Production of biochar is a sustainable environment-friendly approach [1], [2]. It offers prospects to sequester carbon for considerably longer time than raw biomass or solid waste [3]. Biochar as soil amendment influences soil physicochemical and biological properties [4], [5] which in turn enhance crop growth and yield [6]. Moreover, biochar as a soil amendment is a potential tool for climate change mitigation due to sustainable reduction of GHGs emission from agroecosystems [7], [8], [9]. Application of biochars also help to decrease the availability of toxic environmental pollutants and heavy metals in soil [10], [11]. Infiltration of water in landfill covers and slopes can also be managed by application of biochar [12], [13]. Biochar can be used as an alternative source of energy due to lower Sulphur (S) content and higher calorific value [14]. However, this biochar laid benefits are primarily governed by the specific properties of biochar [15] which on the other hand relies on the characteristics of feedstock, production method and temperatures used for its production [16], [17]. Biochars with unique characteristics could be obtained using varied feedstocks and production techniques [18], [19]. Therefore, it is important to select appropriate feedstock, production technique, and temperature for the synthesis of biochars based on the specific requirements.

2.1. Biochar characteristics influenced by feedstocks

A wide variety of biomass sources have been documented as feedstock for biochar [20], [21], [22]. Some of the common feedstocks are agricultural and garden wastes such as plant-based feedstocks (plant residues, wood chips or woody materials, coconut coir, corn cobs cotton stalk etc.), animal litters such as poultry litters, dairy wastes, swine manure, cattle manure etc. Apart from these, other solid wastes such as sewage sludge, algae etc. are used as feedstocks for biochar production [23], [24]. Several studies have been carried out to know the impacts of feedstock on biochar properties [25], [26]. Agricultural waste is the utmost used feedstock source for biochar production all over the world. Globally about 500 MT of agricultural waste is generated annually [27]. The major agro waste produced in India include straw of cereals mainly rice, wheat, sorghum, millet etc. Moreover, sugarcane bagasse and coconut shell are some of the potential sources of feedstocks for production of biochar in India [28]. Due to the varied content of cellulose, hemicelluloses, lignin and inorganic mineral concentration in feedstocks; the produced biochar material exhibits unique physicochemical properties with respect to production technique and temperature [29], [30]. Carbon, hydrogen and oxygen are the key elements which differ with feedstock type [31]. Carbon content in feedstock determines the conversion efficiency of feedstock to biochar. As well as it plays a major role on presence of functional groups in biochars [6]. Whereas H and O demonstrate significant impact on determination of H^+ ions, influencing biochar reactions with organic and inorganic solutes [32], [33], [31]. Nevertheless, it has been suggested by many scientists that irrespective of production temperature, woody feedstock based biochars typically have lower pH than that of the soft wood [34], [35], [36]. Collison et al. [37] achieved higher biochar yield from the feedstocks rich in lignin content. Similarly, Bruun et al. [38] and Suliman et al. [39] recorded biochar with higher fixed carbon from hard wood biomass feedstocks, as well as biochar with lower fixed carbon from feedstocks such as sewage sludge. Weber and Quicker [6] documented drop in H/C, O/C ratio in a heterogeneous set of biochars (produced from grass, woods, and different types of straws) carbonised in different reactors with varied heating rates and residence times. Similarly, presence of plant essential elements in biochars differs according to the feedstock material and production methods [40]. Xiao et al. [31] noted that biochars produced from animal manures and biosolids consist higher elemental contents while crop residue and wood-based biochar has lesser of the same [31]. Fan et al. [41] observed higher elemental content in biochars is directly proportional with the content of ash in the biochar. They also noticed that ash content in biochars is mostly governed by the ash content of the feedstocks. Wu et al. [42] studied the ash levels of eight distinct types of biochars made from herbaceous, woody, and biosolid feedstocks. Significantly different ash content (2.00 to 52.3%) of the studied feedstocks were observed with the highest value in biosolid feedstocks. They further observed the highest elemental content in biochar at elevated levels of ash. The inorganic elements in the biochar influences pH, CEC and specific surface area of biochar. Ippolito et al. [43] revealed presence of 2.2% and 17% P and K in hard wood biochars. Whereas, the soft wood biochar consists of 6% and 27% of P and K respectively indicating higher concentration of both the elements in softwood biochar. Similarly, Dieguez-Alonso et al. [44] documented higher N, P, K in soft wood biochar as compared to hard wood. Agricultural residue and animal manure biochars documented superior CEC and pH compared to wood based biochars [45]. This increased cation exchange capacity could be related to the raise in pH and pH dependent charge of the same biochar [15]. Scientist documented elevated pH in leguminous plant derived biochars than non-leguminous plant-based biochars regardless of the production temperature [46], [47]. Algae and animal manure based biochars shows enhanced cation exchange capacity whereas, lignin rich feedstocks generate decreased values of the same [48]. Uzoma et al. [49], Bird et al. [50], Rondon et al. [51] recorded cation exchange capacity of the biochars between 4.5 to 40.0 cmol kg^{-1}. Likewise, Yuan et al. [47] documented greater cation exchange capacity and superior negative surface charges in the biochar obtained from digested bagasse than biochar obtained from undigested materials.

Biochar production from the animal manure is also a practice of maintaining hygienic environment. Manure feedstocks naturally comprises of higher nutrients compared to other feedstocks [52]. Mixing the animal manure with agro-wastes or wood-based feedstocks could produce biochar with enhanced C, N, and K [53]. Many scientists recommended similar approach of mixing different types of feedstocks during biochar production [54]. Huang et al. [55] produced biochar by combining rice straw and sewage sludge and demonstrated higher quality biochar with high ash and nutrient content.

Furthermore, feedstock properties also influence the morphological properties of the biochar [56]. Increased specific surface area is an indication of volatilization of gas and water present in the feedstock during production process [57]. Documented biochar with greater specific surface area from woody feedstocks compared to feedstocks such as sewage slurry, animal manures, and loose wood biomass. Similarly, Ahmad et al. [58] and Lian et al. [59] observed lower specific surface area in biochars when sewage slurry and animal manures were used as feedstock. Documented lower specific surface area of sewage slurry and animal manures is due to the change in loosely bound internal structures of the pores by cracking or blockage during production process.

Previous studies documented the existence of heavy metals, PAHs and other harmful compounds and the potential release of such compounds from biochars into the soil. The quantity of such heavy metal and other toxic compounds in biochar depends on the type of feedstock [60], [61]. Wu et al. [42] stated that biosolid and sewage sludge biochar typically include greater levels of toxic chemicals. Additionally, greater heavy metal levels in animal wastes and biosolids feedstocks were also found by Amaya et al. [62], and Silveira et al. [63]. Wang et al. [64] described that the feedstock composition majorly mineral and moisture content as well as the presence of oxygen during production process show substantial impact on yield of PAHs in biochars.

2.2. Biochar characteristics influenced by production methods

Various production methods are used for obtaining biochar namely pyrolysis (fast and slow) gasification, conventional char production, hydrothermal treatment, torrefaction, carbonization and flash carbonization [65]. Moreover, temperature and production method determine the yield of biochar. Mostly, biochar yield decreases with increasing production temperature [66]. It has been seen that biochar quality decreases when produced at below 350°C [67]. Modulating the oxygen passage, and temperature (both final and residence temperature) different production units and reactors have been developed [68]. The most extensively performed method for biochar production is slow pyrolysis. Biochars produced in pyrolysis method exhibits superior quantity and higher biochar yield [69]. Sessa et al. [70] reported lower yields of biochars using gasification and fast pyrolysis techniques compared to slow pyrolysis. Similarly, many scientists found higher and sustainable biochar yield under longer residence temperature treatments (heating for several hours at about 400°C) [70], [71]. Modification of gasifier units also shows differential impact on yield and biochar characteristics [72]. In gasification method of biochar production, existing oxygen molecules cause ablation of biochar, which diminish the yield and strength of the produced biochar but increases ash content [73].

Specific surface area of biochar increases with rise in production temperature [74]. At high temperature treatment, the volatile substances are removed from feedstock biomasses generating highly porous biochar structures [75], [76]. Ahmed et al. [23] documented higher specific surface area in the biochars produced from woody feedstocks at pyrolysis temperature of 440°C. Likewise, Ahmed et al. [77] reported more porosity and specific surface area in biochars when produced at higher temperatures than biochars produced at lower temperatures. Enlargement of specific surface area has been noted at initial high temperature treatment and gradually shows a decreasing drift under prolonged heating [78]. These results can be ascribed to the findings of Mohan et al. [79]. They described that prolong heating at high temperature reduces the biochar specific surface area due to the depolymerization of biochar surfaces under heat treatment. Specific surface area is the main reason of controlling biochar capacity to adsorb soil compounds [80]. Greater is the production temperature higher is specific surface area and hence the adsorption [48]. Sun et al. [74] noted that the biochars formed under high temperature treatment has improved heavy metal adsorption capacity, and thus had greater potential for environmental remediation.

Nutrient composition of a biochar is more dependent upon the total nutrient content of feedstock than the production technique [81], [82]. Feng et al. [83] documented that total nitrogen in biochar mostly diminishes with rise in production temperature. However, in most of the studies no significant relationship was noted on nitrogen content and production temperature. Previous studies found that, under slow pyrolysis method, agricultural residue generated biochar exhibited nitrogen content in the range between 0.3 and 3.3%. While nitrogen content was fairly smaller and constant when biochars were obtained from wood chips 0.06 to 1.2% [84]. The C, H, N, S content in biochar is the indicator of its polarity, carbonization and hydrophobicity [85]. Suliman et al. [39] generated 18 biochars and found that increase in pyrolysis temperature decreased the H/C and O/C ratios in all the biochars. The O/C ratio signifies the hydrophilicity and it also describe the polar group concentration in biochar [86]. Whereas H/C ratio is the indicator of the degree of carbonization, lower the H/C ratio higher is the degree of carbonization which is generally exhibited by the biochars produced at elevated temperatures [87]. The polarity index of biochar displays the presence of surface functional groups and consequently determine the aromatic nature of biochar. Lower O/C ratio exhibits increased aromaticity and lesser polarity of biochar [82]. Considering these mechanisms, it has been proved that biochars produced at elevated temperatures are less polar, and highly aromatic and hydrophobic in nature as has previously documented by Al-Wabel et al. [88], Weber and Quicker [6]. Likewise, Cantrell et al. [25] noted inferior aromaticity under larger H/C and reduced polarity under lesser O/C ratio of biochars produced from poultry litter and swine solids at 700°C and 350°C respectively.

The recalcitrance potential of biochar is chiefly determined by the feedstocks and production methods [88], [89]. Crop residues or soft wood biochars are found to be less resistant than the hard wood biochars, which can be attributed to the lignin content of the used feedstocks [90]. Nanda et al. [91] recorded increased aromatic carbon ring structures under higher production temperature. This increase in aromatic carbon determines the resistivity of a biochar [91]. It has been proved that biochar of higher aromaticity is better resistant to microbial and thermochemical degradation

[92]. The H/C and O/C ratios of a biochar start to decline with rise in production temperature [93]. Lower H/C and O/C ratio are the indications of higher aromatic carbon structures and higher calorific value of the biochar making it more recalcitrant [91]. Researchers also noted that biochar generated at high temperatures with less volatile materials has greater recalcitrance potential [94], [95]. Usman et al. [89] reported similar findings in their investigation, they found that biochar produced from date palm waste at 800°C was more recalcitrant than biochar produced from the same feedstock at 300°C. Kim et al. [96] documented that well organized aromatic structures of biochar developed at production temperature of about 400°C. They have also recorded the adsorption intensification of biochar in FTIR spectra width at 3,400 to 2,900 cm^{-1} that declined with rising production temperature and retention time. Which also revealed a decrease of O–H and aliphatic C–H bonds. Rise in production temperature intensifies the adsorption band at 1,400 cm^{-1} due to formation of complex aromatic carbon structures in biochar [96], [97], [50]. Biochars produced at low temperatures normally contains oxygenated functional groups on biochar surfaces which in turn determines the surface acidity or alkalinity of biochar [39]. Biochar with elevated oxygenated functional group is superior with regard to removal of inorganic pollutants. With the rise in production temperature, these functional groups gradually decrease from the biochar surfaces. Similarly, carboxyl acidity also diminished as did the surface acidity [98]. Biochars produced under high temperature are more alkaline in nature [47]. Significant difference in pH of the produced biochars were noted by Bruun et al. [99], when slow and fast pyrolysis method at equal production temperature was used to produce wheat straw biochars. Akhil et al. [100] also recorded greater surface basicity and pH in biochars with increasing production temperature and holding time of temperature treatment. Prolonged heating of feedstocks eliminates acidic functional groups keeping mainly alkaline earth elements and readily soluble salts making the biochar alkaline [101]. Previous studies explained that the X-ray diffraction spectrum and carbonate concentration of the biochars are the reason for biochar alkalinity which are generated at higher temperature treatment [47]. Presence of greater specific surface area and porosity is the primary reason of increased water holding capacity of biochars when produced at elevated temperature [102]. Moreover, the polar groups present on biochars perform as water adsorption sites by enabling the development of water packets on the surfaces [103], [102]. Biochar O/C ratio is related to the hydrophilicity, and this increases with the

increasing production temperature [104]. Differential water retention capacities of biochars produced at various temperatures using chicken manure, water hyacinth and wood chips were documented by Huang et al. [55]. Novak et al. [105] and Shafie et al. [106] investigated the water retention capacity of biochars made from pecan shells, peanut hulls and empty fruit branches respectively at low to high temperature ranges. Findings showed that biochars made at higher temperatures are better in retaining water.

Mukherjee et al. [35] documented that low temperature produced biochar had higher cation exchange capacity. Lee et al. [107] also noted higher cation exchange capacity in the biochars made by fast pyrolysis method as compared to gasification method. Biochars may comprise of toxic heavy metals and compounds such as poly aromatic carbons (PAHs) and volatile organic carbons (VOCs) during production process [108]. Presence of such compounds is released from biochars and can be harmful for soil biota and plants [64]. Therefore, it is important to know the mechanism of release of such toxic compounds and heavy metals before soil application, especially when biochars are produced using sewage or solid waste materials as feedstocks [109], [110], [111], [112]. Significant quantities of heavy metals were recorded in biochars when Lu et al. [112] studied the presence of heavy metals in biochars produced at various temperatures using sewage sludge as a feedstock. Polycyclic aromatic hydrocarbons (PAHs) and volatile organic compounds (VOCs) have a damaging impact on soil and plant health [108]. PAHs generated during biochar production are harmful to plant growth and soil biota as well as causes mutagenic and carcinogenic effect on human health [113]. Quilliam et al. [114] measured the presence of 16 EPA PAHs in biochar treated soil and observed that the extent of PAHs is significantly influenced by feedstock characteristics and production methods. Cole et al. [115], and Keiluweit et al. [116] described that temperature and production technique play important part in deciding the amount and category of elements and compounds that will be released during biochar production process from a feedstock. They observed that, fast pyrolysis and steam gasification based biochars hold more PAH compared to slow pyrolysis. The reason of these variations in presence of PAH is that the slow temperature treatment provides additional time to loss of PAH to the atmosphere, while PAHs gets deposited on biochar pores and surfaces under fast biochar production methods [117].

2.3. Use of biochar as soil amendment

Use of biochar to enhance crop production and soil fertility is gaining attention among the researchers. It has been proved as a profitable low-cost soil amendment for management and amelioration of degraded and infertile soils [118], [119]. Biochar improves soil health by supplying elements that are crucial for plant growth, soil organic carbon and substrate for microbial growth [120], [5]. They enhance soil microbial diversity and consequently improves soil enzyme activity [121]. Furthermore, biochar induced improved soil physicochemical properties (such as cation exchange capacity, water holding capacity, soil aeration etc.) that contributes to soil fertility [122], [123], [124]. Alkaline nature of biochar was proved as conditioner for acid soil [125]. Biochar application increases heavy metal adsorption of soil and has the ability to immobilize toxic contaminates in soil forming complex compounds. Scientist found more superior resistiveness of biochar made from ryegrass compared to other regularly used soil additives like FYM, vermicompost, and biosolids. From an eight-year study, they documented longer stability of biochar in soil [126]. This higher recalcitrance nature of biochar has been acknowledged as an important source for soil carbon sequestration [5].

Many scientists have suggested biochar as a tool to reduced soil acidity [127], [128], [129], [130]. The presence of negatively charged hydroxyl, carboxyl, and phenolic groups on the surfaces of biochar makes soil alkaline upon application [131], [132]. In addition, carbonates, bicarbonates, and silicates in biochar can bind with the hydrogen ion in soil water. This in turn reduces the H^+ concentration and increases pH value [133]. Rise in soil pH also has the ability to increase soil cation exchange capacity and hence intensifies the bioavailability of K, and P based cations, which are the key elements for plant growth [97].

Likewise, the highly porous nature of biochar holds water to a greater level and help to meet the plant water requirement [47]. Biochar addition alter soil structures by modifying soil interpore through greater biochar porosity and hence influence entire soil porosity and bulk density [134]. Besides, biochar added soil with lower bulk density do not pose constructive impact on soil water holding capacity. However, biochars having higher bulk density is directly related improved water holding capacity [135]. Gas exchange (e.g., O_2 and CO_2) within soil and atmosphere is a potential indicator to its better porosity [136], [137]. Improved water holding capacity of biochar-amended soil reduces water runoff from the soil surfaces apart from check in soil erosion and loss in soil fertility [138].

In previous studies, researchers documented improved biological nitrogen fixation (from 50 to 72%) from biochar addition of 90 g kg^{-1}. This increase of Nitrogen level in soil under biochar application was due to the enhancement of soil organic carbon. Thus, biochar can offer a supplementary prospect to cut down the application rate of Nitrogen fertilizers in agriculture [51]. Biochar amendment further enhanced micronutrient availability in soil such as Mg, Ca, Mo, and B [51], [139]. Similarly, considerable quantities of K (8.5–10.2%) and S (20.2–28.3%) were observed under application of sewage sludge biochar [140]. The rise in soil pH under biochar amendment could decrease the bioavailability of heavy metals like Cu, Cd, Pb and Mn and improve the bioavailability of nutrients (Na, K, Ca, Mg, and Mo) thus provides a favourable environment for plant growth [141]. Furthermore, the biochars amendment in soils could adsorb various harmful heavy metals and compounds in its surface, as for example, insecticides, herbicides, PAHs etc. which could cause environmental pollution [142], [143].

2.4. Use of biochar as a growth promoter for soil biota

The addition of biochar for management of soil microbial diversity is a subject of budding attention for the researchers. The study on alteration of soil biota under addition of biochar is important since soil microbial diversity is crucial for soil functions and ecosystem services. These soil functions in return share implications for soil heath [34]. Brussaard et al. [144] recommended that organic amendments are the utmost means of dealing with soil biology. It has been proved in earlier studies that the diverse characteristics of amendments influence differently to soil and its diversity [145]. Changes in soil properties effect soil biota both positively and negatively through shifting growth substrate and habitat [146]. Advances in soil characteristics under biochar addition for example, raised pH, water holding capacity, essential elemental content promote microbial growth in soil [147]. Moreover, biochar correspondingly supports microbial growth by supplying the available labile carbon [148]. According to Jaafar et al. [149] and Ye et al. [150] specific surface area of biochar is one of the fundamental characteristics, which affects soil biota. In their study on biochars produced from three different feedstocks they had documented that the spongy structure and larger specific surface area of biochar favours the microbial growth. Pores of biochars provide corporal protections from predators like mites and nematodes to soil bacteria and fungi living in biochar amended soil [151], [152]. Likewise, Brewer and Brown [131] described that water and soluble components such as different functional groups which are associated with bacterial metabolism were stored in biochar pores. Therefore, it can be said that feedstock, production method and temperature indirectly determine the abundance of soil microbial diversity in a biochar amended soil. Jaafar et al. [149] revealed an increase in microbial colonization in soil due to addition of biochars produced from woody feedstocks. Additionally, they have recorded an improved specific surface area and porosity of biochar to provide optimum habitats for soil microbes.

Steiner et al. [153] proved that the addition of external nutrients in the form of inorganic fertilizers decreases the positive influence of biochar on soil biota. Moreover, Blackwell et al. [154] documented noteworthy improvement on root microbial colonization of wheat crop in biochar treated soils with little or no fertilization. Whereas no significant impact was noted under addition of inorganic fertilizers. Although, they described that these observed results were related to the fertilizer type and the specific microbial population. Biochar induced altered soil pH is one of the chief governing factors for microbial growth. Numerous studies explained increased soil microbial biodiversity with increasing pH [125]. However, specific microorganisms respond differently to pH alterations [134]. Many beneficial soils bacterial growth was found to be increased with increasing pH value around 7-8 [155]. While fungi showed contradictory results [156]. Impact of soil pH on specific type of soil microbes have also been correlated with the differential rhizobium growth of leguminous plants [157]. Capability of biochars to adsorb soil toxic compounds is an additional advantageous reason of intensified soil microbial diversity. Chen et al. [158] synthesized various types of biochars from a pine wood at different temperatures and observed the increased adsorption of chemicals deadly to microbes, such as catechol on the surfaces of biochars. Kasozi et al. [159] also documented similar results. Moreover, drought or limited soil moisture leads to dormancy or death of soil biota [160]. Providing the greater specific surface area with superior water holding capacity, biochar facilitate hydration at the soil pore spaces for delivering moisture to soil biota under stressful conditions [161]. Many scientists documented the rise in survival size and reactivation of numerous bacteria in soil under biochar application. However, varied pore structures, pH and other biochar specific characteristics governs the hydrophobicity and survival capacity of a bacterial species [162], [34]. Literature also showed that the soil nitrification increases with application of biochar [163], [164], [165]. This is due to the adsorption of phenolics which otherwise prevents soil nitrification process [166], [167], [168]. Moreover, the increased growth of ammonia-oxidizing microbes in biochar added soil improves soil nitrification rate [165].

2.5. Influence of biochar on plant growth

Positive influence of biochar on agricultural soil can be described by its higher elemental content and adsorption capacity [169], redox potential [170], liming effect [171], water holding capacity [138], microbial diversity [172], [173]. Biochar addition in soil declines bulk and particle density and upsurges porosity and water-holding capacity, which helps in alleviating soil compaction making it easier for root growth [134]. An experiment on rice paddy exhibited that biochar application at 40 t ha^{-1} lead to decline in soil bulk density and increased the rice yield as compared to control [174]. The main problem for crops growing under stressful soil environment is the root establishment. Roots perform the dynamic key roles for plant growth. A meta-analysis by Xiang et al. [175] displayed that biochar application amplified root biomass, volume, specific surface area, length, number of root tips and diameter by 32%, 29%, 39%, 52%, 17%, 9.9% respectively. Similar results were also observed in several studies suggesting positive role of biochar on root establishment [134]. The increase in plant root establishment and proper growth in turn enlarge the root volume in soil to capture the nutrients needed for plant growth [175]. Another study revealed that, biochar addition at a dose of 15 t ha^{-1} significantly increased maize grain production and that was accredited to the increased soil cation exchange capacity, plant essential elements and decreased hydraulic conductivity [49].

Acidic soils usually partake lower fertility due to the higher availability of Al and Mn with very low level of base cations and suffer from lower crop yield [176]. The alkaline nature of biochars have been documented to neutralize the soil acidity and hence the crop growth. Literature showed that, biochars amendment in acidic soils increased yield of dissimilar crops up to 363% [177]. Among the different biochar types, biochars produced under higher production temperature were found to neutralize soil acidity more due to their higher pH and alkaline surface properties. Al^{3+} responsible for soil acidity is reacted to form less toxic $Al(OH)_3$ and $Al(OH)_4$ compounds in presence of carbonates, silicates and alkaline oxides of biochar amended soil [176]. Moreover, Al^{3+} reacted with functional groups present in biochar to form less acidic compounds. Accordingly, biochar facilitated to increase pH and decrease Al ions apart from enhancing the availability of P, Ca, and Mg in the soil leading to better nutrient supply for the growing crops [178].

Plants grown on nutrient deficit soil suffers from morpho-physiological deficiency symptoms. These symptoms could be small to very severe. Some of the nutrient deficit impacts are cessation of root growth, cell wall disruption, alteration of cytosol pH, disruption in metabolic activity, enzyme production inability etc. These physiological symptoms then cause oxidative stress causing photoinhibition and photooxidation leading to development of chlorosis and necrosis in plant [179]. Previous studies with biochar application revealed to cure these nutrient deficiency syndromes of plants due to the biochar induced enhanced soil nutrient availability. Scientists documented healthy crop growth and productivity in maize [49], bean [51], rice paddy [180], oat [181], and lettuce [182] etc. under biochar application. Reported enhanced crop health and productivity be accredited to the factors like biochar mediated nutrient availability, improved nutrient uptake and ideal rhizosphere rice condition. Dry biomass yield of lettuce and maize crops cultivated in biochar added soil were higher compared to the controlled soil. This hike in biomass yield was related to the increased availability of P and K contents in both soil and the crop [182]. Where, the higher micronutrient concentration in plant biomass proves that biochar as a potential plant nutrient reservoir for slow release of nutrients in soil that could regulate plant requirements of nutrients for whole crop growing period [182]. Additionally, Spokas et al. [183] developed a method to supplement biochar with nitrogen over sorption of nitrogen containing compounds and applied it as a fertilizer that could release nitrogen slowly to the soil for longer period. Mixed application of biochars and other commonly used organic fertilizers also increase plant essential nutrients in soil. Maru et al. [184] observed significant increase in nutrient uptake efficacy of rice paddy when poultry litter biochar was applied with nitrogen fertilizer at 75% of its recommended dose. Ippolito et al. [40] also recommended combining commercial nitrogen fertilisers with softwood based biochars for better outcomes as a soil amendment. Yet, crops that require less nitrogen might be cultivated when softwood-based biochar was applied alone. The availability of potassium in soil with the mixed application of both hardwood and softwood biochar was also predicted by scientists [185]. Scientist also documented enhanced soil properties and two-fold hike in maize yield when biochar and compost were applied together [186]. The increased nutrient uptake ability of plants can be attributed to the increased cation exchange capacity and soil organic matter, which might embrace the nutrients and protected them from leaching [187]. Furthermore, biochar induced altered soil properties and soil microbial community is the key factor for a favourable rhizosphere environment for plant growth and productivity [188].

2.6. Use of biochar in environmental remediation

Biochar has been proved to remediate soil heavy metal contamination [189]. The mechanism of heavy metal remediation by biochar is the immobilization of metals in soil making it less bioavailable [190], [191]. This ability of immobilization varies according to biochar type (feedstock and production method), rate of application, parent soil quality, and type and concentration of heavy metal species present in the soil [58], [192]. Depending upon the type of metal ions present, biochar can either mobilise (anion) or immobilise (cation) metals in soil [193], [194]. Previous researchers suggested that the immobilized metals were bound to the soil organic matter fractions [195]. Medyńska-Juraszek and Ćwieląg-Piasecka [196] noted the ability of wheat straw biochar to cut the availability of Cu, Pb, Zn, and Cd in acidic sandy soil. However, no significant results were documented when the same biochar was applied in alkaline soils. Some researchers observed the efficacy of sugarcane biochar in lowering the bioavailability of heavy metals in contaminated soils [197]. Similarly, Li et al. [198] noted decreased availability of Cd in soil upto 17.1% upon addition of coconut shell biochar. Whereas upto 22.6% reduction of the same was noted under application of rice straw biochar. Moreover, they have recorded improved soil enzyme activity in Cd-contaminated soils following the addition of biochar. Application of biochar to metal contaminated soils resulted in greater improvements in soil fertility, pH, WHC, and microbial diversity [99], [200]. Using bamboo and rice straw biochar as amendments demonstrated decreased extractible Pb, Cd, Cu, and Zn from contaminated soils [195]. Park et al. [201] observed significantly lesser bioavailable form of heavy metals on manure and green waste biochar amended soils. Whereas, addition of chicken manure biochar in Cd, Cu, and Pb contaminated soil increased dry biomass yield of *Brassica juncea*. Moreover, according to Park et al. [201] this increase in biomass yield could be ascribed to decreased heavy metal availability in soil. Furthermore, Xie et al. [84] observed lower aluminium availability in soil under application of high pH biochars.

2.7. Biochar on mitigation of greenhouse gas emission

The climate change mitigation effects of biochar were studied by many scientist [202]. Numerous literatures are available describing the use of biochar as soil amendment and its impacts on soil GHGs emission globally [203]. Biochar characteristics such as $C/N < 30$, $O/C < 0.2$ and $H/C < 0.7$ are positive to reduce GHGs flux from soil [204]. Moreover, with the help of specific biochar properties, the carbon is sequestered in soil that reduces carbon emissions. The resistance of biochar from microbial degradation can be related to the soil carbon sequestration which ultimately advances in climate change mitigation [205], [206]. Along with the biochar characteristics, the parent soil properties are also responsible for the GHGs emission quantity. Several studies documented both reduction and hike in methane and nitrous oxide emissions from agricultural fields under biochar treatments [207], [208], [209], [71]. Usually, biochar with higher nitrogen, lower C/N ratio gives higher level of N_2O flux. Whereas these qualities showed contrasting result in case of CH_4 emissions [210].

Similarly, both positive and negative impact of biochar on soil CO_2 flux have been recorded [68]. Information's are also available about the properties of biochar and their differential influence on soil CH_4 emissions from diverse soil types. The quantities of CH_4 and CO_2 emissions depend upon the physico-chemical characteristics of biochar, soil type, soil biota, water supply and fertilizer treatments Liu et al. [211]. Yu et al. [176] confirmed that soil moisture content and microbial diversity of a soil type greatly decide the quantity of GHGs emission subsequent to biochar application. Reduction of CH_4 flux in biochar added soil was found to be mainly due to inhibition of methanogenic activity [212]. Numerous experiments showed increased soil CO_2 flux due to the use of biochar as amendment [94], whereas some studies documented lowered CO_2 emissions [211]. Furthermore, very few studies recorded no significant effect of biochar on CO_2 emission [213]. Zimmerman et al. [214], Shalini et al. [68] described an instant temporary increase in CO_2 flux soon after the biochar addition to soil. Rice straw and bamboo chips-based biochar in paddy field were found to decrease soil CH_4 and CO_2 emissions where, rice straw biochar was more effective [211]. Zhang et al. [215] exhibited significant drop in secondary CO_2 release from rice ecosystem on biochar addition. Matovic [216] measured that upto 10% of global primary CO_2 addition to atmosphere could be reduced by adding biochar to agricultural soils. Moreover, according to Gurwick et al. [217] and Woolf et al. [218], biochar could reduce global GHGs emissions yearly up to 12% and has the ability to sequester carbon up to 2.2 Gt C yr^{-1}. Gaunt and Lehmann [219] revealed reduction of CO_2 emissions from agricultural fields using corn stover and switchgrass biochar upto 10.7 t CO_2 ha^{-1} and 12.6 t CO_2 ha^{-1} per annum respectively. It has been also found that addition of biochar to soil could sequester carbon around 200 million metric tons (0.2 Pg) yearly [220]. Biochars produced at higher temperature showed more recalcitrance capacity and sequester higher carbon in soil as compared to biochars obtained at lower temperatures [169]. Pokharel et al. [221] documented the beneficial use of woodchip biochar on reduction of soil GHGs flux. Similarly, Sheng and Zhu et al. [222] explored soil microbial diversity and CO_2 release in biochar treated soils of different pH level and biochar application dosages. The results displayed that CO_2 fluxes were higher in acidic soils, while the emission was lesser in alkaline soils. Lehmann [223] studied the impact of biochar in arable soils and documented increased carbon storage on application of biochar.

Several studies reported the impacts of biochar amendment on N_2O emissions from agro ecosystems [224], [225], [226]. Mukherjee et al. [227] experimented using a silty loam soil, they applied biochar obtained from oak tree using slow pyrolysis and documented 92% reduction in N_2O emission in the biochar treated soil. Sun et al. [228] researched on mixed application of biochar and inorganic fertilizer on N_2O emission in sandy loam soil. They applied four doses of inorganic nitrogen fertilizer (0, 50, 100, and 130% of the recommended dose) in wheat and rye field and it was followed by cultivation of radish crop (*Raphanus sativus* L. var. oleiformis). Where, 39% hike in plant nitrogen uptake were recorded under addition of biochar with no inorganic fertilizer accompanied by enhanced soil NH_4^+ and raised CO_2 flux. Whereas no conclusion on N_2O flux and plant nitrogen uptake were recorded when biochar was applied with inorganic fertilizer at the recommended dose. Similarly, biochar application in boreal soils exhibited no noteworthy results of N_2O emission during peak N_2O flux capture period from soil [229]. Brassard et al. [230] suggested that switchgrass cultivation and using it as a feedstock for biochar production could be a sustainable option for climate change mitigation. Nguyen et al. [17] and Liu et al. [231], in their observations on 796 literatures noted noteworthy decrease in soil available nitrate and N_2O emission from agricultural soils. Moreover, Feng and Zhu [232] applied biochars of various types and doses with inorganic nitrogen fertilisers in silt loam soil and observed that the ratio of biochar to fertiliser determines soil N_2O flux, with a larger ratio resulting in decreased N_2O emission. N_2O in soil is mostly produced due to the nitrification and denitrification processes. Biochar amendment encourages the expression of N_2O reductase (NosZ) genes of denitrifying bacteria. The N_2O reductase enzyme helps in completion of denitrification process and thus hinders production of N_2O during denitrification process [233]. This completion of denitrification process is also related to the biochar induced increase in soil pH. It has been proved that higher soil pH encourages complete denitrification process to form N_2 instead of N_2O. Moreover, biochar enhances soil organic C, that increases microbial activity and immobilization of nitrogen leading to lesser N_2O emissions [234]. Presence of biochar in soil for longer time changes its surface characteristics by reacting with oxygen and produce oxygen-containing functional groups [235]. Thus, the older soil biochar pores are clogged with soil organic matter [236]. These changes in functional group on biochar surfaces and soil pore structure ultimately drops the potentiality of biochar to adsorb soil nitrate [235], [17]. Therefore, biochar for longer time in soil successively decreases soil available nitrate concentration and leaching, that consequently reduce N_2O emissions from soil via denitrification pathways [237]. However, application rate of biochar (based on type of soil and biochar properties) and possible uses of biochars are still not attended. Some of the easy available and potential feedstocks (e.g. tea pruning litter) for biochar production are remained unused. However, no literatures were available on production and soil application of biochar from tea pruning litter as a feedstock. Additionally, most studies, the environments and soil type taken for research purposes were different. Furthermore, maximum of the experiments is for short duration only [238], [239]. Hence, environmental factors and pilot studies should be considered to produce comprehensive knowledge on biochar and its impacts on soil, plant, and other biochar application practices.

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