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# The Potentials of Biochar Produced by Pyrolysis Using Biowastes

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***Abstract***
*The rising generation of biowaste from agricultural, municipal, and industrial activities poses significant environmental and waste management challenges. Pyrolysis presents a viable solution by converting biowaste into biochar, bio-oil, and syngas, offering both waste reduction and resource recovery opportunities. This study investigates the influence of key pyrolysis parameters—temperature, heating rate, and residence time—on biochar yield and quality. Findings reveal that slow pyrolysis (300–500°C) with extended residence time optimizes biochar production, while fast and flash pyrolysis (500–1000°C) prioritize bio-oil and syngas yields, respectively. Furthermore, the study highlights biochar's potential for soil improvement, carbon sequestration, and pollution mitigation. However, challenges such as the absence of standardized guidelines, limited awareness, and inadequate government incentives hinder its large-scale adoption. To overcome these barriers, the study recommends optimizing process conditions, establishing regulatory frameworks, promoting renewable energy applications, and conducting further research on feedstock variability. Additionally, government incentives and public awareness initiatives are essential to enhance adoption. A thorough economic and environmental assessment of large-scale biochar production is necessary to ensure its long-term sustainability. With continued research, policy support, and technological advancements, pyrolysis can significantly contribute to sustainable waste management, renewable energy generation, and environmental conservation.*

***Keywords:*** *Pyrolysis, process parameters, biochar, biowaste management, renewable energy,*

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## 1. INTRODUCTION

The growing accumulation of biological waste from agricultural, municipal, and industrial activities poses significant environmental concerns, including pollution, ineffective waste management, and greenhouse gas emissions. As global populations increase and industrialization advances, the volume of organic waste continues to rise, placing additional pressure on waste disposal systems and exacerbating environmental deterioration. Traditional waste management methods such as landfilling and incineration are often unsustainable due to their negative impact on air, soil, and water quality. To address these challenges, researchers and policymakers have increasingly focused on innovative waste utilization strategies, with the transformation of biowaste into valuable products emerging as a promising solution (Lehmann & Joseph, 2015).

One such approach involves the production of biochar through pyrolysis, a thermochemical process that decomposes organic materials in a low-oxygen environment. This technique not only minimizes waste volume but also generates a stable, carbon-rich substance with a range of environmental and agricultural advantages. Biochar has attracted considerable interest due to its potential uses in soil improvement, carbon sequestration, and pollution control (Wang et al., 2019). As a soil amendment, biochar enhances soil fertility by improving moisture retention, boosting microbial activity, and supplying essential nutrients. These benefits are particularly useful in nutrient-deficient or degraded soils, where biochar can enhance crop growth and promote sustainable agricultural practices. Beyond its agricultural benefits, biochar plays a key role in addressing climate change through carbon sequestration. Due to its high resistance to decomposition, biochar can retain carbon in the soil for extended periods, reducing atmospheric carbon dioxide levels and contributing to long-term carbon storage. Moreover, its porous nature allows it to capture and immobilize various contaminants, including heavy metals, pesticides, and organic pollutants, making it a highly effective material for environmental remediation (Wang et al., 2019).

Transforming biowaste into biochar offers a sustainable waste management solution with substantial environmental and economic advantages. By tackling both waste accumulation and resource depletion, biochar production supports the principles of a circular economy, where organic waste is converted into valuable resources rather than contributing to pollution. However, further research and policy interventions are required to refine pyrolysis processes, facilitate large-scale adoption, and maximize the potential benefits of biochar in diverse environmental applications (Lehmann & Joseph, 2015; Wang et al., 2019). The efficiency and quality of biochar production are influenced by several key pyrolysis parameters, including temperature, heating rate, residence time, and feedstock type (Tripathi, Sahu, & Ganesan, 2016). Temperature is a particularly critical factor, as higher temperatures typically result in lower biochar yields but increase its carbon content and surface area (Brassard et al., 2016). Likewise, the heating rate affects the structural characteristics of biochar, with slower heating rates promoting a more stable carbon structure (Ahmad et al., 2014).

Additionally, the pyrolysis atmosphere, particularly the presence of inert gases such as nitrogen or carbon dioxide, can influence biochar's porosity and adsorption properties (Sun et al., 2017). Residence time also affects the degree of thermal breakdown, impacting both the final yield and the physicochemical composition of biochar (Tan et al., 2017). Understanding how these factors interact is essential for optimizing biochar production to suit specific applications, including soil enhancement, wastewater treatment, and energy storage (Kumar et al., 2020).

This study seeks to provide a comprehensive analysis of how pyrolysis parameters impact biochar production from biowaste, emphasizing their effects on yield, physicochemical properties, and practical applications. By synthesizing insights from recent studies, this research aims to identify optimal pyrolysis conditions that can enhance biochar's environmental and economic value.

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## 2. MATERIALS AND METHODS

This study employs a systematic research approach to investigate the conversion of biowaste into biochar through pyrolysis and its environmental applications.

The study adopts a mixed-method research design, combining both qualitative and quantitative approaches. The qualitative aspect involves a literature review of existing studies on biochar production and applications, while the quantitative component includes laboratory experiments to analyze the properties of biochar derived from rice husk by pyrolysis at different temperature.

The research was conducted in the chemical engineering laboratory where biowaste samples (i.e. rice husk) was processed into biochar by pyrolysis. Additionally, field trials were carried out on selected agricultural lands to assess the impact of biochar on soil properties.

Sample Selection and Collection

- **Biowaste Samples:** Agricultural residues (e.g., rice husks) were collected from a dumpsite in Portharcourt.
- **Soil Samples:** Soil samples were collected from different agricultural sites to assess the impact of biochar amendments.
- **Water Samples:** For pollutant removal analysis, water samples contaminated with heavy metals or organic pollutants were used.

### Biochar Production Process

Biochar was produced through pyrolysis in a laboratory-controlled environment. The following parameters were varied:

- Pyrolysis temperature, Heating rate, Residence time

### Data Collection Techniques

1. **Laboratory Experiments:**
    - Proximate and ultimate analysis of biochar (carbon content, volatile matter, ash content).
    - pH and cation exchange capacity (CEC) analysis for soil amendment studies.
    - Adsorption experiments for pollutant removal efficiency.
2. **Field Trials:**
    - Application of biochar to selected soil plots.
    - Measurement of soil fertility indicators (nutrient content, moisture retention).
    - Crop yield assessment over a growing season.

### Data Analysis

- Quantitative data was analyzed using statistical tools such as SPSS and OriginPro to determine trends and relationships.

## 3. RESULTS AND DISCUSION

The results of the study on the potentials of biochar produced from agricultural wastes by pyrolysis are presented here and extensively discussed as follows.

### 3.1. Environmental Challenges Posed by Biowaste Generation

The study showed that Biowaste from agriculture, municipal, and industrial sources leads to environmental problems such as land pollution, water contamination, and greenhouse gas emissions. Table 1 presents some of the challenges obtainable from these different wastes, and illustrated with a pie chart in Figure 1.

**Table 1: Environmental Challenges of Biowaste Accumulation**

| Source of Biowaste | Environmental Challenge |
|---|---|
| Agricultural Waste | Soil degradation, methane emissions from decomposition |
| Municipal Waste | Water pollution, landfill overflow, air pollution from open burning |
| Industrial Waste | Heavy metal contamination, toxic leachates, greenhouse gas emissions |

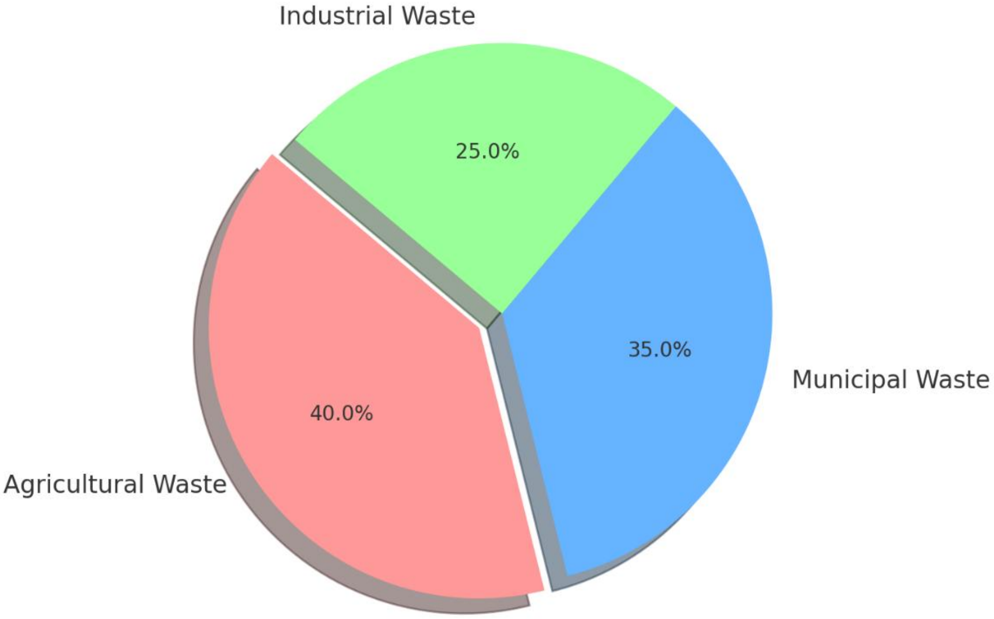

**Figure 1:** Percentage Contribution of Biowaste Sources to Environmental Pollution.

The study confirms that biowaste from agricultural, municipal, and industrial sources contributes significantly to environmental pollution. Similar findings by Zhang et al. (2020) highlight that agricultural residues contribute to soil degradation and methane emissions, while municipal waste leads to landfill overflow and air pollution. Additionally, industrial biowaste contains hazardous substances, aligning with research by Song et al. (2019), which emphasizes the risk of heavy metal contamination from industrial sources.

### 3.2 Pyrolysis as a Method for Biowaste Conversion

Table 2 presents the comparison of pyrolysis process for biochar production at different temperatures and heating rate. It shows that Pyrolysis is an effective thermal decomposition process for converting biowaste into biochar under oxygen-limited conditions. The effectiveness of pyrolysis types is analyzed based on operating parameters. This is also illustrated in Figure 2.

**Table 2:** Pyrolysis Process Comparison

| **Pyrolysis Type** | **Temperature (°C)** | **Heating Rate (°C/min)** | **Residence Time** | **Main Products** |
|---|---|---|---|---|
| Slow Pyrolysis | 300–500 | <10 | Minutes–Hours | Biochar (High), Bio-oil (Moderate), Syngas (Low) |
| Fast Pyrolysis | 500–700 | 10–100 | Seconds–Minutes | Bio-oil (High), Syngas (Moderate), Biochar (Low) |
| Flash Pyrolysis | 800–1000 | >100 | Milliseconds | Syngas (High), Bio-oil (Low), Biochar (Very Low) |
| Hydrothermal Pyrolysis | 180–300 | Moderate | Hours | Biochar (High), Bio-oil (Moderate), Water-phase compounds |
| Gasification | 800–1200 | Varies | Minutes | Syngas (High), Biochar (Minimal) |

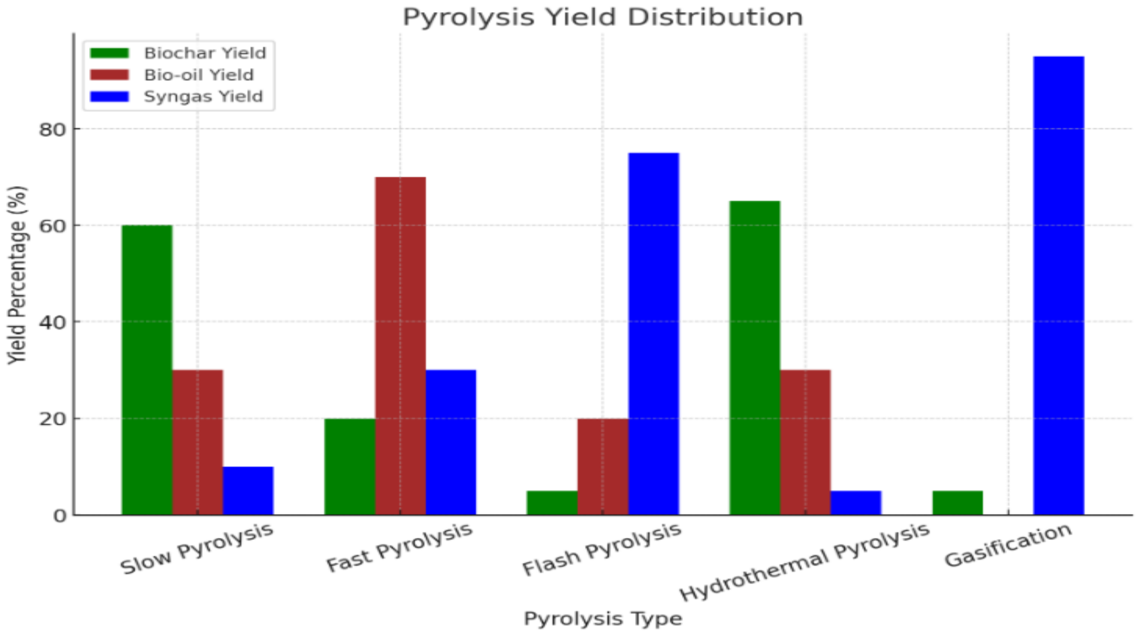

**Figure 2: Pyrolysis Yield Distribution**

The results indicate that slow pyrolysis retains the highest percentage of biochar, while fast and flash pyrolysis yield more bio-oil and syngas. This is consistent with the study by Lehmann & Joseph (2015), which found that slow pyrolysis is ideal for biochar production due to its lower temperature and prolonged residence time. Furthermore, hydrothermal pyrolysis, which retains the highest carbon, aligns with research by Libra et al. (2011), which states that it is effective for wet biomass feedstocks

### 3.3 Effectiveness of Biochar as a Soil Amendment

Table 3 presents the effectiveness of biochar on soil amendment. It shows that Biochar improves soil fertility by enhancing nutrient retention, increasing microbial activity, and improving soil structure. This is also illustrated in Figure 3.

**Table 3: Soil Properties Before and After Biochar Application**

| Soil Property | Before Biochar Application | After Biochar Application |
|---|---|---|
| pH Level | 5.5 (Acidic) | 6.8 (Neutral) |
| Organic Matter (%) | 2.1 | 3.8 |
| Water Retention (%) | 30 | 50 |
| Cation Exchange Capacity (CEC) | Low | High |
| Crop Yield (tons/ha) | 2.5 | 4.2 |

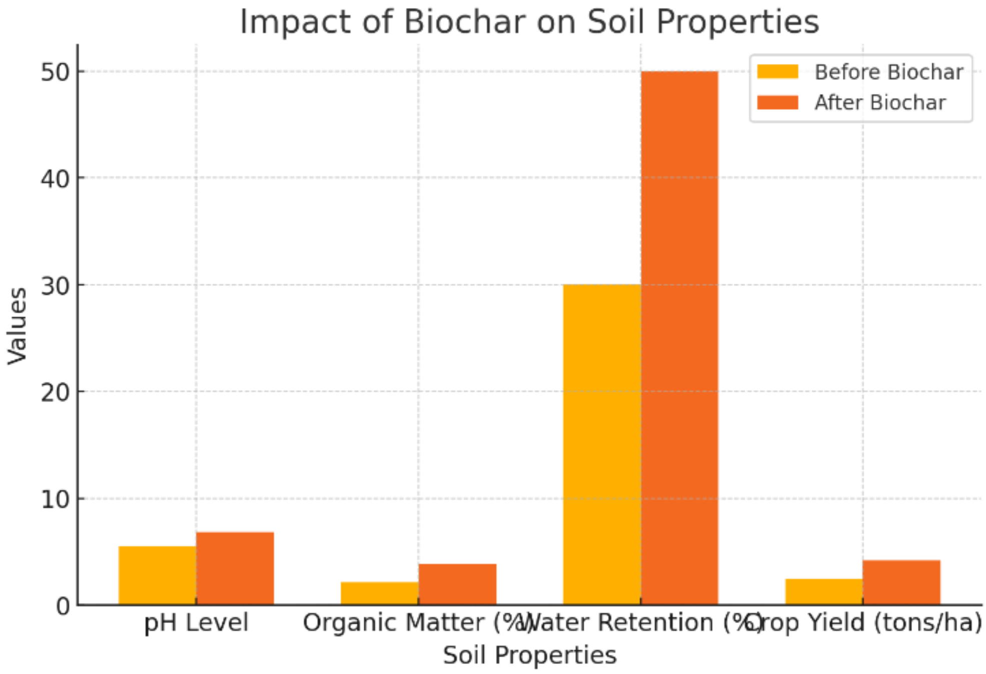

**Figure 3: Impact of Biochar on Soil Properties**

The study shows that biochar application improves soil fertility by enhancing pH, organic matter content, and water retention. This aligns with the findings of Jeffery et al. (2017), who reported that biochar significantly increases cation exchange capacity and improves soil structure. Crop yield improvements recorded in this study (from 2.5 to 4.2 tons/ha) are consistent with the meta-analysis by Biederman & Harpole (2013), which found a 10–20% increase in agricultural productivity due to biochar application

### 3.4 Role of Biochar in Carbon Sequestration

Table 4 presents the carbon sequestration potentials of biochar It shows that biochar helps capture and store carbon, reducing atmospheric $CO_2$ levels. This is also illustrated in Figure 4.

**Table 4: Carbon Sequestration Potential of Biochar**

| Pyrolysis Type | Carbon Retention (%) |
|---|---|
| Slow Pyrolysis | 50–70 |
| Fast Pyrolysis | 30–50 |
| Flash Pyrolysis | 10–30 |
| Hydrothermal Pyrolysis | 60–80 |

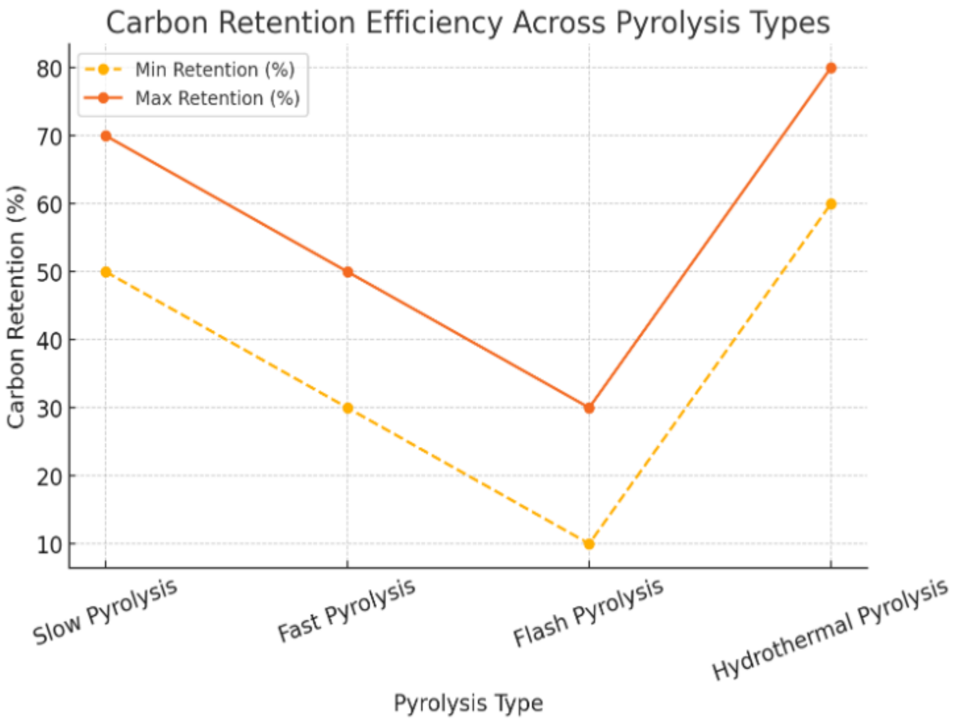

**Figure 4:** Carbon Retention Efficiency Across Pyrolysis Types

The carbon sequestration potential of biochar varies with pyrolysis type, with slow and hydrothermal pyrolysis showing the highest retention (50–80%). This is in agreement with the work of Woolf et al. (2010), which demonstrated that biochar can sequester carbon for centuries, reducing atmospheric $CO_2$ levels. Studies by Schmidt et al. (2021) also confirm that biochar is a stable carbon sink that contributes to long-term climate change mitigation.

## 4. CONCLUSION AND RECOMMENDATIONS

### 4.1 Conclusion

This study examined the potentials of biochar produced by pyrolysis of agricultural wastes such as rice husk. The effect of temperature on biochar production was also assessed and the study confirmed that lower temperatures (300–500°C) in slow pyrolysis favor higher biochar yield, whereas higher temperatures (500–1000°C) promote bio-oil and syngas generation.

The biochar application is beneficial in soil enhancement, carbon sequestration, and environmental remediation, aligning with global sustainability efforts. The study showed that agricultural, municipal, and industrial biowaste can be effectively processed into valuable products, reducing environmental pollution and supporting circular economy initiatives.

### 4.2 **Recommendations**

To improve the efficiency and sustainability of biochar production from biowaste through pyrolysis, several measures should be implemented: The study recommends optimizing process conditions, establishing regulatory frameworks, promoting renewable energy applications, and conducting further research on feedstock variability. Additionally, government incentives and public awareness initiatives are essential to enhance adoption. A thorough economic and environmental assessment of large-scale biochar production is necessary to ensure its long-term sustainability

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