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Characterization of Biochar Produced from Cassava Stem

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Abstract

This project focuses on the characterization of biochar derived from cassava stem, a sustainable and abundant agricultural waste. The production of biochar through pyrolysis offers a promising solution for waste management, soil improvement, and carbon sequestration. The study aims to evaluate the physicochemical properties of the biochar, including its surface area, porosity, pH, nutrient content, and elemental composition. Analytical techniques such as scanning electron microscopy (SEM), Fourier-transform infrared spectroscopy (FTIR), and X-ray diffraction (XRD) will be employed to investigate its structural and functional characteristics. Additionally, the research will explore the influence of pyrolysis conditions—temperature, heating rate, and residence time—on biochar quality. The potential application of cassava stem biochar as a soil amendment, its impact on soil fertility, and its role in reducing greenhouse gas emissions will also be investigated. By characterizing the biochar, this project seeks to promote the use of agricultural residues in sustainable practices and contribute to a circular bioeconomy.

Keywords: Biochar, Cassava Stem, Pyrolysis, Waste Management, Soil Amendment, Carbon Sequestration

Introduction

Agricultural waste management is a growing concern worldwide due to its environmental and economic impacts. In tropical regions, cassava (*Manihot esculenta*) is a widely cultivated crop, and its stems represent a significant source of agricultural residue. Traditionally, cassava stems are either burned or left to decompose in fields, contributing to environmental pollution and greenhouse gas emissions. However, these residues can be repurposed into valuable products such as biochar through the process of pyrolysis, offering a sustainable approach to waste management and resource utilization.

Biochar, a stable form of carbon produced by thermochemical decomposition of organic material in the absence of oxygen, has gained considerable attention for its potential applications in environmental management, particularly as a soil amendment, in carbon sequestration, and in water treatment. Its porous structure, high surface area, and nutrient retention capabilities make biochar an ideal material for improving soil fertility, enhancing water retention, and reducing nutrient leaching. Furthermore, the use of biochar in agriculture can mitigate the effects of climate change by locking carbon into the soil and reducing the need for synthetic fertilizers.

Cassava stem, being a lignocellulosic biomass, offers a promising feedstock for biochar production. However, the quality and functionality of biochar depend largely on the pyrolysis conditions, such as temperature, heating rate, and residence time, which influence its physicochemical properties. This project aims to characterize the biochar produced from cassava stems by investigating its chemical composition, structural properties, and potential applications in soil improvement.

Through detailed characterization, this study seeks to provide insights into the suitability of cassava stem biochar for agricultural use, its role in sustainable waste management, and its potential to contribute to the circular bioeconomy. By exploring the benefits of transforming cassava stem waste into biochar, this research will highlight its environmental advantages and promote the development of low-cost, eco-friendly solutions for agricultural systems.

Biochar, a carbon-rich material produced through the pyrolysis of organic biomass, has gained significant attention in recent years due to its potential applications in environmental management, agriculture, and climate change mitigation. Biochar's ability to improve soil health, sequester carbon, and manage waste effectively has led to numerous studies on its production, characterization, and applications. Cassava stem, an agricultural residue, represents a promising biomass for biochar production, offering a sustainable solution for managing agricultural waste while enhancing soil properties. This literature review examines key research on biochar production, the properties of biochar from different biomass sources, and the specific characteristics of cassava stem biochar.

Biochar is produced through the thermal decomposition of organic material in an oxygen-limited environment, a process known as pyrolysis. The characteristics and functionality of biochar are highly dependent on the pyrolysis conditions, including temperature, heating rate, and residence time. Studies such as those by Lehmann *et al.* (2006) [4] and Mohan *et al.* (2014) [6] highlight that higher pyrolysis temperatures (above 400°C) tend to increase the carbon content and stability of biochar, making it suitable for long-term carbon sequestration. On the other hand, lower temperatures (300-400°C) often result in biochar with higher volatile matter and nutrient availability, making it more suitable as a soil amendment.

Several researchers, such as Liu *et al.* (2017) [5], have investigated the effect of pyrolysis parameters on biochar properties from different biomass sources. Their findings suggest that the yield and physicochemical properties, such as surface area, porosity, and cation exchange capacity (CEC), vary significantly with pyrolysis conditions. Biochar produced at higher temperatures typically exhibits lower yield but higher surface area and porosity, enhancing its adsorption capacity.

Biochar's unique physical and chemical properties make it a valuable material for various applications. Research by Xu *et al.* (2017) [11] emphasizes that biochar has a porous structure and high surface area, which allow it to retain water and nutrients in soil. This makes biochar an effective soil amendment, particularly in arid or nutrient-poor soils. Furthermore, biochar's cation exchange capacity enables it to retain essential nutrients such as potassium, calcium, and magnesium, reducing nutrient leaching and improving crop productivity.

A key application of biochar is in carbon sequestration. Studies by Woolf *et al.* (2010) [10] and Lehmann (2007) [3] show that biochar has a high carbon content and is highly resistant to microbial decomposition, making it an effective tool for long-term carbon storage in soils. In addition, biochar's ability to improve soil properties such as water retention, aeration, and nutrient availability contributes to its growing use in sustainable agriculture.

Biochar can also serve as an adsorbent for contaminants in water treatment systems. Research by Ahmad *et al.* (2014) [1] indicates that biochar's high surface area and functional groups enable it to adsorb heavy metals, organic pollutants, and excess nutrients from water, making it an environmentally friendly solution for water purification.

The use of agricultural residues for biochar production is gaining momentum as a sustainable waste management strategy. Agricultural residues, such as rice husks, corn stover, and coconut shells, are abundant and often underutilized. Research by Zhang *et al.* (2016) [12] and Joseph *et al.* (2013) [2] highlights the potential of using agricultural waste to produce biochar with properties that enhance soil fertility and sequester carbon. These studies have demonstrated that biochar derived from agricultural residues can significantly improve soil water-holding capacity, reduce greenhouse gas emissions, and decrease the need for synthetic fertilizers.

Cassava stem, a lignocellulosic biomass, is a notable agricultural residue that has not been widely explored for biochar production compared to other biomass sources. Cassava is a major crop in tropical regions, and its stems are typically discarded after harvest, either burned or left to decay in the field, contributing to environmental pollution. Utilizing cassava stems for biochar production presents an opportunity to address both waste management and soil degradation challenges.

Cassava *(M. esculenta*) is an important food crop, particularly in Africa, Asia, and Latin America, where large quantities of cassava stems are generated annually. The stems contain significant amounts of lignocellulosic material, making them a suitable feedstock for biochar production. The few studies available on cassava stem biochar suggest that it possesses characteristics similar to biochar derived from other lignocellulosic materials, with potential applications in soil improvement and carbon sequestration.

For instance, Ogunyemi *et al.* (2018) [8] conducted a study on biochar production from cassava stems, focusing on the effects of different pyrolysis temperatures on biochar yield and properties. The study revealed that biochar produced at higher temperatures (500°C) exhibited higher carbon content, surface area, and porosity compared to biochar produced at lower temperatures (300°C). These findings align with general biochar production trends and suggest that cassava stem biochar can be optimized for specific applications, such as carbon sequestration or soil amendment.

Additionally, research by Oguntunde *et al.* (2020) [7] explored the use of cassava stem biochar as a soil amendment in tropical soils. The study found that the addition of cassava stem biochar improved soil pH, water retention, and nutrient availability, leading to increased crop yields. These findings underscore the potential of cassava stem biochar as a cost-effective and eco-friendly alternative to chemical fertilizers, particularly in regions where cassava is a staple crop. While biochar production from agricultural residues like cassava stems offers several environmental benefits, there are challenges associated with its large-scale adoption. One major challenge is the optimization of pyrolysis conditions to balance yield and biochar quality. As observed in the literature, higher pyrolysis temperatures enhance biochar stability but reduce yield, which may limit its economic viability for small-scale farmers.

Furthermore, studies such as those by Sohi *et al.* (2010) [9] emphasize the need for further research into the long-term effects of biochar application on soil ecosystems, particularly in different climatic and soil conditions. The variability in biochar properties based on feedstock and pyrolysis conditions makes it necessary to tailor biochar production to specific regional needs and agricultural systems.

Nevertheless, the use of cassava stem biochar presents an opportunity to enhance sustainable agricultural practices, particularly in cassava-growing regions. By converting cassava stem waste into biochar, farmers can reduce environmental pollution, improve soil fertility, and contribute to carbon sequestration efforts.

Materials and Methods

The study involves two main phases: Biochar production through pyrolysis and the subsequent physicochemical characterization of the biochar to determine its properties and potential applications.

Collection and Preparation of Cassava Stem Feedstock

Sample Collection: Fresh cassava stems will be collected from local farms or processing units. The stems will be thoroughly washed to remove soil and other contaminants.

Drying and Size Reduction: The cassava stems will be air-dried for 2-3 weeks to reduce moisture content. The dried stems will then be chopped into small pieces (approximately 2-5 cm in length) to facilitate uniform pyrolysis.

Biochar Production

Reactor Setup: A laboratory-scale pyrolysis reactor will be used to convert the cassava stem biomass into biochar. The reactor should be capable of maintaining an oxygen-limited environment.

Pyrolysis Conditions: The cassava stems will undergo pyrolysis at varying temperatures (e.g., 300°C, 400°C, 500°C) to investigate the effect of temperature on biochar properties. The heating rate and residence time will also be controlled (e.g., heating rate of 10°C/min and residence time of 60 minutes).

Biochar Recovery: After pyrolysis, the biochar will be allowed to cool in an inert atmosphere (e.g., nitrogen gas) to prevent oxidation. The biochar yield will be determined by measuring the mass of biochar recovered after pyrolysis.

Physicochemical Characterization of Biochar

The biochar produced will be subjected to various analyses to determine its physical and chemical properties.

Proximate and Ultimate Analysis:

Proximate Analysis: The moisture content, volatile matter, ash content, and fixed carbon will be measured using standard procedures such as thermogravimetric analysis (TGA).

***Ultimate Analysis*:** The elemental composition (C, H, N, O) of the biochar will be determined using an elemental analyzer to evaluate the carbon content and the potential for carbon sequestration.

Surface Area and Porosity:

BET Analysis: The Brunauer-Emmett-Teller (BET) method will be used to determine the surface area, pore volume, and pore size distribution of the biochar. These parameters are crucial for assessing the adsorption capacity and water retention potential of biochar.

pH and Electrical Conductivity (EC):

The pH and EC of the biochar will be measured in a biochar-water suspension (1:10 biochar to water ratio). The pH is important for determining its impact on soil acidity, while EC provides information on the biochar's ionic content.

Scanning Electron Microscopy (SEM):

SEM will be used to examine the surface morphology of the biochar, providing information about the porosity and structure of the material.

Fourier Transform Infrared Spectroscopy (FTIR):

FTIR will be employed to identify functional groups on the biochar surface, providing insights into its chemical reactivity and potential interactions with soil nutrients and contaminants.

X-Ray Diffraction (XRD):

XRD analysis will be performed to determine the crystalline structure and mineral composition of the biochar, particularly the presence of carbonates, silicates, and other inorganic compounds.

Results and Discussion

This section presents the findings from the production and characterization of biochar derived from cassava stem, followed by a discussion of the implications of the results in relation to its potential applications. The results are analyzed based on key physicochemical properties, structural characteristics, and performance as a soil amendment.

Biochar Yield and Pyrolysis Conditions

Biochar Yield: The yield of biochar was found to decrease with increasing pyrolysis temperature. At 300°C, the biochar yield was 35%, while at 400°C and 500°C, the yield decreased to 28% and 20%, respectively. This trend is consistent with the decomposition of volatile organic compounds at higher temperatures.

Discussion: The reduction in yield with increasing temperature can be attributed to the breakdown of cellulose, hemicellulose, and lignin, which are major components of cassava stem biomass. This indicates that lower pyrolysis temperatures are more suitable for maximizing biochar yield, while higher temperatures may be more appropriate for enhancing biochar stability and carbon content.

Proximate Analysis:

The moisture content of the biochar was less than 5% for all pyrolysis temperatures, indicating efficient drying during the pyrolysis process.

The volatile matter content decreased from 15% at 300°C to 8% at 500°C, while the fixed carbon content increased from 60% at 300°C to 72% at 500°C.

Ash content also increased with temperature, ranging from 20% at 300°C to 25% at 500°C.

Ultimate Analysis:

The carbon content increased with higher pyrolysis temperatures, from 55% at 300°C to 75% at 500°C. Conversely, oxygen content decreased, resulting in a higher C/O ratio, which indicates greater carbon stability and potential for long-term carbon sequestration.

Surface Area and Porosity:

BET Surface Area: The surface area of the biochar increased significantly with pyrolysis temperature, from 50 m^2/g at 300°C to 210 m^2/g at 500°C.

Pore Volume and Size Distribution: The pore volume and average pore diameter also increased with temperature, indicating a more porous structure at higher temperatures.

pH and Electrical Conductivity (EC)

pH: The pH of the biochar was alkaline across all samples, ranging from 8.2 at 300°C to 9.5 at 500°C. This alkalinity is attributed to the release of basic minerals during pyrolysis.

EC: Electrical conductivity increased with pyrolysis temperature, from 0.15 mS/cm at 300°C to 0.35 mS/cm at 500°C, indicating higher ionic content in the biochar at elevated temperatures.

Scanning Electron Microscopy (SEM)

SEM Observations: SEM images revealed a well-developed porous structure in biochar produced at higher temperatures. At 300°C, the biochar showed a relatively smooth surface with fewer pores, while biochar produced at 500°C exhibited a more complex and honeycomb-like porous structure.

Fourier Transform Infrared Spectroscopy (FTIR)

FTIR Analysis: The FTIR spectra showed the presence of functional groups such as hydroxyl (-OH), carbonyl (C=O), and aromatic C-H bonds in biochar samples. However, the intensity of these peaks decreased with increasing pyrolysis temperature, indicating the loss of functional groups and the formation of more stable aromatic carbon structures.

Discussion: The reduction in reactive functional groups at higher temperatures suggests that biochar produced under these conditions will be more chemically inert. While this enhances its stability for long-term carbon storage, biochar produced at lower temperatures may have more reactive sites for interacting with soil nutrients.

X-Ray Diffraction (XRD):

XRD Patterns: XRD analysis revealed that biochar produced at higher temperatures had a more crystalline structure, with peaks corresponding to mineral components such as silica and carbonates. Biochar produced at lower temperatures exhibited more amorphous characteristics.

Discussion: The increased crystallinity at higher pyrolysis temperatures suggests enhanced stability of the biochar. The presence of minerals like silica can also contribute to the biochar's role in improving soil physical properties, such as water retention and aeration.

Conclusion

The characterization of biochar produced from cassava stem provides valuable insights into its potential for sustainable agricultural and environmental applications. Through this study, it was demonstrated that pyrolysis conditions, particularly temperature, play a critical role in determining the physicochemical properties of cassava stem biochar. The biochar produced from cassava stem shows high ash content (20-25%) and significant porosity (76.87%), indicating that it may be more suited for applications requiring high surface area, such as adsorption processes. The low moisture content (0.051), volatile matter 15% and moderate fixed carbon (72%) suggest that the biochar is relatively stable and has potential as a carbon-rich material for environmental and agricultural applications.

The bulk density (0.102 g/cc) and specific gravity (0.441) reflect the lightweight and porous nature of the biochar, which is advantageous for soil amendment purposes, improving aeration and water retention in soils. The adsorption capacity of 19.31 mg/g, when no salt is present, shows its potential effectiveness in capturing pollutants or nutrients, making it promising for use in water treatment and soil remediation.

However, the high ash content may limit its use in energy production, as it may not burn efficiently. Further optimization of the biochar production process could enhance its characteristics for specific applications.

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