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Review Article

Production of biochar from different feedstocks using various methods and its application for the reduction of environmental contaminants: A review

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Abstract

The production of biochar from agricultural and environmental waste biomass is gaining a lot of interest as a low-cost supplement due to the many potential benefits. It may have for agriculture and the environment as well as its porous structure and ability to hold soil water. Numerous uses for biochar existed, ranging from soil amendment to the generation of heat and power. This review summarizes the importance of low cost biochar derived from biomass related to agriculture and environmental health, crop responses, nutrient dynamics and other aspects. Biochar may be useful for managing agriculture and the environment in relation to problems with the physico-chemical properties of soil. This review's goal was to consolidate the most recent information on the potential use of biochar, its application, and its impacts.

Keywords: Biochar; pyrolysis; waste biomass; soil, biogas; composting; agriculture.

1. Introduction

From last 40 years agriculture has fed a growing population of India but the green revolution is largely seen to be unsustainable and damaging to environment. Therefore, there is a need for a new "double green revolution" that would boost crop production, reduce the negative effects, improve sustainability, and make all of these benefits available to both commercial growers and farmers (Barrow, 2012). Unconventional methods of disposing of agricultural waste will harm the environment, and deplete several bioenergy supplies. It is widely accepted that recycling and reusing of agricultural waste can help in protection of the environment, improve the energy grid, and also promote agriculture production. Problems of waste disposal have been reduced by converting biomass into biochar. Recycling of used materials is not giving rise to any new problems (Sahu et al., 2022). Additionally, biochar might be a useful for soil supplement, for restoring damaged land and making soils productive, which would help to prevent additional logging (Barrow, 2012). Biochar is a soil conditioner having the capacity to hold macronutrients directly, such as nitrogen and a carbon-rich charcoal-like substance that is formed by heating the biomass in an oxygen-deficient condition in a process known as pyrolysis (Das et al., 2018). Although biochar and charcoal are similar, they are differing as follows: biochar is typically used to enhance environmental conditions and it can be for used other than fuel. However, charcoal is basically used as a fuel during the burning process (Godlewska et al., 2021). Biochar, a new material that have the potential to increase a country's food security while perhaps sequestering carbon to decrease the global warming (Kuppusamy et al., 2016). International biochar initiative states that the carbon content of biochar is classified into three categories: category 1 > 60 wt %; category 2 30-60 wt %; and category 3 30 wt% (Seow et al., 2022). Biochar can be made from any waste biomass like sawdust, bagasse, hard wood, orange peels, pine needles, and so on (Manyuchi et al., 2018). It has the ability to enhance plant growth by improving the physical, chemical and biological properties of the soil. The physical properties of soil include density, pore space, hydraulic conductivity, aeration, temperature etc.. The chemical properties of soil include pH, cation exchange capacity, exchangeable activity, nutrient availability, sorption, etc. The biological properties of soil include enzymatic activities, root nodulation and microbial biomass (Das et al., 2020; Nigam et al., 2021). Biochar is material that can provide a favourable environment and nutrition for microbial growth in soil and enhance crop production. It has been reported that biochar addition can invigorate microbial growth or cause a change in the microbial community structure (Zhang et al., 2021). The characteristics and chemical properties of biochar and its by-products depend on the heating rate and nature of the feedstock used, whereas surface properties and pore structure depend on the heating temperature (Wang et al., 2018; Das et al., 2020). The long-lasting stability of biochar depends on its surface characteristics, porosity and ability to increase nutrients bioavailability, which consequently increases crop productivity under specific pedoclimatic conditions (Das et al., 2020). Though it has also been shown that biochar has the ability to change the soil's biological community composition and abundance, the cycling of soil organic matter, nutrient cycles, and plant growth is affected by changes in microbial community composition induced by biochar (Lehmann et al., 2011). It is commonly known that the use of biochar to amend soil can increase agricultural output and encourage yield (Wang et al., 2018). The potential use of biochar in soil amendment, carbon sequestration, renewable energy, waste management and lowering greenhouse gas emissions has attracted interest in recent years (El-Naggar et al., 2019). The ultimate goal of biochar application is to enhance crop response for higher production and crop productivity (Das et al., 2020). Being used solely for environmental and agronomic purposes and not for fuel, biochar's property made it distinct from traditional charcoal. Many studies and reviews highlighted the potential benefits of biochar application as soil amendments covering issues such as waste management, production of bioenergy, enhancing soil fertility through alteration in soil pH, improve nutrient retention, reduction in nitrous oxide and methane along with carbon dioxide (Kuppusamy et al., 2016). The biggest challenge related to using biochar is that harmful substances can be released from the biochar matrix and has impact on living beings (Godlewska et al., 2021). The goal of this review is to examine the most recent developments in feedstock and biochar production technology, their effect on crop productivity and the hazards associated with biochar.

2. Methods for biochar synthesis

For environmental sustainability, it might be possible to convert regular trash to biochar. Common wastes like agricultural residue, sludge waste, manure, biomass crops can generally be used as feedstock to produce biochar. Distinct feedstock exhibits varied proportion of elemental composition so they have distinct properties and as a result, the biochar produced from those feedstock performs differently. For instance, compared to wood biochar (349 mg/kg, pH 8.0), straw-derived biochar had a greater potassium concentration such as 961 mg/kg and pH 9.5. Additionally, the biochar made from straw had more volatile material, which resulted in a high yield of biochar as compared to feedstock with high volatile content, which may result in a low yield of biochar during pyrolysis (Wang et al., 2019). Biochar is frequently prepared by pyrolysis, gasification, hydrothermal carbonization, or microwave pyrolysis as mentioned in Table 1. The physicochemical properties of biochar and its adsorption

2.1 Pyrolysis

Pyrolysis is the process of thermally degrading biomass with heat in the absence of oxygen (Demirbas et al., 2002). Pyrolysis is divided into two types: fast and slow. The later technique facilitates the synthesis of biochar, while the former it was employed to produce bio-oil and syngas. A wide temperature range, a slow heating rate, a lengthy residence period and a high product yield are the characteristics of slow pyrolysis (Zhao et al., 2022; Yang et al., 2019).

Table 1 Different type of preparation methods of biochar

Preparation Method	Heating Method	Temperature (ºC)	Residence Time	Biochar Yield (Weight %)
Slow Pyrolysis	5-10ºC/ Min	300-800	45-550 Sec	35
Fast Pyrolysis	>200ºC/ Min	400-600	0.1-10 sec	12
Gasification	Moderately Very Fast	700-1500	10-20 sec	~10
Microwave Pyrolysis	Slow	550-700	5-20 min	~34
Slow Pyrolysis	5-10ºC/ Min	300-800	45-550 Sec	35

capabilities can be directly impacted by variations in the feedstock and the preparation techniques (Zhao et al., 2022).

2.2 Gasification

Generally speaking, gasification is the partial oxidation and burning of biomass materials in the presence of a specific gas (air, oxygen, or steam) at a temperature of 600–1200 °C. The yield of biochar is quite low because gas is the primary product (Zhao et al., 2022).

2.3 Hydrothermal carbonization

The technique of submerging biomass materials in to water at a specific pressure at a temperature between 175 and 300 °C is known as hydrothermal carbonization. When water is present during the carbonization process, materials with a high moisture content result, whereas the biochar formed by hydrothermal carbonization has a comparatively high surface functional group and acidity (Zhao et al., 2022).

2.4 Microwave pyrolysis

Electromagnetic waves having frequencies between 300 MHz and 300 GHz are known as microwaves. The energy input for microwave pyrolysis may be increased. In comparison to other carbonization techniques, microwave pyrolysis is more effective, simpler to manage, and more time- and energy-efficient since it can swiftly and evenly transfer energy to biomass materials. Microwave pyrolysis produces biochar that is more porous, more stable and has a greater specific surface area (Zhao et al., 2022; Huang et al., 2016).

3. Characteristics of biochar

Biochar is porous, black, and extremely high in carbon (often 40 to 90%). As compared to activated carbon, biochar is typically less pure and can therefore contain more carboxyl, hydroxyl and phenolic functional groups as well as inorganic minerals. Fundamentally, carbon that was organized hexagonally in a honeycomb pattern without oxygen or hydrogen supports the structure of biochar (Zama et al., 2018). The primary factors affecting biochar composition are the biomass feedstock, residence time, pyrolysis temperature and reactor type (Gorovtsov et al., 2020). Overall, when the pyrolysis temperature rises, the yield of BC declines (Borgohain et al., 2020; He et al., 2021). Biochar's physical properties such as density, porosity, specific surface area, pH value, heating value, volatile matter content, cation exchange capacity influenced by its initial organic material, which is biomass as well as the carbonization or pyrolysis technologies by which it is formed. In addition to a number of other physical and chemical characteristics (like value of pH, elemental composition, energy content, degradation and so on), yield can be used to describe the characteristics of biochar (Xie et al., 2022; Qiu et al., 2019; Weber et al., 2018). The final properties and ash content of biochar are mainly depends on type of feedstock used and production temperatures (Fig.1) (Chen et al., 2016).

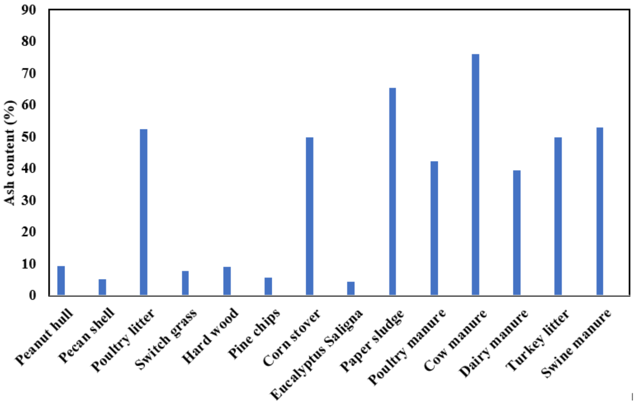

Fig. 1 Ash content (%) present in different waste for producing biochar

3. Application of biochar

3.1 Application of biochar in Wastewater treatment

Nowadays, turning biodegradable biowaste into biochar is a useful recycling technique. Biochar may effectively remove heavy metals from aqueous solutions in place of activated carbon or other water purifiers (Maroušek et al., 2017; Xie et al., 2022). Due to the high soil mobility of Sulfamethoxazole (SMX) and its widespread use in New Zealand to treat animals, it has been demonstrated that SMX seriously contaminates aquifers. SMX is typically removed using materials such as bamboo, sawdust from pine trees, corn cobs, sugarcane bagasse and biochar formed from wood. Due to its wide surface area (795 m^2/g) and less exchangeable cations, which lessen the hydrophilicity of the biochar surface, pine sawdust showed the highest sorption affinity for SMX (Zama et al., 2018).

3.2 Application of biochar in production of biogas

It was discovered that adding biochar increased the activity of methanogenic microbes and decreased the amount of CO_2 in the biogas. All biochar-amended digesters produced higher methane content (75.3–96.7%) than those with no biochar addition, for both mesophilic and thermophilic operations (Fig 2) (Xie et al., 2022; Qiu et al., 2019). When biochar is added to anaerobic digestion, the fatty acids are effectively stabilized, and the rate of substrate breakdown is increased. Additionally, it reduces the buildup of free ammonia and keeps the concentration of ammonia nitrogen (NH_4N) at a low level. Another advantage of adding biochar is that it enhances the activity of the bacteria that do methanogenesis in preset environments, increasing the yield of biogas (Sirohi et al., 2023).

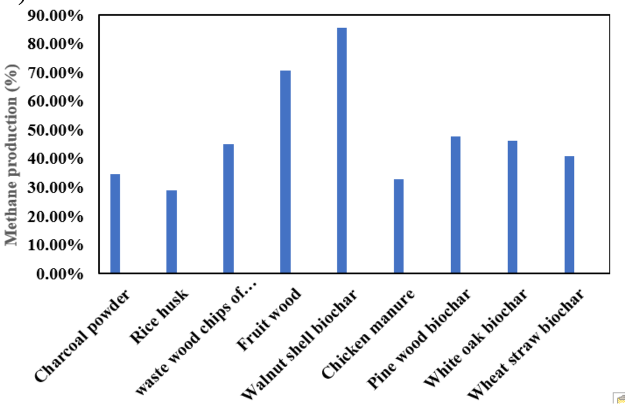

Fig. 2 Methane production efficiency (%)

3.3 Application of biochar in composting

According to research, during the process of composting, biochar is more efficient at breaking down soluble organic carbon (DOC) than the system without the inclusion of biochar. Addition of biochar to composted organic mass increases the porosity of mixture due to having variety of pores, which results in more effective composting process (Godlewska et al., 2017; Xie et al., 2022). Numerous composting studies have been conducted to examine how biochar influences nitrogen loss and NH_3 volatilization. The most effective way to prevent N loss is regarded as the use of biochar in composting. Incorporating 9% biochar into the composting of sludge dramatically reduces the loss of total nitrogen by 64.1% (Zhang et al., 2018; Siedt et al., 2021).

3.4 Biochar used as a catalyst

From cooking oil, about 88% of the biodiesel product that is ester is produced by sulphonated biochar. The solid acid or base biochar catalysts previously reported led to high biodiesel generation from a variety of food oils (Lee et al., 2017; Xie et al., 2022; Li et al., 2022). Tar cracking is accelerated by the presence of the inorganic elements K and Fe in biochar. The surface functional groups of biochar may facilitate the adsorption of metal precursors, an important step in the manufacture of metal catalysts supported on biochar. The tiny surface area and poor porosity of biochar, among other characteristics, preclude its employment as a catalyst. Numerous modification methods were consequently developed to give biochar unique properties. Some of these methods include picking the appropriate feedstock, controlling the synthesis conditions, physical or chemical activation, surface functionalization, and building composites with other materials (Cheng et al., 2018). The generation of biodiesel, biomass pyrolysis, bio-oil upgrading, tar removal, and the Fischer-Tropsch synthesis of liquid hydrocarbons from syngas all use biochar-based catalysts as part of their biomass refining processes (Cheng et al., 2018).

3.5 Electrochemical application

Biochar is stable, highly aromatic, rich in carbon, and environmentally friendly. Due to these benefits, it is ideally suited for the construction of electrochemical and biological sensors. The research on biochar-based electrochemical sensors, particularly biosensors, is still in its early stages, hence there aren't many studies published yet. The main focus of the detection operations is on three techniques for identifying analytes that are based on the previously described characteristics of biochar, namely absorption, electrochemical deposition, and cross-linking. As a result, the various testing objects will necessitate distinct electrode modification techniques and biochar qualities (Xie et al., 2022; Li et al., 2022).

3.6 Application of biochar in remediation of environment contaminated with heavy metal

Soil contaminants like pesticides and fertilizers, waste water irrigation, use of plastic film covers, industrial operations, heavy metal, metalloids, polycyclic aromatic hydrocarbon (PAH) and so on may exhibit high toxicity, persistence in the atmosphere, and bioaccumulation. Due to its ample surface functional groups and porous structure, biochar can effectively absorb, convert and immobilize these soil contaminants (Xiong et al., 2021; Zhang et al., 2018). The majority of urban and suburban soils contain significant amounts of lead, a frequent pollutant. Several forms of biochar, including those formed from wood, husks, sewage sludge, bones, and yard wastes, have been used to study Pb sorption in soil at different pyrolysis temperatures (often 300-700 °C). When it comes to eliminating Pb through sorption from environmental media, the average sorption rates in water and soil for all of these biochar, both modified and unmodified, were 90% and 60%, respectively (Zama et al., 2018). There isn't much research either on the longevity of PAHs in soils that have only been biochar-amended.

After 851 days, 3- and 4-ring PAHs were the most prone to deterioration and soil leaching in a soil treated with straw-derived biochar (Stefaniuk et al., 2017).

3.7 Application in boosting crop growth

By limiting the loss of soil nutrients and enhancing the microbial populations and soil environment, biochar accelerates the growth of crops. To enhance the rate at which fertilizer is utilized, biochar is frequently employed as a carrier of fertilizer in the soil to slow down fertilizer release and reduce fertilizer loss. Additionally, the minerals and nutrients like P, K, Ca, Mg, and N found in biochar itself can provide crops with nutrients directly (Zhang et al., 2018). At 600 °C, eucalyptus species biochar, when placed in ammonium nitrate solution (10 g/100 ml), could absorb nitrate. The process of pyrolysis must occur at a temperature of at least 600 °C. It is clear that feedstock properties affect NO_3 adsorption potentials. To fully comprehend how feedstock properties affect NO_3 adsorption potentials, more research is necessary (Clough et al., 2013).

3.8 Ameliorating soil structure

Improved soil structure stability has contributed to the improvement of other physical and hydro-physical soil properties and resulted in decreased soil bulk density, increased soil water content and higher soil water retention capacity (Horák et al., 2020). When biochar is put to the soil, it gradually transforms, which also affects how it affects the qualities of the soil. During the process of biochar ageing, some of the impact that biochar has on soil and crops may be diminished or even lost. This makes it logical to think about applying biochar to soils repeatedly at predetermined periods. Biochar is distinguished by a relatively low proportion of aliphatic C compounds due to their primarily aromatic structure. These compounds are released into the soil quickly after biochar is incorporated and are thought to be a crucial component for the development and stability of soil aggregates (Juriga et al., 2021).

3.9 Application of biochar in carbon sequestration

It has been repeatedly demonstrated that biochar is a useful method for reducing soil-based greenhouse gas emissions. Horák et al (2020) found that after employing biochar enriched with compost and mineral N (enriched biochar, purchased as a ready-to-use product), in addition to the traditional mixing of biochar and fertilizer. Prior to application, biochar was co-composed after being sprayed with 10% ammonium sulphate and cold-mixed with organic material for compost in a ratio of 50:50% v/v. According to the findings, applying biochar at two different rates (10 and 20 t/ha) and combining it with a lower nitrogen rate (40 kg N/ha) considerably reduced soil CO_2 emissions. The combination of the greater rate of N (80 kg N/ha^{-1}) and the lower rate of biochar (10 t/ha^{-}) increased these emissions at the same time. The production of CO_2 was also significantly boosted by enriched biochar (EBC), whether it was used alone or in conjunction with N-fertilizer. These findings suggest that using biochar alone, without compost or nitrogen, may be a useful strategy for retaining soil carbon and lowering CO_2 flow into the atmosphere. On the other hand, using enriched biochar to reduce CO_2 emission, a significant greenhouse gas is ineffective (Horák et al., 2020).

3.10 Cost effective alternatives

An increased number of oxidation-reduction processes occur inside the soil matrix when biochar is added to the soil. Another advantage of biochar is that it can last in fields for years due to its long-term persistence in the environment and soils. As a result, biochar might not need to be applied again every year, making it a more affordable option (Allohverdi et al., 2021). Due to its renewable feedstock and sophisticated synthesis procedures, the manufacture of biochar is both affordable and convenient. Different methods were created to adjust the physicochemical characteristics of biochar in accordance with its intended use. The presence of inorganic species and surface functional groups are two further aspects of biochar that may make it an effective catalyst or catalyst support. Therefore, biochar-based catalysts are a possible replacement for existing catalysts that are costly or not renewable. A more integrated and sustainable biorefinery system uses biochar-based catalysts to produce biofuel (Cheng et al., 2018).

3.11 Application of biochar in remediation of water pollutants

Biochar has been presented as an adsorbing material for the treatment of contaminated water with diverse contaminants in the recent years. Pollutants that are both organic and inorganic, such as organic dyes, nutrients, heavy metals, etc. One of the most dangerous inorganic contaminants found in groundwater is arsenic, which is produced through naturally occurring arsenic-bearing rocks or by human activity. Consuming As-contaminated water exposes people to a variety of harmful effects, including heart disease, cancer, skin rashes etc. It was effective to use biochar to remediate both As(III) and As(V) species in aqueous solution (Verma and Singh, 2022; Vithanage et al., 2017). When soil was treated with 0.5% modified biochar, the content in the roots, stems, leaves, and grains decreased from 356, 3.93, 4.88, and 0.349 mg/g in the control (without biochar) to 241, 3.08, 3.77, and 0.328 mg/g in the treated soil. This represented reductions of 40.8, 44.3, 33.2, and 17.7%, respectively, in percentage terms (Zama et al., 2018).

3.12 Application of biochar in removal of pesticides and herbicides

Pesticides and herbicides like atrazine, catechol, carbaryl, diazinon, 2,4- Dichlorophenoxyacetic acid, fluridone, naphthalene, oxamyl can be removed from dairy manure, oak, pig manure, H_3PO_4 treated rice straw, wood chip, grass, orange peel, wood chip and rice straw respectively at different temperatures. The removal concentration range for different pesticides may vary (Inyang et al., 2015). In the laboratory or greenhouse, the elimination of atrazine by biochar has likewise proven largely successful. Atrazine removals greatly influenced by soil dissolved organic carbon and pH and it has frequently been accomplished using wood and manure-based biochar (such as pine wood and dairy waste manure) (Zama et al., 2018).

4. Limitations of using biochar

Additionally, the mutagenicity, genotoxicity, and cytotoxicity of biochar have been examined using the AMES test (the mutagenicity test employing Salmonella typhimurium strains). Godlewska et al (2021) investigated aqueous extracts of biochar made at 500 °C from commercial wood pellets or hemp bedding. Despite the fact that both extracts had mutagenic effect, the hemp bedding extract was more so. Biochar contains PAHs due to insufficient pyrolysis of the biomass. Bio-oil, syngas, and biochar are all by-products of pyrolysis. The kind of pyrolysis, pyrolysis temperature, feedstock, and the feedstock's residence time in the reactor all affect the PAH content in biochar (Brtnicky et al., 2021). The high PAHs content in biochar was responsible for the harmful effects that were seen. Among the investigated biochar, pig dung biochar had the highest level of mutagenicity (54% mutagenic potency). Miscanthus and sawdust-derived biochar had the lowest mutagenic potential (almost 1% potent) (Godlewska et al., 2021). Due to its high porosity and specific surface, the use of biochar may reduce the effectiveness of agricultural chemicals such as pesticides, herbicides, insecticides, fungicides, and nematicides. It may be beneficial to reduce pesticides' concentrations to prevent them from leaching into groundwater and surface water, as well as their concentration in non-target organisms. The ability of these chemicals to effectively control pests may be severely hampered by this, though. Pesticides may have less bioavailability if there are strong interactions between them and biochar (Brtnicky et al., 2021). Additionally, biochar can also decrease the bioavailability of metals in polluted soils, which in an agricultural setting may result in metals being locked up and causing micronutrient deficiencies that would ultimately lower production (Lucchini et al., 2014).

5. Effect of biochar on soil biota

There is mounting evidence that biochar does not always benefit soil and its biota and that it is impossible to generalize about how it will affect any given microorganism. Additionally, in spite of its long-term stability, biochar experiences chemical, physical, and biological changes over time, making it very challenging to predict any effects both qualitatively and quantitatively. Studying the potentially negative consequences of biochar on agricultural soil is thus necessary (Brtnicky et al., 2021). In most circumstances, biochar addition increases microbial biomass and drastically modifies the makeup of the microbial community and the enzyme activity in the soil. Additionally, biochar can speed up the absorption of nutrients and water by microorganisms. Even when compared to activated carbon, biochar's ability to hold water is almost two times greater (Chen et al., 2016; He et al., 2021). According to a different study, adding biochar to soils decreased the amount of the polychlorinated biphenyls (PCBs) in the tissue of the earthworm species such as *E. fetida* that was cultivated in soils with amendments of biochar (w/w) 2.8% (reduced 52% PCBs) and 11.1% (reduced 88% PCBs) (Chen et al., 2016). Marks et al. (2014) reported that the survival and reproduction of two soil-dwelling invertebrates were affected by biochar addition. However, the effects were influenced by the type of biochar and even the pyrolysis condition. Soil faunal responses to biochar are highly variable. However, the influences could not be generalized to all types of biochar and soil based on the findings of the current researches. The results, positive or negative, obtained by most studies depend greatly on the type of soil, feedstock used under different production temperatures (Chen et al., 2016). Members of *Bradyrhizobiaceae* and *Hyphomicrobiaceae* families may consume NO_3, N_2, and NH_3 as well as be able to fix N_2 and denitrification during anaerobic phases (Clough et al., 2013). The two types of mycorrhizal fungus, arbuscular [AM] and ectomycorrhizal [EM], respond favorably to biochar. For different groups of microorganisms, microbial abundance may different (Lehmann et al., 2011). It has also been shown that the rate of microbial reproduction rises in some biochar-amended soils. Similar to this, adding biochar (commercial wood charcoal) to biodigesters boosted the number of anaerobic and cellulose-hydrolyzing bacteria. As a result, an energy source, methane (CH_4) is produced (Lehmann et al., 2011). Of all the effects on soil fauna, earthworm interaction with biochar appears to be the most thoroughly researched. Clearly, earthworms consume biochar particles. The earthworms were able to pulverize the substance and incorporate it into the soil; in fact, they preferred soil that included biochar to soil without it (Lehmann et al., 2011; Clough et al., 2013).

6. Challenges regarding use of biochar

Biochar contains PAHs due to inadequate pyrolysis of the biomass. Biochar, syngas, and bio-oil are the by-products of pyrolysis. PAH content in biochar basically depends on the pyrolysis temperature, feedstock type, and residence time of the feedstock in the reactor. However, due to the wide variations in the extraction techniques used, it is challenging to establish a direct correlation between biochar characteristics and their PAH concentration. To ensure biochar safety, regulatory bodies like the International Biochar Initiative (IBI) and the European Biochar Certificate (EBC) have set standard values for biochar-borne PAHs; if these standards are exceeded, these biochar are deemed unsuitable for use in agriculture. The PAHs might be readily absorbed by roots and accumulated in plants (Brtnicky et al., 2021). Because of the thermochemical changes that occur to the molecules present during the pyrolysis of biomass, volatile organic compounds (VOCs) such as acetic, butyric, and propionic acids, methanol, phenol, methylated phenol and cresol are produced. Regardless of the type and circumstances of pyrolysis, VOCs are always present in biochar. VOCs are re-condensed during the pyrolysis process and sorb to the biochar (Brtnicky et al., 2021). Nitrification activity may be decreased by volatile organic molecules related to the synthesis of biochar (Clough et al., 2013).

7. Conclusion

Biochar having ability to increase soil fertility and potential removal capacity of contaminants due to its structure gain extensive attention in recent years. The present review summarizes the properties, preparation method, application related to biochar as well as limitation and challenges associated with it. Although numerous research have looked at the benefits of adding biochar to soil, few of them have chosen the right biochar with customized properties and the right dosage depending on management goals and soil characteristics.

8. Future prospects

Biochar has wide application prospects but still there are some issues that needed for future further studies-Efforts should be made for development of target-oriented biochar. Performance and application of biochar greatly depend on how biochar made, type of feedstock used, type of soil so that studies should be done on this. Preparing cost of biochar must be reduced so that it can reach to the poor farmers also. Sensitivity of biochar should be tested more on soil biota and their performance. Due to the complicated field-related factors, such as various biochar-soil mixing techniques, biochar ageing effect, climate and slope of application field, seasonal and spatial variation of field, impact of biochar amendment may have inconsistent results between field- and laboratory-scale experiments.

Author contribution

Pooja Adwani (Research scholar): Review literature, Writing and Formal analysis. **Jiwan Singh** (Asst. Professor): review, editing and validate the article.

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Conflict of interest

The authors have disclosed no conflicts of interest.

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