilizer for plant nutrients. Most of the manure and litter produced by the poultry industry is currently applied to agricultural land (Sánchez-Monedero et al. 2018; Xu et al. 2012; Anyanwu et al. 2018). When managed correctly, land application is a viable way to recycle the nutrients such as nitrogen (N), phosphorus (P), and potassium (K) in manure (Abbasi and Anwar 2015; Wisnubroto et al. 2017; Zheng et al. 2013). However, pollution and nuisance problems can occur when manure is applied under environmental conditions that do not favour the agronomic utilization of manure-borne nutrients (Mierzwa-Hersztek et al. 2016; Cely et al. 2015). The continued productivity, profitability, and sustainability of the poultry industry depend on the formulation of best management practices (Lehmann et al. 2006). Additionally, this would spur the creation of innovative and cost-effective technologies that provide an alternative to land application of poultry wastes (Guo et al. 2020; Chen et al. 2019). Agricultural residues such as leaves, stalks, stems, molasses, husks, bagasse, seeds, straw, shell, pulp, stubble, peel, root, and tuber fibres, as well as animal waste (dung and droppings) can all be used to produce biochar by heating them at specific temperatures in an oxygen-depleted environment (300-600°C) (Domingues et al. 2017; Evans et al. 2017; Oginni and Singh 2020; Stella et al. 2016; Gurav et al. 2020; Vijayanand et al. 2016). The physical and chemical properties of the resulting biochar are determined by the temperature and time of pyrolysis (Cantrell et al. 2012; Elnour et al. 2019; Méndez et al. 2013). The chief among these is the pH, electrical conductivity, surface area, porosity, and type of surface functional groups.

Reports have shown that biochar obtained from animal sources such as cow manure, droppings from birds and sewage sludge have higher nutritional quality compared to those from crop residues (Méndez et al. 2013; Mukome et al. 2013; Tsai et al. 2012; Lima et al. 2015). Poultry litter is a valuable source of organic fertilizer for plants since it is highly concentrated in necessary macro- and micronutrients (Mierzwa-Hersztek et al. 2016). Hence, the trending advocacy is to stop considering agricultural residues/wastes as undesirable waste, but as resource materials that can be utilized for environmental and economical benefits. This study aims to convert poultry litter into biochar, determine the physicochemical properties of the biochar, and offer recommendations for how to handle the myriad environmental challenges that are caused by incorrect management of poultry litter.

Materials and method

Materials

A high-density polyethylene sieve, mortar and pestle, sample container, muffle furnace, desiccators, crucible, pH meter, measuring cylinder, beaker, stirring rod, oven, analytical weighing balance, conductivity meter, and distilled water are some of the things you'll need for this project.

Scanning Electron Microscope (SEM), Thermogravimetric Analysis (TGA and DTG), Fourier Transform Infrared Spectroscopy (FTIR), and Microwave Plasma Atomic Emission Spectroscopy (MP-AES) are some of the instrumental techniques used in this study.

Sample collection and preparation

The feedstock considered for pyrolysis in this study was biomass in the form of poultry litter particles in the size range of millimetres. It was collected from Oracle Farms in Makurdi Local Government Area of Benue State. The sample was identified at the Department of Biological Sciences, Benue State University, Makurdi. The poultry litter was then air-dried for seven days to get rid of any extra moisture. Following the process of grinding the dried poultry litter with a mortar and pestle, it was sieved through a high-density polyethene sieve. Only parts with a particle size of less than 1 mm were kept and stored in a sample container for use.

Carbonization

Biochar was produced via pyrolysis in a muffle furnace under oxygen-limited conditions. The pre-processed poultry litter (125g) was placed in a crucible and inserted into the muffle furnace in batches, which allowed for vapour removal and maintained an air-free environment throughout the pyrolysis process. The system was preheated to the temperature of 500°C and maintained at that temperature for 20 minutes. After the heating process, the crucible was removed from the muffle furnace and allowed to cool to room temperature in a desiccator for 45 minutes. The biochar (solid residues) was then removed and preserved in a sample container for subsequent use throughout the study.

Physicochemical characterization of biochar

The Physicochemical parameters of the biochar were determined, including percentage yield, moisture content, ash content, pH, bulk density, and electrical conductivity.

The total weight of the poultry litter feedstock used in the pyrolysis process, as well as the total weight of the biochar after carbonization in the muffle furnace, were both measured. The yield was calculated as a percentage of the difference in weights.

$$\text{Percentage yield (\%)} = \frac{Mass\ of\ biochar}{Mass\ of\ poultry\ litter}\ x\ 100$$

The moisture content was determined by the following procedure; a crucible was pre-heated for 5 minutes at 105 °C in an oven, then cooled and weighed. The biochar was then weighed again in the crucible at a known weight (2.0 g). The sample crucible was placed in an oven and heated to 105 °C for 2 hours, after which it was removed and allowed to cool in a desiccator. The moisture content was determined by the sample's weight loss. The following formula was used to determine the moisture content: Moisture content

$$\text{(\%)} = \frac{Loss\ in\ weight\ due\ to\ drying}{Weight\ of\ sample\ taken}\ x\ 100$$

$$= \frac{W_2 - W_3}{W_2 - W_1}\ x\ 100$$

Where: W_1 = Constant weight of a crucible

W_2 = Weight of the crucible with its content

W_3 = Weight of the crucible with its content when cooled in a desiccator

Ash content was determined using a muffle furnace. A crucible was pre-heated for 5 minutes at 700 ºC, then cooled and weighed. After that, a known weight of the sample (2.0 g) was placed into the crucible and weighed again. The charcoal crucible was placed in a muffle furnace and heated to 700 ºC for 10 minutes before being removed and cooled in a desiccator. The ash content was estimated using the formula provided.

$$\text{Ash content (\%)} = \frac{\text{Weight of ash}}{Weight\ of\ sample}\ x\ 100$$

$$= \frac{\mathrm{W}_2 - \mathrm{W}_3}{W_2 - \mathrm{W}_1}\ x\ 100$$

Where: 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

The standard test was used to determine the pH. In a beaker, 200 mL distilled water was added to 2.0 g of the sample, and the mixture was manually agitated with a stirring rod for 20 minutes and allowed to stabilize before the pH was measured using a pH meter.

Electrical conductivity was carried out as described; 200 mL of distilled water was added to a beaker containing 2.0 g of biochar, and the mixture was manually agitated for 20 minutes using a stirring rod. A conductivity meter was used to determine the electrical conductivity, and the results were provided in decisiemens per meter.

The bulk density was determined as the dry weight of the sample divided by its volume. A known weight of the sample was put into an empty measuring cylinder. It was gently tapped for two minutes until it was compact and evenly packed. Then, the volume of the sample in the measuring cylinder was measured.

$$\text{Density} = \frac{\text{Mass } of\ sample}{\text{Minimum volume occupied}}$$

Mineral elemental analysis

The elemental analysis was carried out to identify the particular elements present in the biochar produced.

The samples were prepared using an advanced digestion system, Ehos Easy. Two hundred milligrams (200 mg) of samples were weighed and placed in microwave digestion vessels with a capacity of 90 millilitres (mL). Each jar received ten millilitres of a 7:2:1 mixture of 15.9 N trace metal grade Nitric acid, hydrogen peroxide, and perchloric acid. The materials were processed using a microwave digestion device after standing for one hour (1h). After ramping the temperature from ambient to 200 ºC over 20 minutes and holding it there for another 20 minutes, they were allowed to drop to around 50 ºC before handling. The digestate was transferred to a 50 mL volumetric flask and filtered, and the solution volume was adjusted to 50 mL with deionized water.

The Agilent 4210 MP-AES was used for all measurements. PVC peristaltic pump tubing (white/white and blue/blue), a single pass cyclonic spray chamber, and a single Nebulizer made up the sample introduction system. The background signal was automatically subtracted from the analytical signal using Agilent MP Expert software. A blank solution's background spectrum was recorded and automatically removed from each standard and sample solution under investigation. To improve sensitivity, the program was also utilized to tune the nebulization pressure and viewing position for each wavelength chosen. Each analyte was determined under optimum conditions as a result of this optimization and the fact that all measurements were carried out sequentially. To quickly and simply tune the settings, a standard reference solution was used.

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 cm^{-1} and a resolution of 4 cm^{-1}. The sample was compacted into KBr pellets before scanning. The spectrum of the pure Kbr was measured before the sample measurement.

Scanning Electron Microscope (SEM)

A scanning electron microscope (SEM) generates images of a material by scanning its surface with an electron beam at magnifications ranging from 10 to 5000 times. The SEM analysis was carried out using a scanning electron microscope (SEM) model PhenomProX, Netherlands, to analyze the physical structural change of the samples. The sample was placed on double adhesive on a sample stub and coated with 5 nm gold using a quorum technologies model Q150R sputter coater. It was then taken to the SEM instrument chamber, where it was viewed via NaVCaM for focusing and minor adjustments, before being transferred to

SEM mode, where it was focused and brightness contrasting was automatically adjusted. Finally, the morphologies of various magnifications were obtained.

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 weight loss and thermal behaviour of the biochar on a PerkinElmer TGA 4000, made in the Netherlands, analyzer. The analysis enabled the observed changes in physical and chemical properties of materials (breakdown of the poultry litter biochar) as a function of increasing temperature.

Results and discussion

Physicochemical properties of the biochar

Some properties of the biochar produced from poultry litter at 500 °C are presented in Table 1.

Table 1 Physicochemical Characteristics of the biochar

Parameters	Measurement 1	Measurement 2	Mean±STDev
Percentage yield	72.89 g	68.06 g	56.38 ±1.93%
Ash content	0.631 g	0.657 g	32.20 ± 0.65%
Moisture content	0.035 g	0.045 g	2.00 ± 0.25%
Bulk density (g/mL)	0.610	0.590	0.60 ± 0.01
pH	9.85	9.45	9.65 ± 0.20
Electrical conductivity (**d*S*/m**)	0.00296	0.00332	0.00314 ± 0.00018

Values are expressed as mean ± S.D in 2 decimal places

At the end of the process, it was observed that the product exhibited the physical and chemical characteristics as shown in Table 1; percentage yield 56.38%, ash content 32.2%, moisture content 2%, pH 9.65, electrical conductivity 0.00314 d*S*/m and bulk density 0.60 g/mL.

The value for the percentage yield of the biochar is in good agreement with that obtained by Sarfaraz et al. (2020) at 57%. The pH and high electrical conductivity values are a result of the type of feedstock used in the pyrolysis process. When added to acidic soils, the alkaline property of the biochar would help to increase the pH of the soils and also influence cation mobility in it as indicated by Chaves et al. (2020).

The ability of biochar to conduct electricity is highly reliant on how effectively it has been carbonized, as measured by its carbon content. Carbon has a greater impact on the material's electrical conductivity and pH. The pH of the biochar produced was found to be alkaline, meaning that the material is high in carbon content (Table 1). Mineral element concentrations rise as a result of the loss of volatile molecules, raising EC. The physicochemical properties of biochars produced from rice straw, wheat straw, maize stover, rape stalk, and cotton stalk pyrolyzed from 300 °C to 700 °C were investigated (Sarfaraz et al. 2020). At increasing pyrolysis temperatures, the carbon content, pH, and electrical conductivity of the biochars increased, whereas the O: C and H: C ratios decreased. When the carbonization temperature exceeds 500 °C, the EC of the biochar increases at first, then stabilizes.

Liu et al. (2018) reported that, with increasing carbonization temperature, more acidic functional groups, such as -COOH and -OH groups are removed resulting in larger pores and a higher aromatic/aliphatic carbon ratio in the biochars. The report agrees fairly well with the FTIR and SEM data obtained in this study. Consequently, the pH of biochar rises as the pyrolysis temperature rises.

On the effects of biochar and its combination with compost on lettuce growth, Trupiano et al. (2017) reported that biochar addition together with compost improves soil chemical and microbiological properties and enhances plant growth and physiology more than compost and biochar alone. The researchers averred that biochar alone reduced the population of cultivable microorganisms while increasing the activity of enzymes involved in phosphorus, nitrogen, and carbon cycling including alkaline phosphatase, acid phosphatase, phosphohydrolase, lipase-esterase, esterase, chymotrypsin, and trypsin.

The pH, EC, moisture content, and ash content of the biochar (9.65, 0.00314 dS/m, 2.00%, and 32.20% respectively) were found to be closely related to that reported in the study conducted by Chaves et al. (2020). In another research, Wang et al. (2019) averred that the ability of biochar to alter soil water retention depends on the physical qualities of both the biochar and the soil, which change depending on the feedstock and pyrolysis conditions. As a porous material, biochar can hold water and, when added to soils with poor water-holding ability, may enhance water retention. The effect of biochar on the soil's capacity to retain moisture depends on its pore volume and pore size distribution, and it is more pronounced in soils with a coarser texture. The 2.00% moisture content recorded in Table 1 suggests that biochar has the potential to retain moisture in the soil. According to Zhou et al. (2016), the inorganic fractions of biochar aid in the sorption of mineral ions. The researchers observed that the biomass template and sorption mechanism affect how much ash is present in biochar. The ash content of 32.20 % gives this biochar the vantage application for the sequestration of heavy metals from soil.

Mineral elemental analysis

Elemental analysis carried out on the biochar showed the presence of the following elements as indicated in Table 2.

Table 2 Mineral Elemental Analysis of Biochar

Element	**Concentration (mg/kg)**
Calcium	621.73
Potassium	63.65
Magnesium	48.94
Sodium	13.14
Phosphorus	11.85

Calcium 621.73 mg/kg, Potassium 63.65 mg/kg, Magnesium 48.94 mg/kg, Sodium 13.14 mg/kg, and Phosphorus 11.85 mg/kg. The high calcium content is a result of the composition of the biomass used. Its addition to the soil will serve as a liming effect to a soil that is too acidic and also prevent or eliminate calcium deficiencies of fruits and vegetables planted on such soils. Also worthy of note is that the high pH and electrical conductivity of the biochar, when applied to the soil, has an effect on the availability of macronutrients such as P, K, N, Ca, Mg, and micronutrients such as Cu, Zn, Fe, Mn that can be in more soluble and accessible forms than in raw non-pyrolyzed materials (Sikder and Joardar 2019). Biochar can, therefore, be applied alone or in combination with other fertilizers or manure. A report has shown that combination of biochar and poultry manure, and biochar and NPK fertilizer or biochar alone improved soil physical (reduced bulk density, and increased porosity and moisture content) and chemical (pH, N, P, K, Ca, and Mg) properties, growth and yield of ginger grown on the soil (Adekiya et al. 2020).

Fourier Transform Infrared Spectroscopy (FTIR)

The different chemical bonds in the various components of poultry litter, when pyrolyzed, can easily be identified by FTIR through the rotational and vibrational deformation of bonds, which absorb energy at certain resonance frequencies depending on the characteristics of the atoms involved (Merlin et al. 2014), making the FTIR analysis relevant and consistent with the carbonization process.

Table 3 presents some infrared absorption bands for the raw poultry litter as compared to that for the biochar produced. The raw poultry litter showed a broad and intense band around the region between 3595-3000 cm^{-1} which corresponds to the O-H stretching vibrations of H bonded or OH groups and N-H stretching as earlier described by Merlin et al. (2014); Pavia et al. (2009) who had their bands at regions between 3598-3032 cm^{-1} and 3500-3100 cm^{-1} respectively.

A weak peak was however observed at 3548 cm^{-1} for the biochar which is indicative of the presence of I^{o} amine (N-H) due to stretching. The band at 2920 cm^{-1} observed for the raw poultry litter can be ascribed to the asymmetric deformation of methyl and methylene groups which is in agreement with earlier investigations by Merlin et al. (2014); Pavia et al. (2009) with peak values of 2927 cm^{-1} and 2918 cm^{-1} respectively. This band was not observed for the biochar sample, there was rather a peak observed at 3339 cm^{-1} corresponding to the C-H sp^3 triple bond which is indicative of alkyne stretching (Chaves et al. 2020). The peaks at 2344 cm^{-1} and 2012 cm^{-1} for the biochar sample were O=C=O stretch and C-C indicative of a carbonyl group. An observed weak peak at 1796 cm^{-1} is assigned to C=O combined with a C-N stretching with a sharp peak at 1032 cm^{-1} corresponds to an amide O=CNH$_2$ compound. A medium peak at 1401 cm^{-1} corresponds to a C-H bending vibration of the methyl group in the hydrocarbons, and also the peak at 1543 cm^{-1} is indicative of the presence of a nitro (N-O) group. The functional groups observed in this biochar are in agreement with the earlier investigation by Chaves et al. (2020).

The peaks at 1670 cm^{-1} combined with that at 1600 cm^{-1} which corresponded to the asymmetric deformation of carboxylate ions and C=C vibration in lignin carbohydrates (Merlin et al. 2014; Chen et al. 2019) may have shifted to a higher frequency band (1796 cm^{-1}) for the biochar sample.

Table 3 FTIR Analysis of the produced Biochar

S/No	Frequency (cm^{-1}) Poultry Litter	Frequency (cm^{-1}) biochar	Intensity	Functional Group
1	3595-3000	-	broad	N-H and OH stretching in water, carboxyl and hydroxyl group
2	-	3548	Weak (overtone)	Amine (N-H)
3	-	3339	Weak	=C-H
4	2920	-	Weak	C-H asymmetric axial deformation in methyl and methylene
5	-	2344	Medium	O=C=O stretch
6	-	2012	Weak	C-C
7	-	1796	Weak	C=O
8	1670	-	Medium	C=O
9	1600	-	Weak	C=C
10	-	1543	Medium	N-O
11	1410	-	Medium	CH$_2$
12	-	1401	Medium	-C-H bending
13	1040	1032	Sharp	-C-N Stretching or C-O vibration
14	530	-	Very weak	C-H

The peak at 1410 cm^{-1} corresponds to CH_2 units in biopolymers while the peak at 1040 cm^{-1} which seems to have shifted to a lower wave number (1032 cm^{-1}) for the biochar, is assigned to the C-N stretching in amines or C-O vibration in polysaccharides. These wavenumbers are in good agreement with those of other researchers (Daramy et al. 2020; Chen et al. 2019; Smidt and Parravicini 2009; Bernier et al 2013). The very weak peak around 530 cm^{-1} is assigned to the aromatic C-H out-of-plane deformation or O-H angular deformation in kaolinite and gibbsite (Merlin et al. 2014; Daramy et al. 2020). In summary, the functional groups in the raw poultry litter were greatly altered during the carbonization process.

Poultry litter contains fixed carbon, protein, hemicellulose, cellulose, lignin, water, extractives, and minerals (Dalólio et al. 2017). All of these decompose to some extent during pyrolysis to allow identification of functional groups (C-O, C=O, O=CNH_2. C-N, C=C, etc), except the fixed carbon and non-volatile minerals. In pyrolysis, hemicellulose is first decomposed followed by the decomposition of cellulose and then the decomposition of lignin comes last since it is a comparatively stable component thus requiring high temperature and longer residence time (Simbolon et al. 2019).

Scanning Electron Microscope (SEM)

Fig. 1 represents the surface images obtained from the scanning electron microscopy (SEM) of the poultry litter (a) as compared to the biochar (b). The images showed that there are pore non-uniformity amorphous sample surfaces with no clearly defined shape or form. The morphology of the surfaces of the poultry litter and biochar differs according to the type of pyrolysis, pyrolysis temperature, and the type of feedstock.

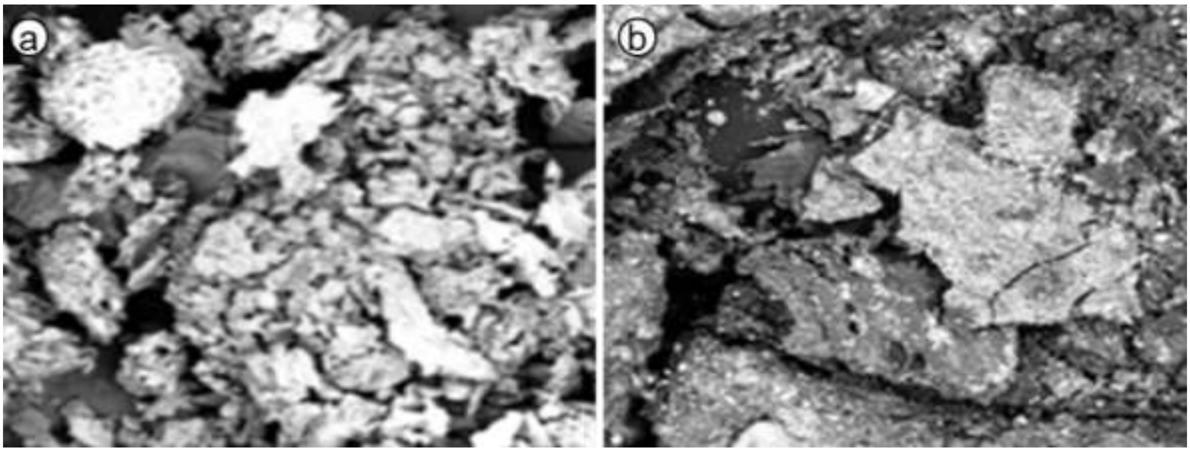

Fig. 1 Micrographs of the biochar before (a) and after (b) carbonization at 500x magnification

Thermogravimetric analysis (TGA and DTG)

A breakdown of the biochar sample with an increase in temperature at the max rate of 20 °C/min up to 1000 °C under a nitrogen atmosphere, was observed through the thermogravimetric analysis (Fig. 2), which showed via the TGA curve that three areas of mass loss occurred.

The first point, at a temperature ranging between 20 °C and 250 °C, can generally be attributed to the loss of water. Between 280 °C and 500 °C, the carbonyl and carboxylated compounds that were remaining during the pyrolysis process will start to burn. After 550 °C, the loss of mass in the thermogram is seen on a continuous and weak scale. As the carbonization process heats up, the carbon, hydrogen, and nitrogen content of the sample continues to reduce. The result of this TGA analysis is consistent with that of Chaves et al. (2020) and Cantrell et al. (2014) who both found three stages of mass loss at temperatures similar to that observed in this work.

When one looks at the DTG curve, one can see how much mass is lost and how quickly the main components in the sample are broken down by heat. As shown in Fig. 3, the first stage showed the loss of water molecules at a temperature of between 0 and 200 °C. In the second stage, maximum devolatilization was seen at a temperature between 220 °C and 400 °C, where most of the moisture is removed, hemicellulose breakdown and cellulose starts to break down. In the third stage, the cellulose and lignin parts of the litter as well as other complex aromatic structures were broken down. Between 250 °C and 600 °C, the poultry litter biochar had a peak that was stronger than the rest of the peaks in the biochar. This is very much like the study that Stella et al. (2016) did.

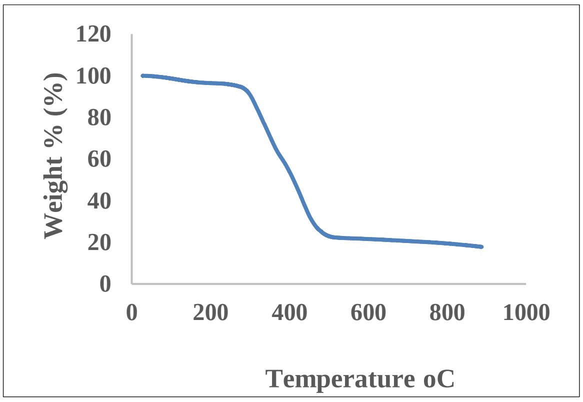

Fig. 2 Thermogravimetric Analysis (TGA) curve of the biochar under a heating rate of 20 °C min^{-1} in an atmosphere of nitrogen

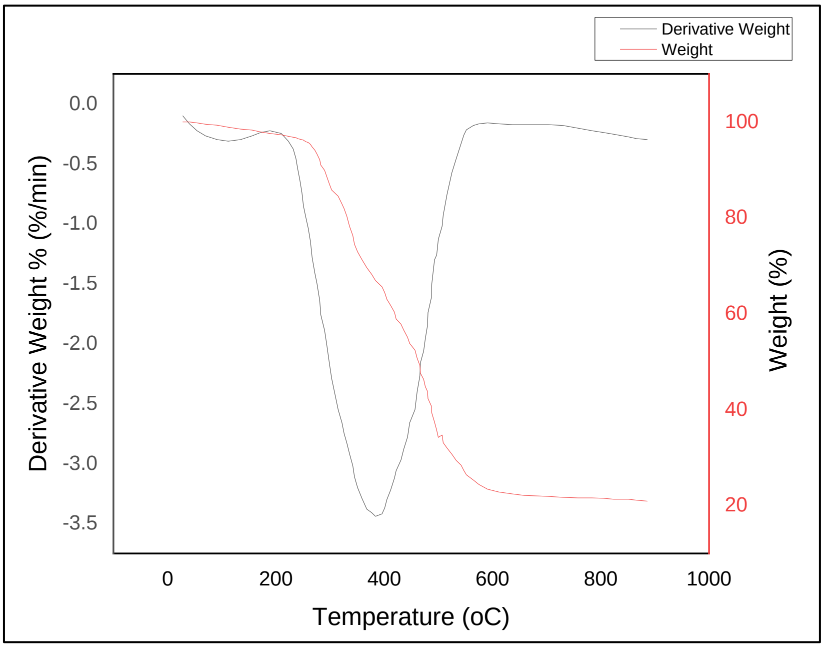

Fig. 3 Derivative Thermogravimetric (DTG) curve of the biochar under a heating rate of 20 °C min^{-1} In an atmosphere of nitrogen

Simbolon et al. (2019) investigated poultry litter conversion into useful fuel energy sources using fast pyrolysis at a temperature range of 400-600 °C. TGA/DTG showed more than three stages of mass loss; the first peak around 100 °C was due to evaporation of water in the sample, the second peak indicated the decomposition of hemicellulose, the third peak showed the decomposition of cellulose. The fourth peak shows the decomposition of lignin from protein contained in the manure. Weak peaks above 600 °C were indicative of the decomposition of fixed carbon and inorganic compounds. The discrepancy here could be a result of the type of pyrolysis used. Fast pyrolysis as reported by Simbolon et al. (2019), occurs at moderate–high temperatures with very short residence time (0.5-10 s) giving liquid fractions (bio-oil) including syngas as the main products. The fast pyrolysis was performed using a pyroprobe reactor, the gas yield was evaluated based on its composition as identified by a micro-GC. The major gases identified were carbon dioxide (CO_2) released during the decomposition of hemicellulose and cellulose, carbon monoxide (CO), and methane (CH_4) released during the decomposition of lignin and cracking of primary tars at high temperatures. Other gases include; hydrogen (H_2), and nitrogen (N_2). The slow pyrolysis like the one used in this research however occurs at lower temperatures and longer residence time (5-30 min) using a muffle furnace with biochar as the main product. These gases being greenhouse gases have diverse effects on the environment. Fifteen per cent (15%) of total anthropogenic greenhouse gas emissions have been reported to come from animal rearing. Greenhouse gas arising from animal litter can be reduced by employing a poultry litter-biochar conversion strategy. The conversion may also release the gases from biochar but at lower levels compared to poultry litter or manure hence reducing their effect on the environment.

The heating rates and the maximum reaction temperatures are the key factors that define both slow and fast pyrolysis. Slow pyrolysis heating rates are typically below -173.15 °C/min whereas fast pyrolysis can achieve rates exceeding 726.85 °C/min. Reaction temperatures of about 300 °C-500 °C correspond to slow pyrolysis while that above 500 °C corresponds to fast pyrolysis (Stella et al. 2016). Consequently, the pyrolysis process performed in this study is slow pyrolysis.

Conclusion

This study reclaimed poultry litter for the production of biochar. The slow pyrolysis process was engaged in this study, which converted poultry litter to biochar with high pH and electrical conductivity. The biochar produced contained a high concentration of mineral elements such as Ca, K, Mg, Na, and P. The FTIR spectrum of the product revealed some functional groups characteristic of biochar. The thermal decompositional analysis of the produced biochar showed three areas of mass loss associated with loss of water molecules, maximum devolatilization where most of the moisture is removed and cellulose starts to break down, and complete breakdown of cellulose and lignin. The high calcium content is a result of the composition of the biomass used. The addition of this biochar to the soil would impose a liming effect on soil that is too acidic and also prevent or eliminate mineral deficiencies of fruits and vegetables planted on such soils. This implies that the poultry litter biochar produced via the pyrolysis process can serve as a soil conditioner, and can be used to neutralize acidic soils. The study showed a considerable level of nutrients such as potassium and phosphorus, and a high exchange capacity, increasing the availability of the nutrients when applied to the soil. The analysis also indicated the presence of functional groups like the carboxylic and hydroxylic groups with negative surface electrical charge thus, can act as cation adsorbent. The negative impacts of poultry litter originating from animal farms can significantly be reduced using the poultry litter-biochar conversion technology as well as improving the bioavailability of nutrients in the soil.

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Compliance with ethical standards

Conflict of interest : The authors declare that there are no conflicts of interest associated with this study.

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