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PREPARATION, CHARACTERIZATION OF BIOCHAR FOR A SUSTAINABLE SOIL HEALTH

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Review Article

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ABSTRACT

Recent research suggests that biochar is a promising approach to minimize soil contamination caused by heavy metals and organic pollutants. It is also involved in the amendment of soil by altering the nutrients, pH and other factors. Through intensive literature review, this paper was aimed to better understand the selection of feedstock processes, preparation, and characterization of biochar. Wide variety of feedstock used for the biochar production based on the cost effectiveness, ease availability and they are ecofriendly to the environment. Among the thermochemical processes, pyrolysis is the promising techniques followed for the production of BC. The stabilization efficacy was mainly determined by cation exchange capacity, pH, and ash content of the biochar. The physicochemical characteristic of the biochar is analyzed using various methods such as SEM, FTIR, TGA and BET analysis. The surface area plays a major role in the metal sorption. The quality characteristics of biochar as a soil amendment varied greatly with the feedstock materials and the pyrolysis conditions. Biochar plays a great role in increasing the pH which helps the acidic soil region and its high-water retention capacity enhance the moisture level in the soil which enhances the microbial communities and its activity. Biochar becomes stabilized in the soil by interacting with soil particles. The inherent characteristics of the biochar as dictated by feedstock and pyrolysis conditions, interact with climatic conditions such as precipitation and temperature to influence how long biochar carbon remains stored in the soil. Due to its carbon sequestration in the soil, it helps in increasing the fertility of the soil and also enhances the crop yield.

Keywords: Biochar, Bioremediation, Pyrolysis, Characterization, Sustainable.

INTRODUCTION

Nowadays with the rapid development of industries, a\ large amount of heavy metals contaminated water is released to the environment (Liu *et al*., 2020). Heavy metals discharged from various industries such as mining, metal finishing, electroplating, glass, textiles, ceramics and storage batteries (Godwin *et al*., 2019). This leads to inevitable release of heavy metals to the environment. They are non-biodegradable, accumulating in living organisms and also aggravating their hazardous impact on the environment (Poo *et al*., 2018). The toxicity of heavy metals are the major risk to all the living beings and alters the environment. Most of the essential heavy metals are toxic and carcinogenic in nature (J.M. Patra *et al*., 2017). Heavy metals react with soil constituents by various mechanisms such as adsorption, fixation and surface precipitation (Campillo *et al*., 2020). It is therefore\ important to struggle with remediation of contaminated soils.

Bioremediation is an ecologically-friendly approach that involves the use of living organisms particularly microorganisms, to degrade contaminants that alters toxic

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to less toxic compounds (Akpomie Olubunmi O *et al*., 2016). Several technologies have been used to remove heavy metals, among these, adsorption is a widely recommended method for the removal of heavy metals ions, due to its high efficiency, fast, ease of operation, inexpensive and availability of various adsorbents (Bordoloi *et al*., 2017). The effect of application of adsorbent is not only a decrease in the bioavailability of pollutants, but also reduced spreading of pollutants in the environment (Koltowsi *et al*., 2017).

In recent days, a cost effective and environmentally friendly remediation approach is the application of Biochar (He *et al*., 2019). This technological review focuses on the selection of feedstock, production, characterization of Biochar (BC) and its application in promoting the sustainable environment.

Biochar

The treatment of biomass by heat under limited oxygen, where the complex chemical compounds are converted into simple, which gives various gaseous compounds termed as "char". The material that has been obtained from biomass of several feedstocks is named as "Biochar" (K Kalus *et al*., 2019). The solid biochar can be obtained from biomass by several thermal decomposition processes such as pyrolysis, combustion, gasification and liquefaction. Based on its applications, scientific researchers emerged in the research includes: its mitigation of climatic change, efficient and cost-effective waste management and also acts as amendment to improve soil quality and sustain crop yield (Sohi SP *et al*., 2010).

Pyrolysis

Among various methods, pyrolysis is considered as a feasible method that can quickly convert biomass into solid biochar. Main thermochemical processes such as slow pyrolysis, fast pyrolysis, flash pyrolysis, catalytic pyrolysis and microwave assisted pyrolysis are commonly used for the production of biochar (Manya 2012).

From the literature search it has been understood that in slow pyrolysis, the temperature is gradually increased at a slow rate in the anoxic condition with a heating rate ranging from 5 to 7°C/min, the residence times of vapor persist longer usually for 10–60 s for the production of biochar (Canabarro N *et al*., 2013, M Sekar *et al*., 2021) and the particle size for degradation ranging between 5 and 50 mm whereas fast pyrolysis produces bio-oil mainly at the higher temperature increased at a faster rate. Rapid heating rate at 300°C–600°C/min, a short vapor residence time and the particle size less than 1 mm.

Biochar Terminology

According to Kanyaporn *et al* (2012), "Biochar is a stable form of carbon, being more stable than the organic form and capable or remaining in the soil for hundreds and thousands of years". The pyrolysis technique is relatively simple and low cost and allows significant flexibility in both the type and quality of the biomass feedstock. Liu *et al*., 2020 described Biochar as "carbon- based porous material prepared by pyrolysis. Senthilkumar *et al.*, 2019 stated that "Biochar can be synthesized from biological material through pyrolysis, in the absence of O_2 or limited oxygen conditions. E Sforza *et al,* (2020) defined "Biochar as a carbon rich material characterized by high porosity with oxygen functional groups and aromatic surfaces. It is produced from the pyrolysis (300°C-700°C) (Wang *et al*., 2019) along with syngas and bio-oil (Singaravelu 2019).

Feedstock for the biochar production

The most important criteria for the production of biochar depends on the stable biomass feedstock selection. The choice of biomass based on the abundance of feedstock, ready availability and low cost (Jang and Kan, 2019).

From the literature it has been used a wide variety of raw materials used such as agricultural waste, municipal solid waste, kitchen waste, crops, sludge, lignocellulosic biomass, non-lignocellulosic material, industrial residues and also living organisms, synthetic polymers/plastics, tyres, coal have been employed (Agrafioti *et al*., 2014, Liu *et al*., 2019, J. Wang *et al*., 2019).

Preparation of biochar

From the literature, different methods of biochar production were carried out from various feedstocks using different materials.

The biochar was prepared using porcelain crucible in a closed furnace, during pyrolysis N2 was mixed at 2500ml/min to prevent explosion in the furnace (K.M. Poo *et al*., 2018). Bird *et al*., 2012 pyrolyzed the algal biomass separately using batch pyrolysis with gas flame support using a Bigchar™ 1000 pyrolysis unit.

Y.Y. Wang *et al* 2016 carried out the biochar preparation in a programmable tube furnace by slow pyrolysis at 300°C for 3 hours under anaerobic conditions. And the heating rate was about 25°C min^{-1} and cooled to room temperature. Pyrolysis was carried out in a muffle furnace and heating rate at 17°C/min (E. Agrafioti *et al.*, 2014). Few researchers carried out biochar preparation in a bench top, high temperature (upto 1200°C) electric quartz tube furnace. The samples heated at High Heating Temperatures (HHT) such as 350°C, 450°C, 550°C and 650°C with a heating rate of 5°C /min and with the holding time of 60 mins. Slow pyrolysis at 450°C -500°C is a viable choice to obtain high yield and good quality biochar (Yu *et al*., 2017). Fixed bed vertical, tubular reactor made of quartz glass was used for the preparation of BC, with 40°C/min heating rate reached a higher level upto 500°C, under the flow of N_2 at 100ml/min (Bordoloi *et al*., 2017). Nitrogen gas used in the pyrolysis process is mainly to avoid oxygen presence inside the reactor (M Sekar *et al*., 2021)

Characterization of biochar

The characteristics of biochar vary by feedstock and by processing condition (Li *et al*., 2018). The elemental composition, pH, specific surface area, surface potential and spectral property of the biochar were analyzed by various analyzer such as elemental analyzer, and inorganic elemental constituents by inductively coupled plasma optical emission spectrometer (ICP-OES), pH meter, surface analyzer, zeta potential analyzer and FTIR spectroscopy (Ni *et al*., 2018). Taghavi *et al*., 2018 characterized the protein content of brown macroalgae was measured by Kjeldahl method based on national standard of GB/T 6432-1994 and in accordance with GB/T 6433-2006 standard, the amount of lipid was obtained by the solvent extraction method. Volatile and moisture content were measured at a temperature ranging from 30°C to 800°C at 10°C/min with a nitrogen gas flow of 20 L min-1 through thermogravimetric analysis (TGA) using thermogravimetric analyzer (TGA/SDTA851 and METTLER-TOLEDO compact). Based on the standard test for determination of ash content of biomass ASTM E1755, the ash content was obtained.

The surface area is the main physical property which affects the metal sorption (Karthik *et al*.,). The specific surface area was quantified using N_2 multilayer surface area and porosity analyzer and the measured data arranged according to the BET method (Son *et al*., 2018). The carbon and nitrogen contents of biochar were studied using Stable Isotope Analyzer (Mahdi *et al*., 2016). And various common analytical techniques of biochar are X-Ray Diffraction (XRD), X-Ray Photoelectron Spectroscopy (XPS), Scanning Electron Microscopy (SEM), Transmission Electron Microscopy (TEM), X-Ray Spectroscopy (EDS), Scanning Transmission Electron Microscopy (STEM), X-Ray adsorption Spectroscopy (EXAFS) and solid state Nuclear Magnetic Resonance (NMR) were briefly presented (Wang *et al*., 2019). The pH and electrical conductivity were measured by pH-EC meter, ash content, volatile matter and yield of biochar was determined by American Society for Testing Material (ASTM) method D1762.

Biochar as a bioadsorbent

Recent researches have shown that biochar is an effective biosorbent which is ecofriendly and easily available in sufficient quantities and it has also been proven to be an effective adsorbent of inorganic and organic pollutants. (Xue *et al*., 2012). Biochar has been shown to be very effective in immobilizing, adsorbing and sequestering a number of heavy metals from soil and water. The adsorption capacity of biochar depends on its physicochemical properties such as surface area, distribution of pore size, functional groups and cation exchange capacity, while physicochemical properties differ with preparation condition (Wang *et al*., 2019). These properties play a major role in the interplay between biochar surfaces and heavy metals.

Biochar promotes sustainable environment

For the sustainable environment, biochars help based on its three sustainability factors such as use of sustainable biomass, sustainable production processes, and sustainable end use (Elad *et al*., 2011). Biochar creates a sustainable agricultural land and environment mainly by neutralizing the soil from acidic state (Jeffery S *et al*., 2011) by which the soil nutrients and microbial activity is increased. Due to its high-water retention capacity, biochar reduces the leaching of soil and improves the water regime of the soil (Novak JM *et al*., 2012). The capability of biochar is to adsorb and neutralize the phytotoxic organic compounds by increasing the surface area during pyrolysis (Thies J *et al*., 2009). Many studies exclaimed that the application of biochar on soil as a greater sorption affinity, it binds with various organic pollutants in the environment.

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