Volume 11, Issue 4(2023) PP. 206-220 **DOI**: 10.48309/ijabbr.2023.2006480.1445

Review Article

Nano-biochar Production and its Characteristics: Overview

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Received: 2023-07-08, Revised: 2023-09-14, Accepted: 2023-09-21

Abstract

Nano-biochar is produced by the process of ball milling and pyrolysis has more significant application in comparison to biochar. Biochar are carbonaceous material which are generated by the anaerobic digestion of organic matter in the absence (pyrolysis) or partial presence of oxygen (gasification). Solid material which is obtained after the pyrolysis has micro-pore for greater sorption characteristics, large specific surface area, and numerous functional groups which bears oxygen. The sorption properties are enhanced several times because of nano-enable properties such as numerous oxyl groups, large surface area, and high reactivity. The biochar conjugated with nanomaterials have also wide applications such as conjunctions of magnetic nanoparticles on biochar enhance its recycling and separation from reactions. Biochar and nano-biochar has great role in remediation of contaminants and toxicants from the soil and water environment. Biochar plays major role in carbon sequestrations, reduced the emission of greenhouse gases, management waste, and amendments soil. Its modified functional groups which bear oxygen can enhance sorption properties. Biochar have wide application in agriculture as it improves soil fertility, enhance growth of crops, and also increase the mobilization of nutrients and minerals, and makes availability higher amount of nutrients to the plants. Compared with biochar, nano-biochar has potential application in the environment management.

Keywords: Biochar, Nano-biochar, Agriculture, Organic matter.

Introduction

Biochar are the black remnants of the burned organic material after the pyrolysis (burning in absence of oxygen) and are preferably are light weights. In simple words biochar can be defined as the, “a thermo chemical conversion of biomass in absence or limited oxygen environment in black solid materials”.

The biochar are well known since Pre-Columbian Amazonians era for their application in agriculture to increase the soil fertility, as it is supposed to be significant agent of carbon sequestrations. It contains remains of C, N, Ca, K, and P and many nutrients which helps in the soil fertility and enhance plant growth.

Biochar can be produced covering burning organic remains with soil which turns it into black soil [1].

It has versatile application in the field of bioremediation, economic, and environment protection, by adsorbing pollutant from the environment. It is considered to be potential sorbent for various contaminants and pollutants like heavy metals and its sorption properties, stability in soil and micro-porosity supports the microbial methane oxidations [2].

Recently, it has been revealed that biochar can be used as the adsorbent material which can have wide application in removal of toxic metal and contaminants wastewater [3].

It can be produced from carbon rich biomass by pyrolysis in optimized environmental condition in less or limited oxygen concentrations. The characteristics parameters present on biochar such as functional groups on surface, high surface area, microporous structure, diverse surface sites, and net negative charge makes it good candidate as adsorbent for the removal of organic and inorganic contaminants and toxicants but its heterogeneity in structure sometime makes it inconsistent [4].

The characteristic parameters of biochar can be improvised and modify to increase its efficiency as the adsorbent for better removal and fixation. For the industrial application in case of removal of carbon tetrachloride (CTC) can be done with addition of more oxygen containing functional groups on biochar [5]. Efficiency of adsorption of biochar can be increased by the modification surface properties such as surface charge, surface area, and pore volume [6]. It can have impact on the soil processes as it has high surface area and porous structure responsible for higher water holding capacity.

This makes soil to have high water retention and prevention of nutrient loss through percolations of small pores and makes surfaces positively charged. The supplement of biochar adds up some of nutrients to the soil which helps in the good conditioning of fertility of soil [7].

The biochar obtained after pyrolysis from plant sources is in crystalline structure, with several pores and nano-pores and because of highly stable aromatic carbon structure are resistant to biodegradation and this material further can be categorized in three forms such as resistant carbon, sensitive carbon, and ash [8]. The composition of biochar contains ratio of H:C is 0.6 and O:C 0.4, as this ratio tends lowers the value, it makes more stable biochar [9, 10] and suitable for soil. The components like minerals, nutrients, and macro- and micro-element present in the biochar (ash) plays important role in the aromatic and chemical structure of biochar [11, 12].

The method of biochar production controls the size which varies micrometers to centimeters; the reduction of size to nano range less than 100 nm can enhance the biochar properties like surface energy and biological effectiveness [13]. The cost and method of nano-materials production is always the issue of discussion as the production is very expensive and the methods used are can be part of environmental pollution [14].

To prevent the production cost and environmental pollution, nano-composite can be significant alternative to it, nano-materials can be mounting on desired supporting materials like biochar which rectify the biochar limitation and enhance the removal and desorption of heavy metals and toxicants, also such nano-composite made by magnetic nanoparticles along with biochar are known to highly attractive sites for the removal of heavy metal removal [15, 16]. Fe particles encapsulated on carbonaceous materials acts as the catalyst for various reactions and can be separated easily by the application of magnetic field, in a similar way, Fe nanoparticles can be encapsulated on biochar [17].

Physical and Chemical Characterization of Biochar

The chemical composition of biomass or feedstock which is taken as the substrate for the conversion and production of biochar affects the physical properties [18]. The chemical content such as cellulose, hemicelluloses, and lignin responsible structural composition and morphology can control processes like thermal decomposition [19]. Thermal stability can be directly relates to chemical composition in the order hemicelluloses < cellulose < lignin of biochar or the substrate used for its conversion such as biomass from grasses or crops [20]. In other cases, to increase the significant sorption characteristics, biochar can be amalgamated with nano-materials such as manganese oxide nanoparticles (MnOx). Nanomaterials like MnOx have efficient adsorption potential because of its high surface area and polycrystalline structure and their conjugation with the biochar can enhance affinity, sorption towards pollutants and adsorption of antibiotics in aqueous solution [15].

Nano Biochar

Nano-biochar can be prepared by the bottom-up approach through the process of ball milling, pyrolysis, or disc milling having properties like small size, differed mobilization, and bioavailability.

With respect to biochar, the nano-biochar should have more significant approach in the environment management applications because of its nano-enabled properties [21]. The sorption properties of nano-biochar can be enhanced because of their significant properties like numerous oxyl groups, large surface area, and high reactivity [22], enhanced nutrient retention and higher pollutant adsorption [23].

Nano-biochar has higher critical coagulation concentration with respect to engineered carbon nanomaterials responsible for greater colloidal stability in comparison to carbon nanotube, fullerene, and graphene oxides [24] and soil colloids (e.g., iron oxides). The sorption properties of nano-biochar influence the environmental risks of toxicants as it plays important role in its transport, suspension, and distribution in solid phases [13]. Nano-biochar is able to adsorbed pollutants from several environmental sources because of its greater surface area and smaller pore size [25].

The nanomaterials obtained from biochar also reported to have capacity to reduction in Cd^{2+} uptake and phyto-toxicity and it has crucial role in several plant processes necessary for plant growth and productivity [22]. Nano-biochar having higher mobility in natural soils, and also it can transport in groundwater. Hence, it can helps in the retention and migration of nutrients and adsorption and immobilization of hazardous contaminants. In one of the reports, it was observed that the presence of biochar nanoparticles in alkaline soil can increase the phosphorus leaching [26], and also it can increase desorption and mobility of arsenic [27].

The nano-biochar produced less than 100 nm sizes can greatly influence the mobility in water and soil environment in comparison micro size biochar obtained through grinding and crushing [28]. Micro size bulk biochar are better in retention of nutrients and immobilization of contaminants while nano-biochar is good in facilitation of natural solutes as a carrier [29]. In other ways, bulk biochar are good in adsorption while nano-biochar along with the adsorption can bring about fragmentations of environmental DNA [39]. Nano-biochar in the size range 3-4 nm are available in the form of multifunctional fluorescence magnetic biochar dots which is used for the removal of metals and pathogens from water environment [30].

It is also reported that, carbonaceous nanomaterials like carbon nanotube (CNTs), fullerene and graphene oxide (GO) poses higher toxic effects to living organisms in comparison to bulk biochar [31]. Often application of biochar in the soil makes accumulation and exposure of more nano-biochar which can also negatively influence living organisms in the environment like carbonaceous nanomaterials [32].

Methods of Production of Biochar

For production of engineered biochar, thorough study and investigations are required to get biochar with necessary modifications and excellent performance [33-35]. There are many methods are reported for the conversion and production of biochar such as gasification, fermentation, combustion, extraction, liquefaction, digestion, enzymatic conversion, and chemical conversion among them pyrolysis is the most popular way to convert organic waste in to useful carbonaceous inert material [36].

The organic substrate such as natural organic matter (NOM) which we can use for the production of biochar and other products charcoal, soot are nothing, but pyrogenic carbonaceous matter (PCM) results because partial combustions, biochar also can be naturally produced forest fires and crop residue burnings for environmental and agricultural applications.

Factors Affecting the Properties of Biochar-Based Nano-Composites

There are many factors are involved in the production of biochar, nano-biochar and biochar derived nano-composites [37]. The factors and methods responsible for the production of biochar are greatly influence the properties of resultant materials [38]. The major factors involved in the production of biochar are the condition for pyrolysis such as thermo-chemical conversion technology, pyrolysis temperature, residue time, etc. and substrate type used for the conversion into biochar [39]. In one of the reports, production of nano-composites of MgO-biochar were prepared using substrate of feedstock for the removal of phosphorus from water environment, the affinity for adsorption of these feedstock towards phosphorus are obtained in the order of sugar beet tailings > cottonwoods > sugarcane bagasse > peanut shells > pine woods [41].

Other derivatives of biochar such as chitosan-modified biochar obtained from different plant sources such as bamboo, sugarcane bagasse, hickory wood, and peanut hull can be used for the adsorption of metals. The biochar obtained from bamboo source are good with adsorption and removal of Pb and Cd, the sugarcane bagasse biochar are good with the Cu adsorption [6].

Application of Biochar

The biochar, nano-biochar, and biochar derived nano-composites are having wide application in the field of bioremediation, heavy metal removal, mobility, and transport of nutrients and minerals in soil and water environment [13, 21]. Biochar is also having catalytic application in the enhancement of renewable energy productions.

Effect of Nano Biochar on Soil Organic Carbon Content

The soil organic content is major source responsible for the CO_2 release in the atmosphere. The biochar and nano-biochar addition to soil environment can enhance soil organic carbon content [42-44] and it is resulted in the higher emission of CO_2 in environment. It is reported that addition of biochar to soil environment can enhance the CO_2 emission into the environment by 8% for first 20 days and gradually declines up to 120 days [45].

Effect of Nano Biochar on Soil Physical Properties

The addition of biochar into soil environments adds up great impact and also responsible for the changes in tensile strength, flow of gases in the soil, and also hydrodynamics. The consequences with respect to soil environment also affect to the soil organisms [45].

The effect of Nano Biochar on Soil Chemical Properties

The soil microbes influence the characters of organic matter content in biochar with respect to the biochemical processes such as aeration, reaction with organic matter and soil minerals, and oxidation [46]. In a similar way, the biochar can influence the characterization of soil and water environment with respect to the parameters like pH, electrical conductivity (EC), cations exchange capacity (CEC), and soil nutrient content [45].

Nano-Biochar for Microbial Fuel Cell

Biochar and nano-biochar can be useful for the production of microbial fuel cells. These tiny cells are used for the conversion of chemical energy into electrical energy [47]. The MFCs are viable cells are containing and anodic and cathodic chamber separated by proton exchange membrane. Microbes survive on carbonaceous organic matter and release monomers and polymeric metabolites which generate electrons and protons through the redox reactions [48, 49].

Nano-Biochar for Hydrogen Production

Nano-biochar can be useful in the production of hydrogen from living sources through three different processes such as water splitting, methane steam reforming, and anaerobic digestion [50] elaborated in detail in the following sections.

Nano-Biochar for Water Splitting

Biochar and nano-biochar can be useful in the reaction of water splitting for production of hydrogen. There is several catalyst and oxides of metal origin are used for the production of generation of hydrogen [51, 52].

Nano-Biochar for Methane Steam Reforming

Nano-biochar and biochar can helps in the generation of methane, organic matter digested anaerobically have higher ratio of hydrogen and carbon i.e. (4:1). The methane further can be decomposed and leads to generation of hydrogen at 1200 °C [50] *for Biogas Production*

Waste management generated through the organic sources is done with the help of anaerobic digestion leads to generation of bio-energy. The nano-biochar addition during anaerobic digestion can enhance the hydrogen emission with reduced dormancy [53]. The application of nano-biochar has also been done for the increase in the production of volatile fatty acids (VFAs), maintenance, and stabilization of pH [54].

Nano-Biochar for Biodiesel Production

Nano-biochar can be useful in the biodiesel production [55]. The long chain fatty acids (C14-C20) are potential substrate for the biodiesel production as it cans high energy density for present engines [56]. The natural oils obtained from various sources are trans-esterified for biodiesel production. For biodiesel production, the catalyst used can be a homogeneous or heterogeneous one.

Agriculture

Biochar and nano-biochar have proved application in the field of agriculture such as improving soil fertility and crop productivity [57]. The biochar comes with porous texture which makes highly sorptive for the maintenance of soil moisture and nutrients. The biochar can be used individually or along with certain nutrients can enhance plant growth in comparison to treatment of chemical fertilizer [58]. The application of biochar along with organic and inorganic fertilizer can enhance the content of necessary elements such as total nitrogen and potassium, available nitrogen, potassium, and phosphorus [59]. The presence of biochar in the soil environment can enhance the availability of P through direct anion or cations exchange or indirect retention of phosphorus [60]. Biochar also have role in nitrogen cycle and influence soil nitrification, it can reduces inorganic nitrogen and emit N_2O, helps to increase rate of nitrogen fixation, and makes available nitrogen to crops [61]. The biochar addition in soil enhances the growth of soil ammonia-oxidizing microorganisms, and also it can accelerate rate of nitrification [17].

Enhancer of Soil Efficiency

The biochar can be a good supplement for enhancement of soil fertility, and also it can improve utilization efficiency of chemical fertilizer which leads to the higher crop yield [62]. Sometimes, biochar application in soil environment is unpractical as the biochar is runoff after some and it has no use in soil improvement [63]. Alternative to biochar there is nano-biochar which last longer in soil environment and can be recycled in soil-vegetation-atmosphere [13]. High-efficiency fertilizer can be produced with the application of nano-biochar in comparison to biochar as nano-biochar have large surface area and small size of particle which makes highly pheasible for the coupling of nutrients and microelement of soil. Nano-biochar also useful in the prevention of nutrient's loss because of run-off by rainwater and loess slopes and it can significantly influence moisture movement in Loess Plateau [64]. In one of the study, it was found that application of nano-biochar can enhance the crop yield around 10-20% and also it can reduce the use of fertilizer by 30-50% [21].

Soil Remediation

Nano-biochar has wide application in environment cleaning and remediation [65]. Nano-biochar has well sorption potential which makes it suitable candidates for the removal of several pollutants and toxicants from soil and water environment [66]. The main toxicants involved in soil and water environments are herbicides, pesticides, toxic metals, polychlorinated biphenyls, and polycyclic aromatic hydrocarbons (PAHs) [67, 68]. The nano-biochar is along with sorption of particular toxicants, involved in neutralization of acidic pH of soil environment [69].

The characteristics which makes it potential candidate for remediation of soil and water environments are large specific surface area, micro-porosity, hydrophobicity, and functionality [70]. The method of biochar production such as biomass pyrolysis involving duration of milling and temperature can control its size and other characteristics of biochar [71].

Biochar in Au NP Catalysis

Biochar synthesized as the byproduct of biomass carbonization can be used as the catalyst for gold nanoparticles. The structurally biochar are composed by the stacks of graphite along covering graphene and graphene oxides layer and edges of this assembly is the significant sites for Au-NPs [72].

Conjugation of biochar with magnetic nanoparticles increase the efficiency of catalysis, and also it can be easily recycled [72-76].

Conclusion and Future Prospects

Biochar are the carbonaceous stacks of graphene and graphene oxides, micro-porous in nature, and can be potential sorbent for multiple applications like removal of toxicants and contaminants and internal curing of the high-performance concrete. Reduction of risk with respect to the contaminants and toxicants can be achieved with co-pyrolysis. The production and application of nano-biochar through green techniques can increase the potential of water and fertilizers in soil. The addition and supplement of biochar and nano-biochar is seems to be beneficial in soil and water environment by improving soil structure, texture, porosity, particle size distribution, and density, and also it can influence the rhizospheric flora, capacity of water storage, concentration of oxygen in air, pH, electrical conductivity (EC), cations exchange capacity (CEC), nutrient levels, and consequently metal sorption efficiency and nutritional status. Biochar can be a good source of macro and micronutrients by absorbing nutrient from fertilizers, supplement of nano-biochar can enhance and improve the growth of plant even in saline environmental conditions.

There are more aspects that need to be revealing by pyrolysis using different organic and inorganic substrates for significant applications. Nano-biochar can be optimized with respect to structure of pores, induction of oxygen species along with functional groups, and reduction of risk with respect to contaminants. The biochar can be combined with novel materials like carbon nanotube, nanofibers, double layered hydroxides, etc. to improve its characteristics with the help of microwave-assisted pyrolysis and co-pyrolysis.

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How to cite this article:
Umesh Pravin Dhuldhaj, AbdulBasit Shaikh, Jaya Puri. Nano-biochar Production and its Characteristics: Overview. *International Journal of Advanced Biological and Biomedical Research*, 2023, 11(4), 206-220.
Link: https://www.ijabbr.com/article_707976.html