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(Review Article)

Industrial Cannabis sativa-Hemp: Biochar applications and disadvantages

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Abstract

This review paper highlights Industrial *Cannabis sativa*-Hemp uses and disadvantages particularly in the form of biochar. Biochar is defined as the burning of the organic material at high temperature under limited oxygen supply to produce carbon rich material is known as biochar. Biochar is a carbon-rich product that is formed under pyrolysis of different organic materials. Biochars were generally characterized by having a porous nature and large surface area. Biochar can provide nutrients to the soil directly because it contains nitrogen, phosphorous, potassium, magnesium, and calcium. Progressive mineralization of biochar in soil releases inherent nutrients into the soil. Hemp biochar carbonized at 800–1000°C displayed interesting electrical conductivity, opening opportunities for its use in electrical purposes. Biochar is an important material for environmental management to mitigate greenhouse gas emissions, such as sequestration of CO_2 and CH_4, and ozone-depleting N_2O emissions. Biochar can be utilised as a soil conditioner and a container substrate amendment in agriculture and horticulture. Biochar also has the potential to improve a variety of soil and substrate physical, chemical, and biological qualities. However, there are some disadvantages of biochar, is that the addition of biochar resulted in such a high pH that the plant growth was severely reduced, which might have obscured any potentially beneficial effect of using biochar. This however highlighted the challenge in using biochar in organic growing media due to the difficulty in maintaining the pH at an adequate level for plant growth.

Keywords: Biochar; Biomass; Carbon sink; Cannabis; Electrical conductivity; Hemp; Pyrolysis

1. Introduction

Industrial *Cannabis sativa*-Hemp is a herbaceous annual plant (family *Cannabaceae*) that has a 4- to 8-month life cycle, is naturally dioecious, reproduces via seed propagation grown for the production of fibre, seeds and oil [1-21, 58]. Hemp seeds are used as a functional food and medicine since it contains Cannabidol (CBD), and very low levels (0 to 0.3% dry wt) of Λ9-tetrahydrocannabinol (THC) [1-21, **76**]. The growth and reproductive cycle progression of hemp is photoperiod-sensitive. Hemp (*Cannabis sativa* L.) is a multi-use crop that has been investigated for its potential use in phytoremediation of heavy metals, radionuclides, and organic contaminants, and as a feedstock for biochar and bioenergy production [1-22, 58]. The morphological features of hemp, such as faster growth, beautiful, green leaves, as well as aromatic flowers, make it suitable for use as a landscaping plant [58]. According to the findings, Cannabis has a high ornamental potential and high viability for sustainable exploitation in the horticultural and ornamental industry [1-22, 58]. Hemp plants can grow to heights of up to 5 m and can develop a tap root penetrating up to 2 m into the soil. The majority of above ground hemp biomass comes from the tall lignocellulosic plant stalk, which has been used for fibre for thousands of years [1-22]. The hemp stalk has two main fibre types: long bast fibers and short hurd fibres [1-22, 58]. The outer bast fibers surround the vascular tissue of the hemp stalk, whereas the hurd makes up the woody core. Hemp is a bast fiber, which means fiber is extracted from the stalk of the plant [1-22, 58]. Hemp "line" is the term

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that refers to the long fibers that lie straight and parallel [1-22, 58]. This results in yarns that are softer and smoother. Chemically, the bark fibres of the hemp stalk contain considerably more cellulose and holocellulose, and significantly less lignin than either hardwoods or softwoods [1-22, 58]. Hemp core, on the other hand, contains less cellulose than wood, about the same holocellulose fraction, and generally the same lignin content as hardwood species [1-22, 58]. Costs of growing hemp for bioethanol are similar to those of Kenaf (*Hibiscus cannabinus*), and higher than those for Switchgrass (*Panicum virgatum*) and Sorghum (*Sorghum bicolor*) [1-22, 75]. The different fibre types can be used to make a variety of textile and industrial products such as fabric, paper/ pulp, insulation, composite boards, plastic, paint, sealant, biochar and bioenergy [1-22, 58].

Cannabis sativa L., is classified into two types as Industrial *Cannabis sativa*, hemp or Medical *Cannabis sativa* L.(drug or marijuana) based on its Λ9-tetrahydrocannabinol (THC) content [1-21, **76**]. Medical *Cannabis sativa* (drug or marijuana) contains very high levels of THC (above 0.3 to 38% of dry weight) and grown inside the greenhouse controlled conditions for the production of unfertilized female flowers and used as a medicine for many health disorders [1-21, 58]. On the other hand Industrial *Cannabis sativa* L. (Hemp) contains very low levels of Λ9-tetrahydrocannabinol (THC) (0 to 0.3% of dry weight) grown outside in a large agriculture farms for the production of fiber, seeds, oil, medicine, bioenergy and biochar [1-21, 58]. The ability to utilize the entire plant for multiple purposes creates opportunity for the market to value hemp products [1-21, 58]. Hemp production technology varies depending on the type of hemp cultivated (grain, fibre, or Cannabinoids), soil characteristics, and environmental factors [1-21, 58]. Hemp has the potential to be a very sustainable and ecologically benign crop [1-21, 58, 76]. Hemp roots have a significant potential for absorbing and storing heavy metals such as lead, nickel, cadmium, and other harmful substances [1-21, 58, **76**]. In addition, hemp has been proven to be an excellent carbon trap and biofuel crop [1-21, 58]. Hemp has the ability to successfully suppress weeds, and it is generally regarded a pesticide-free crop [1-21, 58, 76].

Biomass is considered as an important and promising renewable energy source with a good prospect for power generation [53-74]. Furthermore, biomass-to-power technologies can be low-cost and low-risk strategies to replace fossil fuels [22-34, 53-74]. **Biochar** is a fine-grained, high-carbon residue created most often by advanced pyrolysis techniques (direct thermal decomposition of biomass in the absence of oxygen and preventing combustion) [22-34, 53-74]. It makes a combination of solids (biochar), liquids (bio-oil), and gases (**Syngas**) as a result of the process. Biochar is a product that is produced from biomass through a pyrolysis process [22-34, 53-74]. Biochar is an important material for environmental management to mitigate greenhouse gas emissions, such as sequestration of CO_2 and CH_4, and ozone-depleting N_2O emissions [22-34, 53-74]. In addition, to use as soil amendments and solid fuel, biochar materials produced through thermochemical processes exhibit a diverse range of interesting properties (electrical conductivity, porosity, thermal stability, activated surface area) that make them suitable for innovative integration in coatings, nanomaterials and bio-composites [22-34, 53-74]. In the following section, the production of biochar, applications, disadvantages has been discussed.

2. Biochar Definition

Biochar is defined as the burning of the organic material at high temperature under limited oxygen supply to produce carbon rich material is known as biochar [22-74]. Biochar is a carbon-rich product that is formed under pyrolysis of different organic materials [22-28, 53-74]. Pyrolysis refers to the process of thermal degradation of biomass in an oxygen-restricted environment, in which gas and bio-oils are produced in the first hand, and biochar is generated as a solid residue [22-34, 53-74]. Biochar is a carbon-rich porous material, and its main industrial applications are relevant to the construction, plastic, paper, and textile sectors [22-34, 53-73]. Application of crop residues and biochar have been demonstrated to improve soil biological and chemical properties in agro ecosystems [22-34, 53-74]. Biochars were generally characterized by having a porous nature and large surface area [22-34, 53-73]. The interest in biochar has escalated in recent years, much owing to its well-documented capacity to sequester atmospheric carbon into soil [22-34, 53-74]. The carbon sequestration capacity is explained by the exceptionally stabile structure of biochar, which is a result of the pyrolysis process in which aliphatic C is transformed into aromatic C [22-34, 53-74]. Consequently, biochar has been recognized as a carbon sink and as a potential climate mitigation tool. In addition, the porous nature of biochar enables a good water-holding capacity, which is associated with improved nutrient retention [22-34, 53-74]. Thus, biochar has successfully been used to reduce nutrient loss from leaching and gaseous emissions [22-34, 53-73]. Types of biochar depend on material biomass from which biochar is produced. Primarily, biomass is used for biochar production, it includes different varieties of feedstocks such as urban green waste, animal manure, paper items, rice husks, and agriculture waste, etc [22-34, 53-74].

The term biochar, in fact, emerged to distinguish the charred organic matter for soil applications from charcoal which is used mainly for heat or in the iron-making industry [22-34, 53-74]. The International Biochar Initiative (IBI) provides a standardized definition of biochar as a solid material obtained from the thermochemical conversion of biomass in an oxygen-limited environment [22-34, 53-74]. Biochar can also be extremely valuable as soil amendment because it can increase soil organic matter and fertility, microbial activity, nutrient availability, water retention, crop yields, and good plant growth while decreasing fertilizer needs, soil and pollutant mobility [22-34, 53-74]. Furthermore, biochar has the potential for long-term carbon sequestration being recalcitrant [22-34, 53-74]. The defining property of biochar is that its organic portion has a high carbon content which mainly comprises aromatic compounds characterized by rings of six atoms of carbon bound without oxygen or hydrogen [22-34, 53-74]. Biochar can also be obtained through biomass gasification that consists in the conversion of the carbonaceous material in a gaseous fuel by means of a gassifying medium (e.g. air). The gas produced can be used in internal combustion engines for power generation [22-34, 53-74].

3. Biochar Production

To make biochar, organic materials such as hemp husk, timber waste or poultry litter are heated to a high temperature in the absence of oxygen. Such decomposition is called as pyrolysis [22-34, 53-74]. The heating removes water and gases and leaves a stable, mostly-carbon substance [22-34, 53-74]. For use in farming, the biochar is ground into a powder that is applied to the soil. It provides many of the same advantages as compost, such as water and nutrient retention and a better microbial community [22-34, 53-74]. However, compost breaks down within one year in a hot, humid climate, biochar can last for hundreds or thousands of years. The most famous example is in the **Amazon basin**, where biochar added as far back as 6000 years ago still renders the soil darker and much more fertile than the surrounding, low-quality soil [22-34, 53-74].

4. Biochar Applications

Biochar is an organic substance that is typically manufactured from a range of biomass, such as wood, branches, leaves, agricultural waste, shells, husk, animal and poultry waste [22-37, 53-74]. The biomass feedstock can be pyrolyzed at a high temperature with limited oxygen. The resulting material (biochar) is highly porous and stabilized and can be utilized as an adsorbent due to the large surface area, microporosity, functional groups, and hydrophobicity [22-37, 53-74]. Biochar is a carbon-rich and porous material that finds application in different sectors and can be extremely useful in agriculture as soil improver or organic fertilizer [22-37, 53-74]. It is also possible to convert plant biomass into other products through the pyrolysis process which is a sequence of endothermic (dehydration and heating) and exothermic (volatile release and pyrolysis) reactions that degrade plant biomass by heating it in the absence of oxygen [22-37, 53-74]. During pyrolysis, biomass particles are decomposed and form char, gasses (CO, CO_2 and CH_4), condensable vapours containing organic compounds, and water [22-37]. The output of this process is biochar, bio-oil, and gaseous products [22-37, 53-74]. Different types of pyrolysis lead to different products. The feedstock used for the biochar production was pellet composed by blending two residual biomasses, hemp hurd (50%m/m) and fir sawdust (50%m/m) [22-37, 53-74]. Hemp hurd is a lignocellulosic material, fragmented in small flakes (length between 1 and 5 cm) [1-34, 53, 53-74]. This biomass is quite abundant and, in fact, is the main by-product of hemp fiber production [22-37]. Hemp hurd can be employed as filler for construction material or as fuel for combustion facilities [1-34, 53-74]. According to one of the study it was reported that higher the temperature, higher the carbon and ash content and the biochar pH and the lower the hydrogen content and the char yield [22-37, 54-74]. The most noticeable differences between pyrolysis and gasification biochars were the pH and the surface area (considerably higher for gasification char) and the low content of hydrogen in the gasification biochar [22-34, 53-74]. The addition of biochar caused an increase in the pH that can be attributed to the alkalinity of biochar [22-37, 53-74]. Higher pyrolysis temperatures generally yield high pH biochar with more basic surface functional groups and reduced acidic groups, promoting an overall liming effect [22-37, 53-74]. Biochar was reported to carry basic cations such as $Ca+$, $Mg+$, $Na+$, and $K+$ that convert into hydroxides, oxides, and carbonates, resulting in increased alkalinity of the soil and, hence, its pH [22-37, 53-74].

The characteristics and efficiency of biochar vary depending on the feedstock and pyrolysis temperature [22-37, 53-74]. The pyrolysis temperature is an important factor in determining the adsorption capacity of heavy metals in each feedstock. For instance, biochar produced at higher temperatures performed better for metal immobilization than those produced at lower temperatures [22-37, 53-74]. It was also reported that oxygen-containing functional groups tend to be formed at lower pyrolysis temperatures, while aromatic structures and alkaline minerals are always formed at higher temperatures. Because of its porous structure, biochar is perfect for adsorption and has been effectively used to stabilize different pollutants in soil [22-37, 53-74]. Temperature was the most important factor that influenced the biochar physical-chemical characteristics, more than the residence time or biochar-making setup [22-37, 53-74]. Furthermore, the temperature of the process influences germination and plant growth, affecting the pH of the biochar. The concurrence of high temperature and gas purging biochar during the process gave better results on average, in terms of high carbon content and high germinability rate [22-37, 53-74]. Concerning the main differences between pyrolysis and gasification, biochar obtained through gasification showed a much higher pH, porosity and specific surface area, and a much lower hydrogen–carbon ratio and yield [22-37, 53-74].

The elemental composition of biochar was greatly influenced by the composition of the feedstock from which it was derived and the pyrolysis temperature during its production [22-37, 53-74]. One of the study reported that carbon and oxygen percentages of 77.81 and 8.76%, respectively, for biochar produced at 450°C [22-37, 53-74]. Biochar rich in carbon can play an important role in carbon sequestration and contaminant adsorption from soil. Low- temperature pyrolysis (450°C) causes the thermal breakdown of hemicelluloses and cellulosic plant materials, thereby giving rise to large pore spaces that can serve as a habitat for soil microflora, which ultimately improves soil health [22-37, 53-74]. This porous structure of biochar helps in retaining water and nutrients that can be beneficial for soil quality and soil microflora [22-37]. Most of the volatiles are removed because of pyrolysis, leaving behind exchangeable cations such as Ca+2 and Na+, which concentrate and, thereby, increase in the pH and elemental carbon of biochar [22-37, 53-74]. A temperature range of 200 °C to 300 °C causes cellulosic materials to decompose, resulting in alcoholic and phenolic substances (-OH containing substances) that impart alkalinity to biochar [22-37, 53-74]. Moreover, at temperatures above 300°C, alkaline minerals begin to disengage from the organic matrix, resulting in increased pH [22-38, 53-74]. The maximum biomass loss occurs when the hemicelluloses degrade at a temperature range of 250°C to 350°C. Cellulosic components of the biomass begin to decompose at temperatures ranging from 325°C to 400°C, while lignin structures start to degrade at temperatures ranging from 300°C to 550°C. Following are few advantages of addition of biochar to the soil [22-37, 53-74].

The application of biochar primarily increased the organic matter, which improved soil organic carbon [22-37, 53-74]. As a result, the application of biochar at 1% and 5% can be justified by the fact that biochar produced at low pyrolysis temperatures had a substantial volatile carbon content, which, being mobile in because it has enhanced the soil microbial community[22-37, 53-74]. Previously, many studies have documented that biochar application increased soil organic carbon [22-37, 53-74]. These attributes of biochar were the main reason for imparting a high cation exchange capacity (CEC) to biochar, which, in turn, resulted in higher soil pH. About 68% of the changes in soil pH following biochar addition was attributable to the property of high cation exchange capacity [22-37, 53-74]. These salts imparted a higher soil elemental carbon when biochar was decomposed or oxidized. In addition, hydrophobic compounds also leach from the biochar to alter the soil elemental carbon [22-37, 53-74]. Furthermore, increased soil elemental carbon can be linked with the ionic content of biochar. Similarly, many other researchers have reported an increase in soil pH and soil elemental carbon as compared to the control on the addition of biochar to soil [22-37, 53-74].

Biochar can provide nutrients to the soil directly because it contains nitrogen, phosphorous, potassium, magnesium, and calcium. Progressive mineralization of biochar in soil releases inherent nutrients into the soil [22-37, 53-74]. Moreover, enhanced pH due to alkaline minerals in biochar promotes the formation of NH_3 which takes part in the nitrification process because biochar addition stimulates the activity of nitrifying bacteria, which increases available nitrogen [22-37, 53-74]. The positive priming effect of biochar, i.e., accelerating the decomposition of already present organic matter in the soil, can also be the cause of enhanced available nitrogen. In addition to increasing available nitrogen content, biochar can effectively adsorb nitrate and ammonium ions through surface functional groups; mainly the hydroxyl and carboxyl groups, thereby retaining their availability in soil over a longer period [22-37, 53-74]. Phosphorous is a vital component of plant growth, and its availability can be affected by biochar [22-37, 53-74]. Increased Soil available phosphorous (SAP) could be the result of the direct addition of biochar itself to the soil because of its inherent available nutrients, such as phosphorous and potassium [22-37, 53-74].

5. *Cannabis sativa*: Hemp Biochar

There has been a great interest in biochar in recent years, owing to its observed ability to capture atmospheric carbon and improve soil fertility [22-42, 56-73]. With an excellent capacity to retain water and nutrients when applied to soil, biochar can contribute to long-term soil fertility [22-42, 53-74]. Hemp (*Cannabis sativa L.*) is an annual plant that grows under various climate and soil conditions. [1-42]. Hemp fits well in a crop rotation by providing good soil structure, elimination of competing weeds and the ability to withstand pests without the use of high levels of pesticides and insecticides [1-42]. Additionally, the required calcium and water to grow hemp are usually found in sufficient levels naturally, and supplementation, when needed, is relatively low [1-43]. The hemp plant is quite versatile, and all parts can be used for different applications. Hemp is primarily grown for producing Cannabidiol (CBD) oil extracted from the flowers and leaves [1-43]. The remaining hemp by-products, i.e. the stalks, including fibres and shives, represent about 70% of the plant's dried weight and are likely to end up as low-value products or waste [1-42]. Due to a fast growth rate, high amount of biomass and promising energy output-to-input ratios, hemp is considered a potentially valuable energy crop [1-42, 53-74]. Hemp's solid fuel properties are similar to those of woody biomass (i.e., willow) and higher than those of cereal straw, miscanthus and reed canary grass grown in the European region [1-42, 58]. The multifunctional hemp's abundance of beneficial ecological, agronomical, and pharmaceutical properties qualifies it as a useful raw material for a variety of conventional (fibre, food, oil, medicine) and advanced industrial products, biochar [1-22, 58]. Hemp is unusual in that it may be used to produce a wide range of products. It has traditionally been grown for fibre or as a crop with two uses (both grain and fibre) [1-22, 58]. It is widely regarded as a crop with various uses and a wide range of current and future applications, including those for nutrition, energy, textiles, healthcare, and a wide range of industrial goods [1-22, 58].

Hemp is a crop that accumulates biomass faster than other row crops and as such is efficient at capturing 15 tons of atmospheric carbon dioxide per hectare, which makes it a strong bio-sequestration candidate for building soil organic carbon (SOC) [1-42, 58]. As an emerging crop among farmers, the high biomass from CBD hemp can be leveraged, via conversion to biochar, to enhance soil health and nutrient cycling in the face of increasing climate variability as the return of crop residues has been deemed desirable to mitigate building soil organic carbon (SOC) loss and greenhouse gas emission[1-42]. Therefore, for a crop (hemp) known for its high biomass production, it is important to examine the effects of hemp residue and hemp-derived biochar amendments on soil health indicators under different events in soils with contrasting properties [22-42]. Therefore, the application of hemp residue, hemp, and hardwood biochar would affect soil microbial community structure, enzymatic activity, and multiple chemical and biochemical [pH, permanganate oxidizable carbon (POXC), nitrate-N, total soil organic carbon (SOC), total nitrogen (TN)] soil health indicators in response to hydrological cycles in different soil types [22-42]. Biochar properties are unique depending on the feedstock, and pyrolysis temperature, and type [22-42, 53-74]. One of the study demonstrates that both hemp residue and hemp biochar occasionally improved soil microbial enzyme activities (*e.g.*, β- glucosidase, β -glucosaminidase, acid phosphatase, arylsulfatase, and phosphodiesterase), though the extent varied with soil type within the same moisture cycle [22-42, 53-74]. Based on this study, the application of hemp biochar has the potential to enhance soil health, considering the positive effect on soil microbial functional diversity and promote soil health [22-43, 53-74].

The long hemp fibers were reported as a potentially effective reinforcement in polylactic acid (PLA)-based composites that showed improved features [43]. Specifically, polymeric composites reinforced by hemp plant fibres demonstrated interesting properties such as high strength, low weight, and reduced environmental impact [22-43]. Polylactic acid (PLA) is a biobased aliphatic polyester produced by the fermentation of natural glucose-rich resources such as corn, cassava, and sugarcane[42-43]. The polylactic acid (PLA) matrix has demonstrated distinctive compostability, rigidity, and processability [42-43]. The global demand for polylactic acid (PLA) continues to grow and is forecasted to increase 18.1% annually until 2028. Polylactic acid (PLA) is used in various applications such as food packaging, 3D printing filaments, textiles, and biomedical tools [42-43]. Polylactic acid (PLA use is limited by its price, degree of crystallization, inherent brittleness, and its relatively low glass transition temperature that negatively affects thermal resistance [42-43] Reinforcing polylactic acid (PLA) with plant hemp fibers can enhance the resulting mechanical and thermal properties [43].

Biochar is an interesting candidate to reduce prices and improve the performance of polylactic acid (PLA) composites [22-43]. Biochar is a carbon-rich material derived from biomass pyrolysis at high temperatures in an oxygen free atmosphere [22-43, 53-74]. Biochar is a renewable and abundant material prepared from many types of biomass, including waste and low-value feed stocks [22-74]. Biochar recently emerged as filler in polymeric composites, including thermoplastics and thermosets [22-43, 53-74]. The attractiveness of biochar lies in its superior characteristics (depending on pyrolysis conditions), such as hydrophobicity, electrical conductivity, high surface area, and porosity [22-43, 53-74]. Biochar is an interesting candidate when introduced for up to 5 % wt of polylactic acid (PLA) or hemp/ polylactic acid (PLA) in the case of bio-composites production [22-43, 53-74].

One of the study evaluated the influence of biochar reinforcement (0.25 wt%) prepared from different agricultural biomasses (cassava rhizome, durian peel, pineapple peel, and corncob) on polylactic acid (PLA)-biochar composites [22-43, 53-74]. Their results indicated that biochar powder derived from cassava rhizome increased the composite's elastic modulus and impacted energy by 20.7% and 76%, respectively, compared to polylactic acid (PLA) [22-43]. Similarly, another study investigated the mechanical properties of polyvinyl alcohol (PVA) thin films reinforced with hardwood biochar [22-43, 53-74]. They found that the tensile modulus increased by 129%, 271%, and 429% when adding 2 wt%, 6 wt%, and 10 wt% of biochar, respectively, compared to pure polylactic acid (PLA) [22-43, 53-74]. Another study found the effect of biochar incorporation in wood-polypropylene (PP) composites. They concluded that samples reinforced with 5 wt% and 40 wt% biochar exhibited higher tensile strength and water resistance compared to wood-PP composites [22-43]. Other studies used waste wood biochar in PP-30 wt% wood flour bio-composites. They reported the positive effect of biochar addition on mechanical and thermal properties, with 24 wt% addition of biochar exhibiting the best properties [22-43, 53-74].

One of the recent study reported that hemp biochar carbonized at 800–1000°C displayed interesting electrical conductivity, opening opportunities for its use in electrical purposes [40-44]. The electrical conductivity was related to the evolution of the biochar microstructure (development of graphite-like structure and changes in microporosity) in regard with the thermochemical conversion process parameters [44]. Hemp biochar carbonized at 400–600°C were classified as lignocellulosic materials with a good potential for solid biofuel applications [40-44, 54]. Specifically, the resulting carbonized biochar presented low moisture content (below 2.50%) favourable for high fuel quality, low volatile matter (27.1–10.4%) likely to show lower particle matter emissions, limited ash content (6.8–9.8%) resulting in low risk of fouling issues during the combustion, high carbon content (73.8–86.8%) suggesting strong energy density, associated with high higher heating values (28.45–30.95 MJ kg− 1) [40-44, 53-74].

One of the study investigated reinforcing bio-composites by using biochar produced from hemp straw in E-glass fibre in a vinyl-ester polymer matrix [40-51, 54]. Another study indicated that the addition of biochar in polyvinyl alcohol/biochar composites increased tensile modulus and storage modulus above the glass transition temperature but reduced the tensile strength, increased the thermal decomposition temperature of the composites, and provided to the composites an electrical conductivity similar to the most carbon nanotube and graphene reinforced polyvinyl alcohol composites [40-51, 54-74]. The electrical conductivity of biochar, specifically, has attracted attention for the development of batteries, supercapacitors, and pressure sensor materials [40-51, 54]. Recent other study reported that bio-based carbon from hemp hurds and bast fibres prepared via hydrothermal processing and chemical activation showed interesting specific capacitance and high energy density with good potential for an application as supercapacitor electrodes [40-51, 54-74].

In terms of solar-thermal energy conversion and storage, the carbonization of biomass to biochar not only has a rich porous structure, but also has increased graphitization and good light absorption capacity, leading to improved thermal conductivity as well as solar-thermal conversion efficiency of ss-CPCMs [74]. As cheap and renewable sources, the exploitation of biomass resources was of great value in phase change energy storage [74]. In one of this study, hemp stems were converted into biochars with three-dimensional multi-level anisotropic pores through a temperature-controlled charring process, which were used as supports for polyethylene glycol (PEG6000) to form shapestable composite phase change materials (ss-CPCMs) [74]. It is shown that the ss-CPCMs using anisotropic hemp-stem-derived biochar obtained at a carbonization temperature of 900°C as a support has high PEG6000 loading rate (88.62wt%), large latent heat (170.44 J/g) and favourable thermal stability owning to its high surface area and hierarchical pores [74]. The biochar based ss-CPCM also has good light absorption ability with a maximum solar-thermal conversion efficiency of 97.70% [74]. In addition, the different thermal conductivities in the transverse and longitudinal directions of ss-CPCMs reflect the unique anisotropic structure [74].

6. Biochar: Soil Natural fertilizer and Conditioner

The idea of regenerative agriculture using soil as a carbon sponge to help fight climate change is gaining momentum around the world [35, 52]. Climate change is severely affecting the conditions of soil all around the globe [22-35, 52]. The increasing rate of soil erosion due to extreme weather events is not appropriate for lands where crops are cultivated [22-35, 52, 71]. The overall crop production is likely to be decreased by the climate crisis [35, 52, 71]. Soil biodiversity also reduces the impacts of extreme droughts and floods, which are becoming more common as the climate changes. Invertebrates like earthworms and ants are ecosystem engineers [35, 52, 71]. They craft and maintain the structure of soils with their tunnels and burrows, allowing for the flow of nutrients, air and water throughout the ecosystems below ground [35, 52, 71]. Healthy soil with good structure acts as a sponge readily absorbing water during intense rains and holding on to it during dry times improving farmers' outcomes during weather extremes [35, 52, 71].

Soils contain an abundance of biologically diverse organisms that perform many important functions such as nutrient cycling, soil structure maintenance, carbon transformation, and the regulation of pests and diseases [35, 52, 71]. Many terrestrial invertebrates have declined in recent decades. Habitat loss and agrichemical pollution due to agricultural intensification have been identified as major driving factors [35, 52, 71]. A typical functional soil community is comprised of hundreds to thousands of species of macroinvertebrates and nematodes as well as a vast abundance of microorganisms, including hundreds of fungal and thousands of bacterial species [35, 52, 71]. Soil invertebrates perform a variety of different ecosystem services essential for agricultural sustainability [35, 52]. Soil biodiversity enables self-perpetuating ecosystem functions that fuel specialized processes such as soil structure maintenance, nutrient cycling, carbon transformations, and the regulation of pests and diseases [35, 52, 71]. Burrowing activity by soil organisms modifies soil porosity by increasing aeration, water infiltration and retention, and reducing compaction [35, 52]. Earthworms alone involved in decreasing soil erosion by 50% via increased soil porosity and water infiltration [35, 52, 71].

However, soil pollution with heavy metals has become a global issue because of anthropogenic activities causing gradual loss of soil nutrients and fertility, thus, reducing agricultural production [35, 52, 71]. As a consequence of human activities such as mining, oil drilling, waste disposal, industrial operations, pesticide and metal processing, heavy metal pollution has become a global challenge for sustainable agriculture in recent years [35, 52, 71]. Agricultural pesticide use and its associated environmental harms is widespread throughout much of the world. Pesticide contamination of the soil can also result in environmental harm [35, 52, 71]. The extensive use of inorganic fertilizers to replenish soil nutrients is disregarded as a cause of heavy metal accumulation in agricultural soil [35, 52]. In addition to the tremendous amount of heavy metal pollution, soils all over the world are being overexploited for food production, raising concerns for the agricultural ecosystem [35, 52, 71]. Continuous cropping practices lead to gradual loss of soil fertility that will promote the widespread use of inorganic fertilizers that contain essential nutrients along with trace quantities of heavy metals [35, 52, 71].

Biochar is generally referred to as charcoal that is obtained from a process called pyrolysis [22- 35, 52, 53-74]. In this thermochemical process, the biomass is converted into biochar in the absence of oxygen [22- 35, 53-74]. The final product has sufficient carbon content that improves soil health [22- 35, 53-74]. Biochar is recommended as an organic and environment-friendly option to address the issue of nutrient deficiency and heavy metal pollution [22- 35, 53-74]. Biochar is regarded as a soil conditioner because it influences soil properties such as high water holding and cation exchange capacity, which helps in retaining nutrients and microbial activity in the soil [22- 35, 53-74]. Soil is not only a substrate for plant growth but also the ultimate sink for organic and inorganic pollutants such as pesticides and heavy metals [22- 35, 53-74]. Once heavy metals enter the soil environment through irrigation with wastewater or land application of contaminated biosolids, they can induce irreversible damage to plant growth and enter the human body through ingestion of edible plants parts, causing inactivation of enzymes and destruction of proteins [22- 35, 52-74].

Organic fertilizers, including compost and manure, were created as alternatives to chemical fertilizers; nevertheless, despite their eco-friendliness, they include pathogens, pharmaceuticals, and organic waste and have the potential to contaminate streams and groundwater with nutrients [22- 35, 52-74]. Due to their organic nature, pharmaceuticals and organic waste were readily decomposed by soil microbes, whereas heavy metal removal requires costly and risky physical and chemical processes such as precipitation, ion exchange, adsorption, and electro-coagulation [22- 35, 52-74]. Moreover, increased pH due to the biochar addition could also be the cause of metal immobilization facilitated by hydrolysis [22- 35, 52-74]. The ash content of biochar was accompanied by many different compounds, including phosphates, carbonates, and sulphates. These compounds play an important role in stabilizing the heavy metal cations in soil by precipitation of these contaminants in the form of insoluble metal carbonates [22- 35, 53-74].

The use of biochar to stabilize heavy metals was a proven approach, and it was considered as a low-cost and efficient solution to the heavy metal contamination problem[22- 35, 53-74]. In addition to the biodegradable fraction, much of the biochar was composed of the recalcitrant carbon fraction that ensures its sustenance in the soil for thousands of years [22- 35, 52-74]. Furthermore, it is renowned for its ability to adsorb heavy metals, rendering them immobile [22- 35, 52-74].

Adsorption is a fast and cost-effective method for recovering heavy metal polluted soils [22- 35, 52-74]. Adsorption is also an explanation for the metal stabilization scenario because biochar, being negatively charged, attracts the positively charged heavy metal cations [22- 35, 52-74]. It was also found that the addition of biochar has a significant effect in increasing the soil microbial community that can aid in the stabilization and passivation of the metals through the inorganic ion transport mechanism [22- 35, 53-74]. In other words, biochar can be used as a growth medium for advantageous rhizobacteria, which, in turn, promote agriculture and soil health [22- 35, 53-74]. It provides multiple ways to improve agriculture and full the food demand in a sustainable way [35, 53-74]. Additionally, it offers a fresh perspective because biochar may be combined with various substrates and nanomaterials to increase its effectiveness and longevity in a system [22- 35, 52, 53-74].

6.1. Advantages of Biochar

- As a result of forest fires and previous soil management techniques, biochar may be found in soils all over the world. An in-depth investigation of biochar-rich dark piles of earth in the **Amazon (terra preta)** has resulted in a greater understanding of biochar's unique qualities as a soil enhancer [22-57-74].
- Biochar is a natural fertilizer that enhances soil nutrients and prevents them from leaching [22-57-74].
- Biochar is used to promote soil health by retaining soluble nutrients in the soil. Because biochar is porous, it retains both water and water-soluble nutrients, making it suitable for soil enrichment [22-57-74]. Biochar is well-known for providing a variety of soil health advantages. As a result, it can improve water quality, minimise nutrient depletion, reduce soil acidity, and reduce irrigation and fertiliser needs [22-57-74].

- Biochar is often used for the remediation of soil suffering from heavy metal pollution [22-74].
- During unfavourable weather conditions, biochar retains water due to its porous nature and provides nutrients to microbial communities living in the soil [22-57-74].
- Biochar is a stable product that could stay in the soil for many years, ultimately reducing the emission of greenhouse gases from the burning of biomass [22-57-74].
- Biochar has moderate porosity that increases the water retention of soil. In this way, it assists soil in growing plants and vegetables [22-57-74].
- The conversion of biomass into biochar does emit carbon in the air but it is less as compared to the combustion of biomass. Hence biochar represents carbon sink in soil [22-74].
- The application of biochar in the soil increases agricultural productivity and promotes agricultural resilience [22- 57-74]. Biochar is hydrophilic, which means it can absorb and hold water from the air. This makes it appropriate for use as a soil material in areas where water scarcity is widespread [22-57-74]. Phosphate and nitrogen, which are essential for a plants health, are preserved, resulting in healthier plants that use significantly less fertiliser [22-57-74].
- One of the main advantages of biochar is it helps in decreasing soil acidity which hinders crop production [22-74].
- In regions with severely depleted soils, few organic resources, insufficient water and chemical fertiliser supplies, biochar can be an effective tool for increasing crop productivity and agricultural diversification [22-74].
- Biochar also enhances water quality and quantity by retaining nutrients and agrochemicals in the soil for plant and crop consumption. Instead of seeping into groundwater and producing pollution, more nutrients stay in the soil [22-57-74].
- Biochar carbon is resistant to deterioration and may be used to store carbon in soils for hundreds to thousands of years. Biochar can enhance the physical and chemical qualities of farming soils and substrates while lowering water and nutrient losses, resulting in economic savings [22-74].
- Sustainable biochar techniques can yield oil and gas byproducts that can be utilised as fuel, giving clean, renewable energy in addition to soil enhancement. When biochar is used as a soil enhancer and buried in the ground, the system might turn "carbon negative [22-74].
- By substituting fossil fuel consumption and sequestering carbon in stable soil carbon pools, biochar and bioenergy co-production can help to prevent global climate change. It may also help to minimise nitrous oxide emissions [22-74].
- Large volumes of carbon dioxide and methane are released into the atmosphere when biomass is burned or naturally degraded. Biochar releases the same components into the atmosphere, but the carbon concentration is more stable [22-57-74]. As a result, biochar allows for adequate carbon storage in the ground, potentially lowering atmospheric Greenhouse Gas (GHG) while improving soil fertility and agricultural output [22-74].
- Biochar can be utilised as a soil conditioner and a container substrate amendment in agriculture and horticulture. It also has the potential to improve a variety of soil and substrate physical, chemical, and biological qualities [22-74].

6.2. Disadvantages of Biochar

- The horticultural industry is facing the challenge of substituting peat – a material that is highly appreciated for its growing properties but is also associated with negative environmental effects and biochar has been suggested as a potential alternative [34]. One of the study reported that biochar was used in different proportions and in combination with either peat or hemp for lettuce cultivation in a greenhouse pot experiment [34]. The addition of biochar resulted in such a high pH that the plant growth was severely reduced, which might have obscured any potentially beneficial effect of using biochar [34]. This however highlighted the challenge in using biochar in organic growing media due to the difficulty in maintaining the pH at an adequate level for plant growth [34, 53-74].
- Due to the application of biochar in soil, the activity of worms reduces which is essential for soil productivity [56, 57].
- Biochar does increase agricultural production but it absorbs nutrients causing deficiency of nutrients available to growing plants [56, 57].
- The frequent application of biochar causes soil compaction which in return decreases crop yield [56, 57].
- Biochar also affects the application of pesticides hence reducing the efficiency of pesticides in soil [56, 57].
- The application of biochar could lead to soil degradation making soil vulnerable to harsh climates [56, 57].
- Biochar, like charcoal, is a combustible substance that must be handled with caution. When exposed to air, biochars become spontaneously combustible, which means they can self-heat and even ignite [56, 57].

- Dust is the most serious health hazard associated with biochar, as well as the most difficult aspect of its use in the field. Small biochar particles can irritate and cause lung damage when breathed in [56, 57].
- Another area of ambiguity is the methodology for incorporating biochar into the soil, particularly in low tillage or no-till operational processes [56, 57].

7. Conclusion

Hemp (*Cannabis sativa L.*) is an annual plant that grows under various climate and soil conditions. There has been a great interest in hemp biochar in recent years, owing to its observed ability to capture atmospheric carbon and improve soil fertility. With an excellent capacity to retain water and nutrients when applied to soil, hemp biochar can contribute to long-term soil fertility. Biochar is a carbon-rich and porous material that finds application in different sectors and can be extremely useful in agriculture as soil improver. One of the recent study reported that hemp biochar carbonized at 800–1000 °C displayed interesting electrical conductivity, opening opportunities for its use in electrical purposes. Biochar is a fine-grained, high-carbon residue created most often by advanced pyrolysis techniques (direct thermal decomposition of biomass in the absence of oxygen and preventing combustion). It makes a combination of solids (biochar), liquids (bio-oil), and gases (syngas) as a result of the process. Biochar is a product that is produced from biomass through a pyrolysis process. It has numerous uses that improve the soil structure and trigger agriculture production. The use of biochar to stabilize heavy metals was a proven approach, and it was considered as a low-cost and efficient solution to the heavy metal contamination problem. The characteristics of biochar make it a favorable option to be used during dry weather conditions. Biochar provides moisture to the soil and it could be considered a solution to soil infertility due to climate change. Biochars were generally characterized by having a porous nature and large surface area.

Compliance with ethical standards

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