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A Comprehensive Review on Biochar

Manish Ramesh Pandao [a++], Gandikota Rupa Lalitha [b#*], Ankireddypalli Jaya Kishore [c†], Smruti Ranjan Padhan [d#], Narinder Panotra [e‡], Shani Gulaiya [f#] and Shivam Kumar Pandey [g^]

[a] *Department of Soil Science and Agricultural Chemistry, Dr. Panjabrao Deshmukh Krishi Vidyapeeth, Akola, India.*
[b] *Department of Soil Science and Agricultural Chemistry, Tamil Nadu Agricultural University, Coimbatore, Tamil Nadu, Pin Code: 641003, India.*
[c] *Department of Soil Science and Agricultural Chemistry, ICAR-Indian Agricultural Research Institute, New Delhi, Pin code: 110012, India.*
[d] *Division of Agronomy, Indian Agricultural Research Institute, New Delhi, 110012, India.*
[e] *School of Biotechnology, SKUAST-Jammu, Chatha, Distt Jammu J&K, J&K 180009, India.*
[f] *Department of Agronomy, Jawaharlal Nehru Krishi Vishwa Vidhalay (JNKVV), Jabalpur (M. P.), India.*
[g] *Rashtriya Raksha University, India.*

Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

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Review Article

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ABSTRACT

Biochar from the pyrolysis of organic biomass is a highly porous carbon with many useful applications. While providing practical options for disposal and disease control, it also contributes to carbon sequestration by trapping carbon in plant biomass. The composition and structure of biochar

[++] *Ph. D Scholar;*
[#] *Ph. D Research Scholar;*
[†] *M. Sc Research Scholar;*
[‡] *Assistant Professor;*
[^] *Research Scholar;*
**Corresponding author: E-mail: rupalalithagandikota123@gmail.com;*

depends on factors such as temperature, heating rate and production time. It also leads to bio-oil and biogas, which can be used for biochar production, electricity generation and the production of various chemicals. Incorporating biochar into the soil improves pH, electrical conductivity, water holding capacity, cation exchange capacity and microbial activity.It reduces nutrient leakage and all necessary fertilizers reduce environmental pollution. Biochar also plays an important role in crop improvement. Besides improving the soil, biochar also has the advantage of reducing greenhouse gas emissions, reducing pesticide use and being used in the construction, cosmetics and treatment, wastewater and food industries. India is rich in biomass resources and has great potential for biochar production. This study explores various production technologies, their effects on biochar energy and the benefits of using biochar.

Keywords: Biochar; greenhouse gas; fertilizer; pyrolysis; biomass.

1. INTRODUCTION

The production of biochar involves subjecting organic biomass or agricultural residues to high temperatures in a low-oxygen environment, resulting in the conversion of the biomass into a carbon-rich charcoal. Biochar has gained attention as a potential solution for mitigating climate change and improving soil health. By sequestering carbon from the environment, biochar helps reduce greenhouse gas emissions. Studies have estimated that biochar production could potentially reduce GHG emissions by about 12% [1]. Its tenacious nature slows the removal and mineralization of carbon monoxide, then ensures long-term carbon sequestration. A key benefit of biochar is its ability to improve soil fertility and quality. When applied to soil, biochar can improve storage, increase water holding capacity, and improve microbial activity. It provides habitat for beneficial bacteria and creates a good environment for plants to grow. In addition, biochar can reduce the leaching of nutrients and pollutants, thus maintaining water quality [2].

The utilization of surplus organic matter or agricultural residues for biochar production offers a sustainable approach to waste management. Instead of being burned or left to decompose, these biomass resources can be converted into a valuable soil amendment [3]. By incorporating biochar into agricultural fields, it not only improves soil quality but also reduces the need for synthetic fertilizers, minimizing their associated environmental impacts. The widespread adoption of biochar has the potential to make significant contributions to global efforts in reducing carbon emissions, enhancing soil health, and achieving sustainable development goals. Ongoing research and studies continue to explore the optimal production methods, characterization, and specific applications of biochar in different agricultural systems and environmental contexts [4].

2. ORIGIN OF BIOCHAR PRODUCTION

The production of biochar has its origins in ancient practices that date back thousands of years. Indigenous cultures, such as the Amazonian tribes, utilized a technique called "terra preta" to improve soil fertility and productivity. Indeed, the concept of biochar has been practiced for centuries, but the term "biochar" itself was coined relatively [4,5]. However, the use of biochar in ancient civilizations, such as in the Amazon Basin, is evident from the discovery of terra preta soil. Terra preta soil refers to the dark, highly fertile soil found in the Amazon Basin, which supports agricultural activities in the region. The soil in terra preta contains a significant amount of organic matter and char. It has a neutral pH and excellent nutrient retention capacity, making it more productive compared to the surrounding soil. The presence of terra preta near human settlements suggests that it was created intentionally by humans [6].

They do this by mixing them into the soil, which increases the soil's ability to retain and encourage crop growth. In recent years, interest in biochar production has increased again due to its carbon sequestration and soil remediation potential. Modern biochar processes involve the pyrolysis of organic biomass or agricultural products. Pyrolysis is a thermal decomposition process that occurs in the absence of oxygen, usually at temperatures between 400 and 700 degrees Celsius [7].

During pyrolysis, the biomass undergoes a series of complex chemical reactions. The volatile components are released as gases and bio-oils, which can be captured and utilized for energy generation or chemical production. The remaining solid residue is the biochar, a carbon-rich material with a highly porous structure [8]. The production of biochar can be carried out using different techniques and equipment, including traditional methods like pit burning or modern systems such as pyrolysis reactors. The choice of production method depends on various factors, including the scale of production, feedstock availability, and desired properties of the biochar.

In recent years, research and development has focused on optimizing biochar production processes to maximize its benefits. This includes examining the effect of pyrolysis conditions (temperature, heating rate, residence time) on biochar energy as well as investigating different raw material options and their impact on biochar quality [9].

3. PRODUCTION OF BIOCHAR

Biochar production involves several technologies, including pyrolysis, which can be further categorized into slow pyrolysis and fast pyrolysis, as well as gasification [10].

3.1 Slow Pyrolysis

Slow pyrolysis is a process that produces more biochar than other technologies. It provides up to 50% carbon savings in raw materials. Slow pyrolysis is used in many industries such as the chemical industry for the production of methanol, charcoal, activated carbon and other chemicals from wood. It is also used to convert biomass into syngas and biochar and to convert waste into disposable products [11].

3.2 Intermediate Pyrolysis

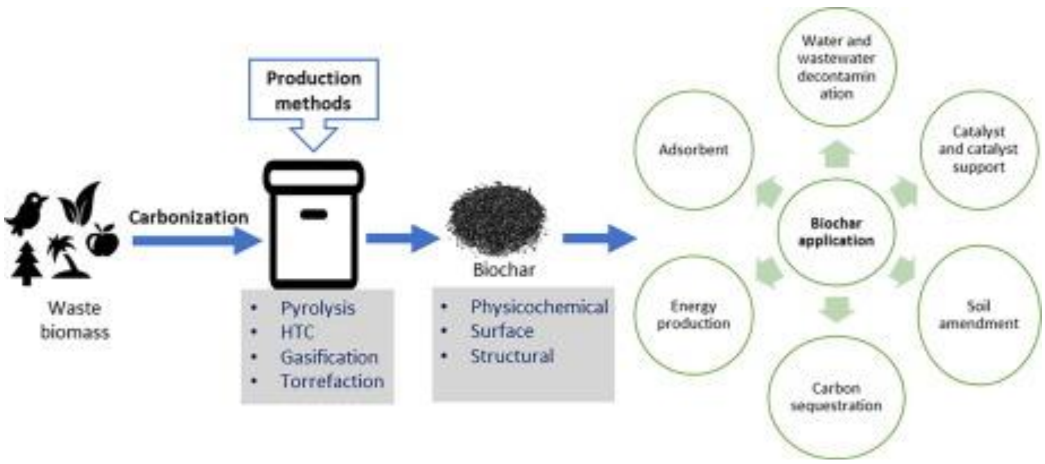
During intermediate pyrolysis, the biomass is heated in the absence of or limited to oxygen, resulting in the release of volatile compounds, bio-oil and biochar. Process parameters such as temperature, residence time and heating rate affect the results and properties of the products obtained. Intermediate pyrolysis provides a balance between biochar production and the production of valuable products such as bio-oil, making it suitable for applications that require the use of both biochar and bio-oil [12].

3.3 Fast Pryolysis

Fast pyrolysis, on the other hand, happens in a matter of seconds or less. To encourage the formation of charcoal, process factors such as temperature, residence time, heating rate, and sweeping gas flow rate must be carefully controlled. Fast pyrolysis produces a variety of products, as illustrated in Fig. 1 of the reference [13,14].

3.4 Gasification

Gasification is a thermochemical conversion process that takes place at high temperatures (>700°C) and with controlled oxygen levels. As a result, combustible gases known as syngas or producer gas are produced. The gasification process converts biomass into carbon monoxide (CO), hydrogen (H2), and trace amounts of methane (CH4). Gasification syngas can be efficiently combusted at higher temperatures or used in fuel cells. Gasification is thought to be more efficient than direct combustion of the original fuel, and it can also be used to treat



Picture 1. Biochar production and application

biodegradable waste. Furthermore, the high-temperature conditions of gasification aid in the removal of corrosive components such as chloride and potassium, resulting in cleaner gas generation [15].

These technologies enable the manufacture of biochar while using waste materials and contributing to energy demands and soil carbon sequestration. Each technology has its own set of pros and disadvantages, and the technology used is determined by a variety of parameters such as the target biochar production, process efficiency, and specialised uses [16].

3.5 Carbonization

It is a process that converts organic materials into carbon-rich material. It represents multiple pyrolytic methods, akin to the classic charcoal producing process. The temperature fluctuates between 280oC and 500oC. The biomass spontaneously decomposes and creates charcoal, as well as some combustible and noncombustible gases [17].

4. PROPERTIES AND COMPOSITION OF BIOCHAR [18]

4.1 Elemental Composition

- Carbon (C): Biochar is mostly made of carbon, accounting for 50% to 95% of its entire composition.
- Hydrogen (H): Present in small amounts.
- Oxygen (O): Varies depending on the production process and feedstock, typically ranging from 5% to 45%.
- Nitrogen (N): Present in varying amounts, depending on the feedstock and production conditions.
- Sulfur (S): Present in trace amounts.

4.2 Ash Content

- Biochar contains inorganic components referred to as ash, which remains after the organic matter undergoes pyrolysis.
- Ash content varies depending on the feedstock and production conditions, typically ranging from 1% to 50%.
- The ash content affects the nutrient content and properties of the biochar.

4.3 Porosity and Surface Area

- Biochar possesses a highly porous structure with a large internal surface area.
- Pores can be categorized into macro-pores, meso-pores, and micro-pores, contributing to the overall biochar porosity.
- The high surface area and porosity provide biochar with a large number of sites for adsorption and nutrient retention.

4.4 Pore Structure

- Biochar's pore structure affects its water-holding capacity, gas exchange capabilities, and nutrient availability.
- Macro-pores facilitate water infiltration and root penetration, while micro-pores are involved in nutrient adsorption and retention.

4.5 Chemical Stability and Recalcitrance

- Biochar exhibits high stability and recalcitrance, meaning it resists decomposition and remains in the soil for an extended period.
- The recalcitrant nature of biochar allows for long-term carbon sequestration and helps mitigate greenhouse gas emissions.

4.6 Surface Chemistry

- Biochar's surface chemistry plays a crucial role in its interactions with nutrients, water, and soil microorganisms.
- Hydroxyl and carboxyl groups on the charcoal surface can contribute to nutrient adsorption and cation exchange capacity.

4.7 Mineral Content

- Biochar may contain minerals and trace elements from the feedstock and production process.
- The mineral composition of biochar can influence its agronomic and environmental effects, including nutrient availability and potential impacts on soil pH.

5. CARBON RICH FEED STOCK FOR BIOCHAR PRODUCTION

The major feedstock for biochar formation is carbon-rich biomass. It refers to organic compounds with a high carbon content that can be generated from a variety of sources, including [19]:

5.1 Agricultural Residues

Crop leftovers such as straw, husks, stalks, and shells from crops such as rice, wheat, maize, and sugarcane can be utilised as feedstock for biochar production. These residues are plentiful and frequently regarded as waste materials, making them a viable alternative for biochar synthesis.

5.2 Forestry Residues

Biomass residues generated from forestry activities, such as tree branches, bark, sawdust, and wood chips, can be utilized as feedstock for biochar production. These residues are commonly obtained from logging operations, timber processing, and forest management practices.

5.3 Energy Crops

Dedicated energy crops, including fast-growing plants like bamboo, switchgrass, and miscanthus, can be grown specifically for biochar production. These crops have a high biomass yield and can be cultivated on marginal lands, reducing competition with food crops.

5.4 Organic Wastes

Agricultural waste, food waste, animal manure, and sewage sludge are all examples of organic waste that can be used as feedstock for biochar production. These waste products provide a sustainable and environmentally friendly waste management and biochar production alternative.

5.5 Residues from Bioenergy Production

Biochar can be made from byproducts or wastes created during bioenergy production procedures such as bioethanol production, biodiesel manufacturing, or biogas generation. These residues can be lignocellulosic biomass, algae biomass, or anaerobic digestate.

6. BIOCHAR IN ENVIRONMENTAL SUSTAINABILITY

Biochar offers several environmental benefits, making it a valuable tool for sustainable resource management and climate change mitigation. Some of the key environmental benefits of biochar are [20]:

6.1 Carbon Sequestration

Biochar is a stable form of carbon that may be stored in soil for hundreds to thousands of years, thereby removing carbon from the atmosphere. Biochar helps reduce greenhouse gas emissions, mainly carbon dioxide (CO2), and mitigates climate change by storing carbon in the soil [21].

6.2 Soil Improvement

Biochar improves soil fertility and productivity when applied to the soil. It promotes healthy plant growth by improving soil structure, water retention capacity, and nutrient availability. Biochar also enhances soil organic matter content and promotes microbial activity, which benefits soil ecosystem health and resilience [22].

6.3 Nutrient Retention

Biochar has the ability to retain nutrients such as nitrogen, phosphorus, and potassium in the soil, preventing their leaching into water bodies and reducing the need for synthetic fertilizers. This helps minimize nutrient runoff and eutrophication of water systems, protecting water quality and aquatic ecosystems.

6.4 Reduced Soil Erosion

The incorporation of biochar into soil can enhance its stability and resistance to erosion. Biochar improves soil structure, increases water infiltration rates, and reduces surface runoff. By minimizing soil erosion, biochar helps preserve valuable topsoil and prevents sedimentation in rivers, lakes, and reservoirs

6.5 Improved Waste Management

Biochar production can utilize organic waste materials, including agricultural residues, forestry waste, and organic by-products. By converting these waste materials into biochar, valuable resources are recycled and diverted from landfills or open burning, reducing methane emissions and environmental pollution.

6.6 Water Management

The application of biochar to soil improves water holding capacity and drainage, reducing water stress on plants during dry periods and minimizing the risk of waterlogging in heavy rainfall events. This can be particularly beneficial in areas prone to droughts or heavy precipitation,

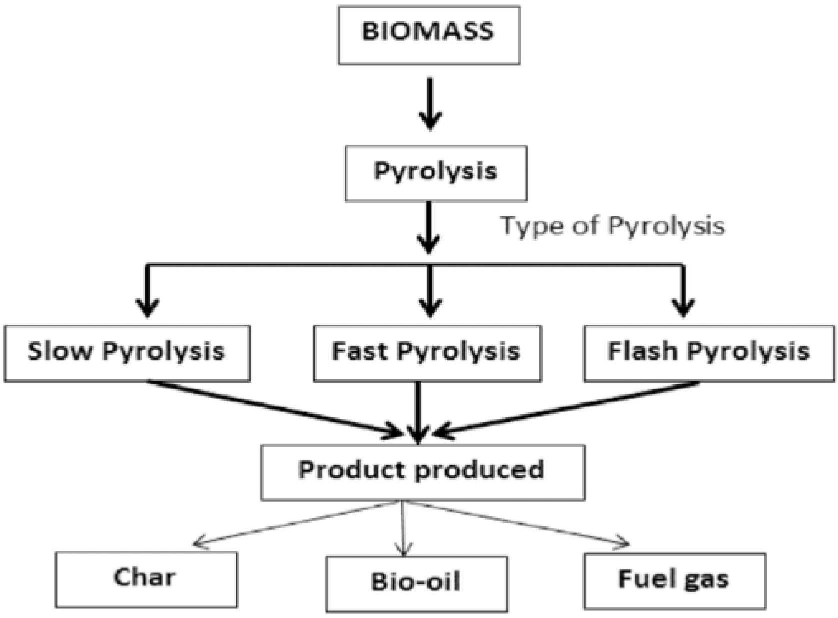


Fig 1: Types of pyrolysis

enhancing crop resilience and water use efficiency.

6.7 Reduced Greenhouse Gas Emissions

Biochar has the potential to reduce emissions of greenhouse gases such as methane and nitrous oxide from agricultural soils. Its incorporation into soil can alter microbial processes, leading to decreased emissions of these potent greenhouse gases, further contributing to climate change mitigation.

7. APPLICATIONS OF BIOCHAR

Biochar has numerous applications in a variety of industries. Some of the most important biochar applications are [23]:

7.1 Soil Amendment

Biochar is commonly used as a soil amendment to improve soil fertility, structure, and nutrient availability. It enhances water retention capacity, reduces nutrient leaching, and promotes beneficial microbial activity in the soil. By incorporating biochar into agricultural soils, it can improve crop productivity and nutrient uptake.

7.2 Carbon Sequestration

Carbon Sequestration biochar is an efficient carbon sequestration technology. Biochar reduces greenhouse gas emissions and mitigates climate change by storing carbon in a stable form. It can be used to sequester carbon for long periods of time in land restoration projects, reforestation operations, and carbon offset programmes.

7.3 Waste Management

Biochar production provides a sustainable solution for managing various types of organic waste materials. Agricultural residues, forestry waste, and other biomass can be converted into biochar, reducing waste disposal and potential environmental pollution.

7.4 Water Filtration

Because of its adsorptive qualities, biochar is useful for water filtration and purification. It can remove heavy metals, herbicides, and organic pollutants from water, thereby improving water quality. To minimise pollutant levels, biochar filters can be utilised in residential water treatment systems, wastewater treatment plants, and stormwater management.

7.5 Livestock and Animal Husbandry

Biochar can be used as a feed additive for livestock to improve their digestion, nutrient absorption, and overall health. It can also reduce odors and pathogens in animal waste management systems, improving environmental conditions and reducing the impact on surrounding ecosystems.

7.6 Renewable Energy

Biochar production produces byproducts such as bio-oil and syngas, both of which can be used as renewable energy sources. Bio-oil can be converted into biofuels or utilised to generate heat and power. Syngas can be utilised to generate energy and heat using gasification operations.

7.7 Environmental Remediation

Biochar has the potential to remediate contaminated soils and brownfield sites. Its adsorptive properties can help immobilize and detoxify pollutants, reducing their mobility and bioavailability. Biochar amendments have been used to remediate contaminated sites and restore soil health.

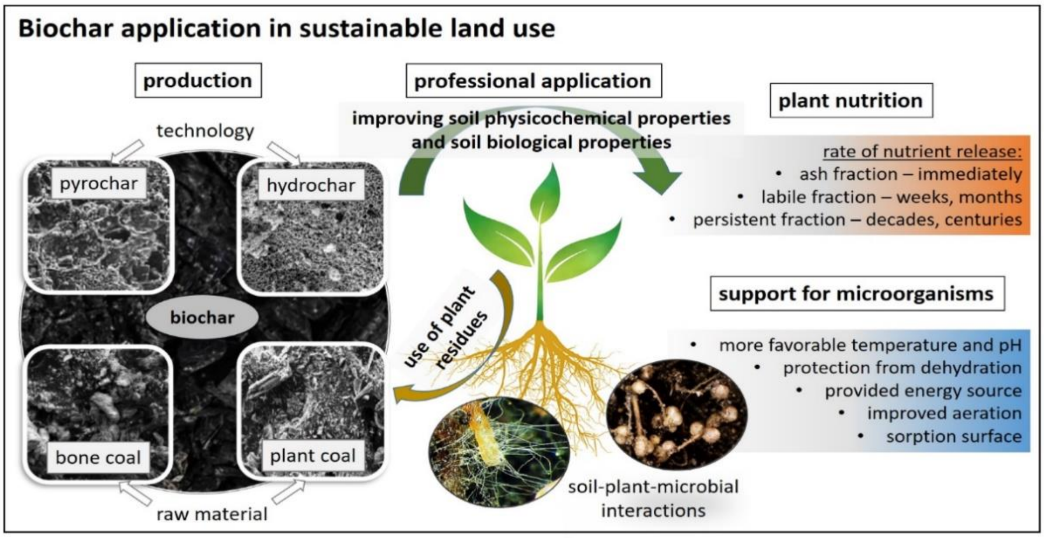
7.8 Construction and Building Materials

Biochar can be used as an additive in construction materials, such as concrete and cement, to improve their strength, durability, and thermal insulation properties. This application reduces the environmental impact of construction materials and promotes sustainable building practices.

8. BIOCHAR APPLICATION FOR SUSTAINABLE LAND USE

Biochar application offers a sustainable land use solution with multiple environmental benefits. When integrated into soil, biochar acts as a soil amendment, enhancing fertility and improving its physical, chemical, and biological properties. It promotes nutrient retention, reduces the need for chemical fertilizers, and mitigates the risk of water pollution. Additionally, biochar's porous structure improves water retention in arid soils and enhances drainage in clayey soils, fostering optimal plant growth. Its ability to sequester carbon contributes to mitigating climate change by storing carbon in the soil for extended periods. By utilizing organic waste materials for biochar production, it provides a sustainable waste management strategy while supporting soil health and biodiversity [24]. Furthermore, biochar exhibits potential in remediating contaminated soils by reducing the bioavailability of

Picture 2. Application of biochar



Picture 3. Biochar application in sustainable land use

pollutants. Overall, biochar application demonstrates its potential as a valuable tool for sustainable land use, offering a pathway to enhance agricultural productivity, mitigate climate change, and foster environmental resilience [25].

9. CONCLUSION

Biochar, a carbon-rich biomass product, holds immense potential for sustainable solutions. Through the process of pyrolysis, biomass is transformed into a stable form of charcoal that can sequester carbon for long periods. Biochar application in agriculture improves soil fertility, water retention, and nutrient cycling, thereby enhancing crop productivity and reducing reliance on synthetic fertilizers. Additionally, biochar mitigates greenhouse gas emissions, acting as a carbon sink while reducing the release of nitrous oxide and methane. It also offers promising opportunities for waste management by converting organic residues into a valuable resource. By harnessing the power of biochar, we can address pressing environmental challenges, promote sustainable practices, and contribute to a greener and more resilient future.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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