Ilorin Journal of Science
FAPSCON 2024 PROCEEDINGS, 2024, pp.167– 171 (Printed in Nigeria)
ISSN: 2408 – 4840 © 2024 Faculty of Physical Sciences, University of Ilorin
https://doi.org/10.54908/iljs.fapscon.2024.11.03.1022

ILORIN
JOURNAL OF SCEINCE

ILJS-24-072 (SPECIAL EDITION)

TEMPERATURE AND ITS INFLUENCE ON THE CHARACTERISTICS OF BIOCHAR PRODUCED FROM PLANTAIN TRUNKS AGRO-WASTES

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Abstract

The effects of different pyrolytic temperatures on char produced from plantain trunks were characterized for its pH, Nitrogen (N), Phosphorus (P), Ash, and Volatile matter contents. Thermogravimetric analysis (TGA) indicated that the pyrolysis can be done between a temperature of 48.55 to 553ºC for 30 mins at a nitrogen flow rate of 10ºC/mins. The initial and the final decomposition temperature (IDT and FDT) for the characterization were 250ºC and 550ºC). Results showed that pyrolysis of plantain trunk significantly ($p<0.05$) increases its pH from 8.37±0.01 (raw state) to 10.75±0.03 % and 10.96±0.03, P content decreases from 2.70±0.06 % (raw state) to 2.19±0.02 and 1.91±0.01% while N content decrease from 1.08±0.02 (raw state) to 0.93±0.03 % and 0.75±0.03 %. Ash content increases from 23.36±0.03 (raw state) to 70.96±0.03% and 36.46±0.29 %, while the volatile matter decreases from 76.74±0.14 (raw state) to 29.01±0.01 % and 63.54±0.29 %, at 250ºC to 550ºC respectively.

Keywords: Pyrolysis, Agro-wastes, and Biochar

1. Introduction

Biochar produced through pyrolysis at high temperatures, particularly around 700°C, exhibits highly recalcitrant properties, making it a valuable tool for carbon sequestration and long-term storage of carbon in soils (Keiluweit *et al*., 2010; Qambrani *et al*., 2017). Advanced analytical techniques, such as synchrotron-based near-edge X-ray absorption fine structure (NEXAFS), have demonstrated that biochars formed at elevated temperatures are typically poorly crystalline, likely due to the volatilization of metals and a reduction in the mineral content within the carbon matrix (Zhao *et al*., 2018; Bridgwater and Boocock, 2006). These high-temperature biochars, while stable, tend to exhibit lower reactivity in soils when compared to biochars produced at lower temperatures, which are more effective at enhancing soil fertility and promoting plant growth (Steinbeiss *et al*., 2009; Leng *et al*., 2019).

At moderate pyrolysis temperatures, biochars are capable of concentrating essential plant nutrients such as phosphorus (P), potassium (K), calcium (Ca), and magnesium (Mg), which makes them particularly beneficial as soil amendments (Gaskin *et al*., 2008; Kammann *et al*., 2015). This nutrient retention property can contribute significantly to improving soil health, especially in agricultural applications.

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Agricultural waste materials, including plantain trunks, are a promising source of biomass for biochar production. Their utilization offers substantial environmental advantages, such as reducing waste and contributing to sustainable energy production (Garcia-Delgado *et al*., 2015; Joseph *et al*., 2021). Biochar is generated through pyrolysis, a process that thermally decomposes biomass under oxygen-limited conditions at temperatures ranging from 250°C to 700°C. The pyrolysis process captures volatile gases, oils, and other emissions, which can be repurposed as renewable energy sources, including syngas, while leaving behind carbon-rich biochar (Lehmann *et al*., 2011; McHenry, 2022).

Studies, such as those by Baldock and Smernik (2002), indicate that the pyrolysis temperature has a significant impact on biochar's chemical composition. When organic materials are exposed to temperatures above 200°C, structural changes occur, transforming O-alkyl carbon into more stable aromatic forms, which increase biochar's durability (Tan *et al*., 2021). Biochar produced at lower temperatures tends to support gradual nutrient release, while high-temperature biochar functions more like activated carbon, with enhanced sorption capabilities (Sohi *et al*., 2010; Wang *et al*., 2020).

Plantain (Musa paradisiaca) is an important tropical crop, cultivated extensively across approximately 8.8 million hectares. Beyond its agricultural value, plantain trunks have potential industrial uses, particularly in biochar production. Biochar derived from plantain trunks can serve as a natural sorbent, offering utility in bioremediation, recycling applications, and water purification (Kumar *et al*., 2012; Nartey & Zhao, 2014). This paper reviews recent developments on the impact of pyrolysis temperature on biochar produced from plantain trunk biomass, exploring its physicochemical characteristics and potential environmental applications.

2. Materials and Methods

Plantain trunks and soil samples were collected from multiple locations across Nigeria and transported to the Biotechnology Advanced Laboratory in Abuja for detailed analysis. The plantain trunks were thoroughly cleaned to remove sand, dirt, and adhering plant material. Afterward, the cleaned trunks were sun-dried to reduce moisture content. Once adequately dried, the trunks were cut into smaller pieces and further dried in an oven at 100°C for five hours.

The dried plantain trunks were then ground into a fine powder for pyrolysis. Using a thermogravimetric analyzer (TGA Q500), 11.352 mg of ground plantain trunks were accurately measured and prepared for pyrolysis, ensuring a consistent weight of 14.00 ± 0.5 mg. The pyrolysis process was carried out in a muffle furnace under an inert nitrogen (N2) atmosphere. Pyrolysis temperatures of 250°C and 550°C were applied at heating rates of 25°C/min, with the samples held for 20 minutes and 10 minutes, respectively (Novak *et al*., 2007).

After cooling the furnace, the resulting biochars were carefully removed, sieved to achieve uniform particle sizes, labeled, and stored in sealed containers to prevent oxidation. This step is critical, as exposure to air could lead to oxidation of the biochar, altering its surface-active functional groups and potentially impacting its properties (Figueredo *et al*., 2017).

3. Results and Discussion

3.1 Properties of plantain trunk biochar at different pyrolysis temperatures

The effect of pyrolysis temperature on the characteristics of biochars produced from the biomass plantain trunk is presented in Table 1. Pyrolysis of plantain trunk significantly ($p<0.05$) increases its pH from

8.37±0.01 (raw state) to 10.75±0.03 % and 10.96±0.03, ash content from 23.36±0.03 (raw state) to 70.96±0.03% and 36.46±0.29 %, and MBAC from 30.36±0.03% (raw state) to 75.81±0.16% and 71.54±0.29 % at 250 to 550^{o}C respectively. The volatile matter decreases from 76.74±0.14 (raw state) to 29.01±0.01 % and 63.54±0.29 %, phosphorus content decreases from 2.70±0.06 % (raw state) to 2.19±0.02 and 1.91±0.01% while nitrogen content decrease from 1.08±0.02 (raw state) to 0.93±0.03 % and 0.75±0.03 % at 250 to 550^{o}C respectively (Table 1). Similarly, an increase in pyrolysis temperature from 250 to 550^{o}C caused significant ($p<0.05$) decreases in the phosphorus and nitrogen content of plantain trunk biochar. However, the effect of pyrolysis on volatile matter and ash content of biochar were not dependent on the degree of temperature. An increase in pyrolysis temperature from 250^{o}C to 550^{o}C had no significant ($p>0.05$) effect on pH and MBAC (Table1)

Table 1: Effect of Pyrolysis Temperature on Characteristics of Plantain Trunk Biochars

	Raw State	250^{o}C	550^{o}C
Ph	8.37±0.01 ^{a}	10.75±0.03^{b}	10.96±0.03 ^{b}
Volatile matter (%)	76.74±0.14 ^{c}	29.01±0.01 ^{a}	63.54±0.29 ^{b}
Ash content (%)	23.36±0.03 ^{a}	70.96±0.03 ^{c}	36.46±0.29 ^{b}
Phosphorus (%)	2.70±0.06 ^{c}	2.19±0.02 ^{b}	1.91±0.01 ^{a}
Nitrogen (%)	1.08±0.02 ^{c}	0.93±0.03 ^{b}	0.75±0.03 ^{a}
MBAC	30.36±0.03 ^{a}	75.81±0.16 ^{b}	71.54±0.29 ^{b}

Values are Mean ± Standard Error of Mean of five replicate determinations. Values with different alphabets along a row are significantly different ($p<0.05$).

3.2 MBAC=Methylene Blue Absorption Capacity

Consequently, biochar that is produced with the key role of being a soil fertility amendment needs to be specifically aimed at carbonizing the biomass material under moist conditions and at low temperatures (Novak *et al*., 2007). Investigations conducted on the effect of different pyrolytic temperatures on pine chars showed that there was a reduction in the organic content with increasing pyrolytic temperature in the range of 30 to 700 °C. These studies also showed that the weight loss of chars declined from 37 % to 24 % when the biomass was pyrolyzed at 500 °C during different time intervals comprising 10 to 300 minutes. Therefore, it was suggested that pyrolytic temperatures play a more important role than pyrolytic time in carbonizing pine wood (Zhou *et al*., 2009). Other studies revealed that the pyrolysis temperature affects the yield of biofuel and biochar. An increase in temperature resulted in a reduction in the recovery of biochar, while the concentration of carbon increased (Daud *et al*., 2001; Demirbas, 2004).

Cao and Harris (2010) investigated the effect that different heating temperatures have on the physical, chemical, and mineralogical properties of dairy-manure-derived biochar. The untreated air-dried biochar was dried at a room temperature of 25 °C and 500°C respectively and used for comparative purposes. It was found that the following properties increased as a result of increased temperature during pyrolysis; specific surface area (SSA), ash (%) content, pH, and concentrations of P, Ca, and Mg. The SSA increased exponentially between 200 and 500 °C. The increase in ash content was due to the high presence of calcite and quartz minerals in the manure. At a temperature of 500 °C, the biochar produced more than 95 % ash, thus indicating the complete combustion of C. The pH increase was dependent on the heating temperature.

Initially, the untreated manure at room temperature was alkaline at pH 7.5-8.0. At 200 °C, the pH declined to neutrality at about pH 7 (Cao and Harris 2010). At temperatures of 300 °C and above, the C began to ash and subsequently increased the biochar pH to above 10.0, where it became constant (Cao and Harris 2010). In addition, the mean total P, Ca, and Mg concentrations increased from 0.91 %, 3.23 %, and 1.11 %, respectively at 100 °C to 2.66 %, 9.75 %, and 3.02 % at 500 °C. The total P, Ca, and Mg increases were attributed to increasing temperature.

4. Conclusion

The quality of biochar is influenced by its characterization, which plays a crucial role in determining its suitability for use in remediation. Generally, lower temperatures favor the production of higher-quality biochar (Anastasakis & Ross, 2011). Analysis of biochar samples reveals a consistent trend where volatile matter decreases with increasing temperature, while the ash content increases. The decrease in volatile matter content of plantain trunk biochar with increasing temperature indicates that at high temperatures, more volatiles are released. This finding aligns with a previous study that reported considerable mass loss in the form of volatiles during the thermal degradation of cellulose between 250ºC and 350ºC, leaving behind a rigid amorphous carbon matrix (Baldock and Smernik, 2002).

The increase in ash content with temperature could be attributed to the concentration of biomass mineral matter in the biochar after thermal treatment. As the temperature increases, the loss of organic matter from the residue intensifies, leading to a higher concentration of mineral matter and an increase in ash content. Overall, these findings suggest that as the pyrolysis temperature rises, the proportion of aromatic carbon in the biochar also increases due to the relative increase in the loss of volatile matter and the conversion of alkyl and O-alkyl carbon to aryl carbon (Baldock and Smernik, 2002; Demirbas, 2004).

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