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Characterization of closed-house chicken litter by size for conversion to biochar through 250 °C pyrolysis

H Herviyanti¹ M Monikasari² A Maulana³ and I Darfis¹

¹ Department of Soil Science and Land Resources, Agriculture Faculty, Andalas University, Padang City, Indonesia

² Master Program of Soil Science, Agriculture Faculty, Andalas University, Padang City, Indonesia

³ Post-doctoral Program of Agriculture Faculty, Andalas University, Padang City, Indonesia

E-mail: herviyanti@agr.unand.ac.id

Abstract. The closed-house chicken farming industry generates substantial waste in the form of a mixture of sawdust and chicken manure in chicken coops. The chicken farming sector in West Sumatra generates 5 tons of litter per harvest (40 days) with a livestock capacity of 100,000 chickens. The usage of closed-house chicken litter is required in order to transform waste into fertilizer whose raw materials are renewable, easily available, and eco-friendly, implying that it has the potential as an ameliorant. This research is to assess this potential based on the characteristics of <2 mm chicken litter (CCW) and biochar from >2 mm closed-house chicken litter at 250 °C pyrolysis for 1 hour (BCW). The size separation of chicken litter makes its characteristics different in chemical and proximate properties. CCW and BCW had pH 7.6 and 9.45; organic carbon (Organic-C) 6.58% and 6.68%; CEC (cation exchange capacity) 50 Cmol Kg⁻¹ and 105 Cmol Kg⁻¹; N-total 7.8% and 5.6%; volatile matter 74.7% and 66.9%; moisture 17.3% and 12.2%; ash 32.1% and 25.1%; and fixed carbon 0.31% and 0.34%; and contain different macro and micro nutrients. In addition to fertilizer, CCW and BCW can also be used as biosorbents due to the presence of functional groups (O-H or N-H groups and C=O groups) through Fourier Transform Infrared Spectroscopy (FTIR) analysis. BCW has characteristics that are considered to have more potential to improve soil characteristics and increase the adsorption of contaminants in the soil so that they are not available for uptake by plant roots.

Keyword: *Ameliorant, Biosorbent, Biochar, Fertilizer, Temperature.*

1. Introduction

In closed-house poultry production systems, waste materials comprising chicken manure and sawdust bedding can be converted into biochar for use as an ameliorant and adsorbent, with an estimated yield of 3–5 tons per production cycle (± 32 days) from houses containing 80,000–100,000 broiler chickens [1]. [2] explain that the nutrient composition of chicken litter in closed housing systems contains macro nutrients (C 6.88%; N 0.06%; P 5.89%; K 34.89%; Ca 36.28%; S



5.76%) and micronutrients (Fe 2.49%; Mn 1.39%; Mn 1.22%; Cu 1.01%; and Cl 5.15%). The closed house system utilizes cage mats that maintain moisture in the cage, such as the addition of sawdust, which is often replaced every harvest, resulting in waste that can pollute the environment.

Chicken litter biochar is produced from chicken dung and bedding materials utilized in poultry farms, such as wood shavings, sawdust, straw, or other organic substances, in addition to feathers, feed spills, and deceased birds [3]. The bedding utilized may adversely affect both the health and welfare of chickens and overall food safety, as pollutants can be transmitted to humans consuming chicken meat [4]. One approach to reduce the potential spread of infections originating from these raw materials is to convert poultry litter into biochar through thermal treatment at a controlled temperature. Biochar is produced via pyrolysis, a process involving thermal decomposition under limited oxygen conditions.

Pyrolyzed chicken litter from decommissioned buildings, when handled at optimal temperatures, exhibits enhanced capacity for pollutant adsorption. Several studies indicate that biochar can significantly diminish the transfer of organic and inorganic contaminants in soil environments [5]. The application of biochar to soils adjacent to lakes or other water bodies can significantly reduce groundwater contamination by decreasing the concentration of pesticides that leach into groundwater [6]. Especially if the waste is disposed of without first converting it. Low-temperature pyrolysis (e.g., 250 °C) has gained attention due to its lower energy requirements and potential to retain more labile organic compounds, which may enhance biochar's efficacy as a soil amendment. This method is an alternative approach to turning waste biomass into products with additional value, such as biochar, syngas, and bio-oil. During the process, lignocellulosic components such as cellulose, hemicellulose, and lignin undergo reaction phases such as depolymerization, fragmentation, and cross-linking at specific temperatures to generate a variety of product states, including solid, liquid, and gas [7].

The direct application of chicken litter to soil is deemed wasteful and harmful to soil fertility, due to concerns that disease-carrying microorganisms in the litter may impede plant growth. Biochar has attracted significant interest in recent years due to its porous structure and availability of functional groups, including carboxyl, phenolic, and hydroxyl groups ([8];[9]). Several studies have shown that biochar has the potential to degrade organic and inorganic pollutants in soil environments effectively [5];[10].

[11] used a furnace method at a temperature of 200 °C for one hour for the pyrolysis of chicken litter with the following characteristics: pH H₂O 6.62; pH KCl 5.51; Organic matter (OM) 25.44%. However, there is very little knowledge on the effect of particle size on the properties of biochar generated from closed-house chicken litter via low-temperature pyrolysis. Characterizing this waste based on particle size before conversion is crucial for optimizing pyrolysis outcomes and understanding the quality of the resulting biochar. Litter that is differentiated based on the level of fineness will have different characteristics because there will be a separation between chicken manure and sawdust.

The high lignin content in sawdust is expected to be effective as a biochar that is more porous to the soil. Due to its high content of cellulose (45–50%), lignin (23–30%), and hemicellulose (20–30%), sawdust can be utilized as a common natural adsorbent and a cost-efficient material in remediation techniques for contaminant removal from soil and aquatic environments [12]. Therefore, the main objective of this study is to examine the potential of chicken litter that has been separated and converted into biochar to be used as a soil conditioner and adsorbent. This study serves as the basis for determining the potential of chicken litter as an adsorbent based on

its physical, chemical, and biological characteristics, as well as determining its role in improving soil fertility when applied.

2. Methods

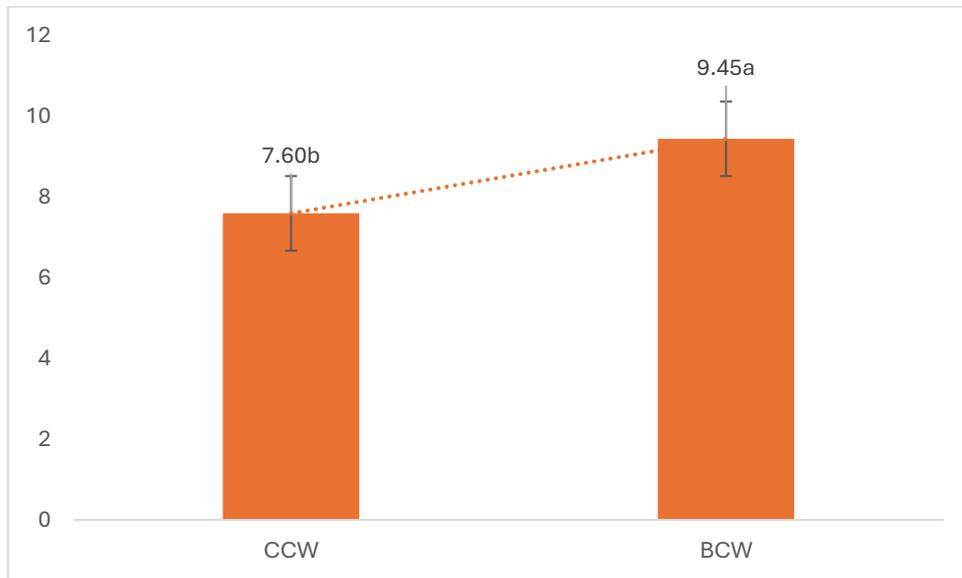
The biochar production process is carried out using the pyrolysis method by heating chicken litter in a heating oven at a temperature of 250°C with limited oxygen. Chicken litter from a closed-house system was collected from an industrial poultry farm in Payakumbuh, West Sumatra. In this study, biochar production involved separating the chicken litter using a 2 mm sieve. The wood powder fraction separated from the chicken litter was then subjected to pyrolysis in an oven at 250 °C for approximately 60 minutes. The created charcoal is moistened slightly to prevent it from converting to ash upon exposure to air, so it transforms into biochar. The char materials were ground using a mortar and pestle and subsequently passed through a 0.5 mm sieve [13].

Chicken litter that passes through a 2 mm sieve is designated as CCW, whereas the material that does not pass the filter and is converted into biochar is referred to as BCW. The characterization of the material was carried out using a completely randomized design with 2 treatments (CCW and BCW) and 3 replicates. CCW and BCW were characterized in terms of surface charge properties (pH, cation exchange capacity, and organic carbon content), proximate composition, and total nitrogen content [14]. The observational data were subjected to statistical analysis utilizing the F test at a 5% significance level. Subsequent evaluations were performed utilizing Duncan's New Multiple Range Test (DMNRT) at a 5% significance level.

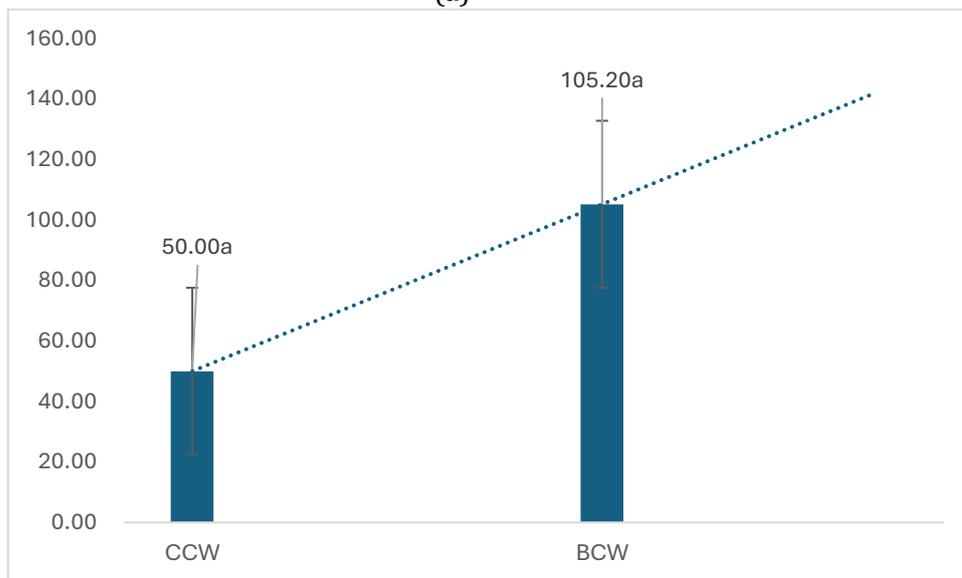
3. Results and Discussion

3.1 Surface Charge of CCW and BCW

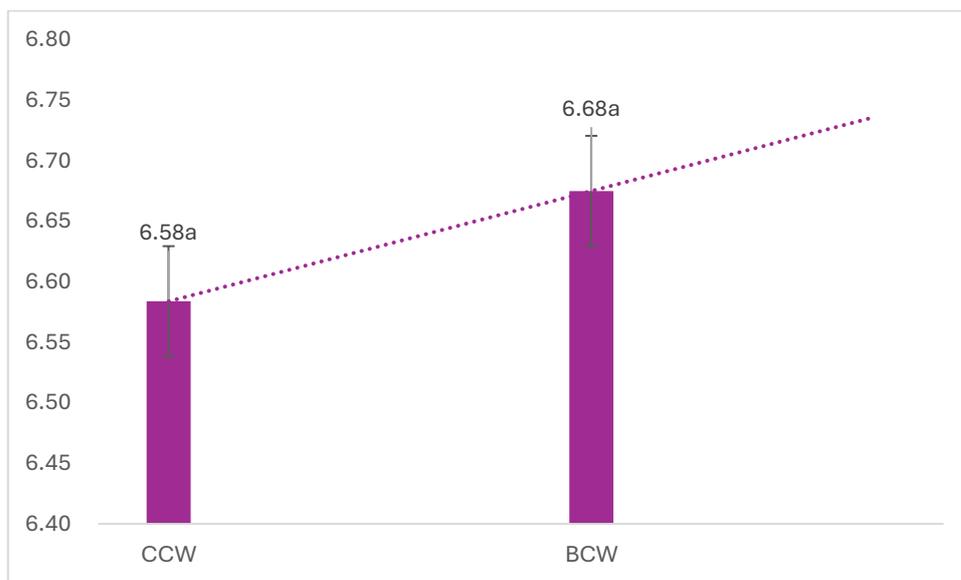
The characteristics of biochar are highly dependent on the feedstock source, particularly its chemical composition, while nutrient levels may differ significantly due to variations in feed, bedding materials, and management conditions [15]. Furthermore, the pyrolysis process at specific temperatures alters the chemical properties of the biochar, including pH, Organic-C, CEC, and total nitrogen levels, which differ significantly from those of the original unprocessed material (Figure 1).



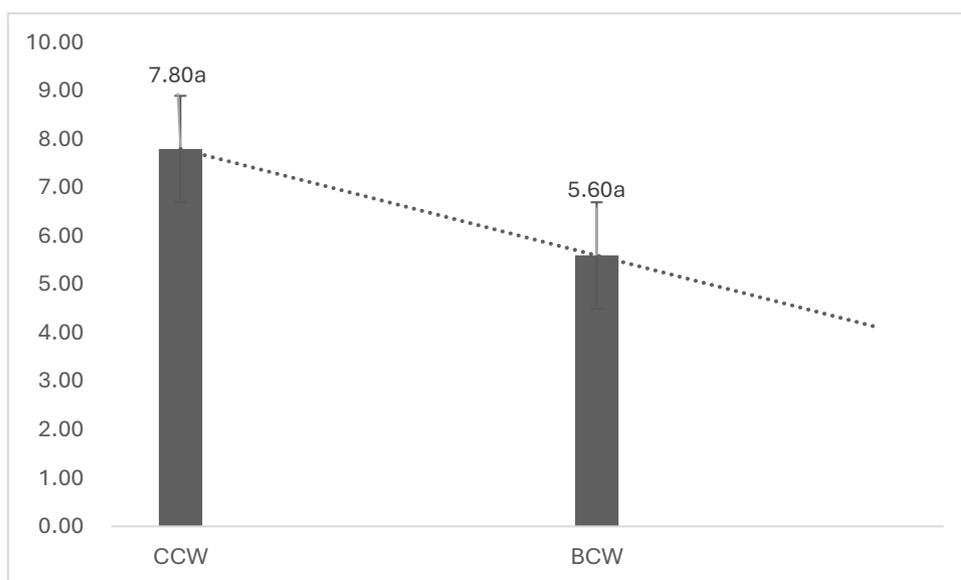
(a)



(b)



(c)



(d)

Figure 1. Physicochemical characteristics of chicken litter that passed through a 2 mm sieve (CCW) and chicken litter-derived biochar (BCW), including (a) pH, (b) cation exchange capacity (CEC), (c) organic matter content, and (d) total nitrogen (N-total).

According to the study [11], Pyrolysis conducted in a furnace at 200 °C produced biochar with pH values ranging from 5 to 7, whereas oven-based pyrolysis at 250 °C resulted in higher pH levels, reaching up to 9. This difference in pH values is attributed to the variation in pyrolysis temperature and method, which influence the decomposition of organic matter and the formation of alkaline compounds during the pyrolysis process. The pH, CEC, and Organic-C of biochar derived from closed-house chicken litter (BCW) are higher than those of the unprocessed material (CCW). Therefore, BCW holds significant potential as a soil amendment to improve soil chemical properties. These enhancements are primarily attributed to the pyrolysis process, which improves the material's ability to adsorb and exchange cations.

The increased organic carbon content in BCW contributes to a greater number of negative charges (anions), enhancing its capacity to retain cations in the soil. The functional groups in chicken litter biochar increase the negative charge, particularly when added to soil, boosting its adsorption capacity. Slightly carbonized biochar produced at pyrolysis temperatures below 500 °C exhibits low porosity and C/N ratios, relatively high concentrations of dissolved organic carbon and oxygen-containing functional groups, and a strong potential for removing residual contaminants [16]. These functional groups are actively involved in the sorption of metal ions. The dissociation of hydroxyl groups within the carboxyl structure contributes to the development of negative charges, which directly influence the material's ability to retain contaminants. This negative charge facilitates electrostatic interactions with positively charged contaminants, thereby promoting efficient adsorption processes [2]

In contrast, N-total content in the unpyrolyzed material (CCW) is higher than that in the resulting biochar (BCW). This is due to nitrogen losses during the pyrolysis process, which occurs through volatilization or thermal decomposition of nitrogen-containing compounds, leading to a lower N-total content in the biochar compared to the original material [17]. Numerous studies have reported that the total nitrogen (N-total) content in biochar decreases with increasing pyrolysis temperature. This decline is primarily attributed to the volatilization and thermal decomposition of nitrogen-containing compounds during the pyrolysis process. Regardless of the feedstock type, higher pyrolysis temperatures tend to result in greater nitrogen losses, leading to lower nitrogen retention in the final biochar. The production of biochar is determined by both feedstock characteristics and pyrolysis parameters, including temperature, heating rate, and reactor configuration [18].

3.2 Proximate analysis

The characteristics of biochar depend on how it is produced and the raw material that is used [19]. Various residual and waste products can be converted into biochar, including forestry, crop waste, food industry residual biomass, and animal manure. Temperature, residence time, rate of temperature increase, pre- and post-processing of feedstock and biochar, are the specific production parameters that affect the quality of the biochar, and can impact the nutrient availability to crops, the physical and chemical properties of the biochar, and the amount of stable carbon sequestered. Recent studies on biomass pyrolysis suggest that biochar production is affected by various factors, particularly biomass type, moisture content, particle size, and reaction conditions such as temperature, residence time, and heating rate [20]. The results can be seen in the results of its proximate analysis according to Table 1.

Table 1. Proximate analysis on BCW and CCW

Treatment	Moisture (%)	Volatile Matter (%)	Ash (%)	Fixed Carbon (%)
CCW	17.3a	74.7a	32.1a	0.31a
BCW	12.2b	66.9a	25.1a	0.34a
*Critical Value for comparison	4.3353	9.1475	28.632	0.2119
*Standard error for comparison	1.5599	3.2914	10.302	0.0762

Remarks: *Statistical analysis components

The characterization of raw chicken litter (CCW) and its resulting biochar (BCW) revealed significant changes in proximate analysis due to pyrolysis. The moisture content of CCW has a ratio of 0.051% compared to BCW, indicating effective water removal during the thermal process. In addition, the volatile matter content of CCW is 0.078% higher than that of BCW, reflecting the

loss of unstable organic compounds and thermally unstable components. Interestingly, the ash content of CCW is 0.070% higher than that of BCW, which may be due to the volatilization of certain mineral elements or the redistribution of inorganic components. On the other hand, the fixed carbon content of CCW is 0.03% higher than that of BCW, indicating the formation and retention of a more stable carbon structure in the biochar.

The fixed carbon content of biomass is directly related to its lignin content, and it increases substantially after pyrolysis, becoming the dominant component of the resulting biochar [21]. These changes confirm that pyrolysis not only reduces water content and volatile fractions but also enhances carbon stability, thereby increasing the potential of biochar produced from chicken manure for use as a soil amendment and long-term carbon storage.

4. Conclusions

The results of this study demonstrate that pyrolysis significantly improves the physicochemical properties of closed-house chicken litter. Biochar derived from chicken litter (BCW) exhibited higher pH, cation exchange capacity (CEC), and fixed carbon content compared to the raw chicken coop waste (CCW), while showing reduced moisture, volatile matter, and ash contents. Although a decrease in total nitrogen was observed after pyrolysis, BCW retained a considerable amount of organic matter and essential macro- and micronutrients. The separation of litter size further contributed to variations in chemical and proximate characteristics. Overall, the enhanced properties of BCW highlight its potential as a more stable and effective soil amendment compared to untreated chicken litter. In the long term, the structural stability, high CEC, and surface characteristics of BCW also suggest promising potential as an adsorbent for environmental contaminants, supporting both soil remediation and sustainable land management practices.

5. ACKNOWLEDGMENT

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