

Nano-biochar Production and its Characteristics: Overview

Umesh Pravin Dhuldhaj*^{ID} | AbdulBasit Shaikh^{ID} | Jaya Puri^{ID}

Department of Biotechnology, School of Life Sciences, Swami Ramanand Teerth
Marathwada University, Nanded, India

*Corresponding Author E-mail: umeshpd12@gmail.com

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-enabled 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 (Palansooriya et al., 2020).

It has versatile application in the field of bioremediation, economic, and environment protection, by adsorbing pollutant from the environment (Jin et al., 2018). 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 (Hassan et al., 2020).

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 (Ahmad et al., 2018).

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 (Enaime et al., 2020).

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 (Liu et al., 2018). Efficiency of adsorption of biochar can be increased by the modification surface properties such as surface charge, surface area, and pore volume (Ambaye et al., 2021). 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 (Rawat et al., 2018).

The biochar obtained after pyrolysis from plant sources is in crystalline structure, with several pores and nanopores 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 (Kianfar, 2019). 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 (Kianfar, 2020; Kianfar & Viet, 2021) 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 (Yang et al., 2020; Kianfar et al., 2020).

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 (Chausali et al., 2021). 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 (Dhuldhaj et al., 2021).

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 (Li et al., 2020; Almawgood et al., 2021). 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 (Zhang et al., 2022).

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 (Ippolito et al., 2020). The chemical content such as cellulose, hemicelluloses, and lignin responsible structural composition and morphology can control processes like thermal decomposition (Amalina et al., 2022). 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 (Yogalakshmi et al., 2022). 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 (Li et al., 2020).

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 (Rajput et al., 2022). The sorption properties of nano-biochar can be enhanced because of their significant properties like numerous oxyl groups, large surface area, and high reactivity (Lian et al., 2019; Yue et al., 2019), enhanced nutrient retention and higher pollutant adsorption (Pratap et al., 2021).

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 (Sun et al., 2018) 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 (Chausali et al. 2021). Nano-biochar is able to adsorbed pollutants from several environmental sources because of its greater surface area and smaller pore size (Amdeha, 2023).

The nanomaterials obtained from biochar also reported to have capacity to reduction in Cd²⁺ uptake and phytotoxicity and it has crucial role in several plant processes necessary for plant growth and productivity (Yue et al., 2019). 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 (Chen et al., 2018), and also it can increase desorption and mobility of arsenic (Kim et al., 2018).

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 (Ramanayaka et al., 2020). 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 (Bolan et al., 2023). In other ways, bulk biochar are good in adsorption while nano-biochar along with the adsorption can bring about fragmentations of environmental DNA (Lian et al., 2020). 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 (Guo et al., 2020).

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 (Kharlamova & Kramberger, 2023). 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 (Liu et al., 2018).

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 (Sajjadi et al., 2019; Wu et al., 2019; Yang et al., 2019). 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 (Khalid et al., 2018).

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 (Lan et al., 2021).

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 (Das & Panda, 2022). The factors and methods responsible for the production of biochar are greatly influence the properties of resultant materials (Tomczyk et al., 2020). 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 (Yaashika et al., 2020). 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 (Venkatesh et al., 2022).

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 (Ambaye et al., 2023).

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 (Chausali et al., 2021; Rajput et al., 2022). 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 CO₂ release in the atmosphere. The biochar and nano-biochar addition to soil environment can enhance soil organic carbon content (Kianfar and Salimi 2020; Syah et al., 2021; Majdi et al., 2021) and it is resulted in the higher emission of CO₂ in environment. It is reported that addition of biochar to soil environment can enhance the CO₂ emission into the environment by 8% for first 20 days and gradually declines up to 120 days (Husseina et al., 2022).

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 (Husseina et al., 2022).

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 (Mukherjee et al., 2022). 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 (Husseina et al., 2022).

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 (Sciarria et al., 2020). The MFCs are viable cells are containing an 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 (Do et al., 2021; Yadav et al., 2020).

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 (Goswami et al., 2022) 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 are several catalysts and oxides of metal origin are used for the production of hydrogen (Yang et al., 2021; Jiang et al., 2021).

Nano-Biochar for Methane Steam Reforming

Nano-biochar and biochar can help 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 (Goswami et al., 2022).

Nano-Biochar 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 (Osman et al., 2022). 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 (Sugiarto et al., 2021).

Nano-Biochar for Biodiesel Production

Nano-biochar can be useful in the biodiesel production (Cheng & Li, 2018). The long chain fatty acids (C14-C20) are potential substrate for the biodiesel production as it has high energy density for present engines (Neupane, 2023). 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 (Hamidzadeh et al., 2023). The biochar comes with porous texture which makes highly sorptive for the maintenance of soil moisture and nutrients (Kocsis et al., 2022). The biochar can be used individually or along with certain nutrients can enhance plant growth in

comparison to treatment of chemical fertilizer (Agarwal et al., 2022). 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 (Liu et al., 2022). 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 (Hossain et al., 2020). Biochar also has a role in nitrogen cycle and influence soil nitrification, it can reduce inorganic nitrogen and emit N₂O, helps to increase rate of nitrogen fixation, and makes available nitrogen to crops (Ayaz et al., 2023). The biochar addition in soil enhances the growth of soil ammonia-oxidizing microorganisms, and also it can accelerate rate of nitrification (Yao et al., 2022).

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 (Yadav et al., 2023). Sometimes, biochar application in soil environment is unpractical as the biochar is runoff after some time and it has no use in soil improvement (Li et al., 2018). Alternative to biochar there is nano-biochar which lasts longer in soil environment and can be recycled in soil-vegetation-atmosphere (Chausali et al., 2021). High-efficiency fertilizer can be produced with the application of nano-biochar in comparison to biochar as nano-biochar has large surface area and small size of particle which makes highly feasible for the coupling of nutrients and microelement of soil (Kocsis et al., 2022). Nano-biochar is also useful in the prevention of nutrient loss because of run-off by rainwater and loess slopes and it can significantly influence moisture movement in Loess Plateau (Zhou et al.,

2018). 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% (Rajput et al., 2022).

Soil Remediation

Nano-biochar has wide application in environment cleaning and remediation (Sonowal et al., 2023). Nano-biochar has well sorption potential which makes it suitable candidates for the removal of several pollutants and toxicants from soil and water environment (Jiang et al., 2023). The main toxicants involved in soil and water environments are herbicides, pesticides, toxic metals, polychlorinated biphenyls, and polycyclic aromatic hydrocarbons (PAHs) (Molina and Segura 2021; Alengebawy et al., 2021). The nano-biochar is along with sorption of particular toxicants, involved in neutralization of acidic pH of soil environment (Chugh et al., 2023).

The characteristics which makes it potential candidate for remediation of soil and water environments are large specific surface area, micro-porosity, hydrophobicity, and functionality (Murtaza et al., 2023). The method of biochar production such as biomass pyrolysis involving duration of milling and temperature can control its size and other characteristics of biochar (Novotny et al., 2023).

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 (Lopes et al., 2021).

Conjugation of biochar with magnetic nanoparticles increase the efficiency of catalysis, and also it can be easily

recycled (Jiang et al., 2018; Lopes et al., 2021).

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.

Orcid

Umesh Pravin Dhuldhaj:

<https://orcid.org/0000-0002-7439-4669>

AbdulBasit Shaikh:

<https://orcid.org/0000-0003-3280-5981>

Jaya Puri:

<https://orcid.org/0009-0008-2473-6676>

References

1. Agarwal H, Kashyap VH, Mishra A, Bordoloi S, Singh PK, Joshi NC. Biochar-based fertilizers and their applications in plant growth promotion and protection; 3 *Biotech*; 2022 Jun; 12(6):136. <https://doi.org/10.1007/s13205-022-03195-2>
2. Ahmad M, Ahmad M, Usman AR, Al-Faraj AS, Abduljabbar AS, Al-Wabel MI. Biochar composites with nano zerovalent iron and eggshell powder for nitrate removal from aqueous solution with coexisting chloride ions, *Environmental science and pollution research*; 2018 Sep; 25:25757-71. <https://doi.org/10.1007/s11356-017-0125-9>
3. Alengebawy A, Abdelkhalek ST, Qureshi SR, Wang MQ. Heavy metals and pesticides toxicity in agricultural soil and plants: Ecological risks and human health implications, *Toxics*; 2021 Feb 25; 9(3):42. <https://doi.org/10.3390/toxics9030042>
4. Abd Almawgood OM, El Tohamy SA, Ismail EH, Samhan FA. Sugarcane Bagasse Biochar with Nanomagnetite: A novel Composite Heavy Metals Pollutants Removal, *Egyptian Journal of Chemistry*; 2021 Mar 1; 64(3):1293-313. <https://dx.doi.org/10.21608/ejchem.2020.43158.2870>
5. Amalina F, Abd Razak AS, Krishnan S, Sulaiman H, Zularisam AW, Nasrullah M. Advanced techniques in the production of biochar from lignocellulosic biomass and environmental applications, *Cleaner Materials*; 2022 Aug 30;100137. <https://doi.org/10.1016/j.clema.2022.100137>
6. Ambaye TG, Vaccari M, van Hullebusch ED, Amrane A, Rtimi SJ. Mechanisms and adsorption capacities of biochar for the removal of organic and inorganic pollutants from industrial wastewater, *International Journal of Environmental Science and Technology*; 2021 Oct 1:1-22. <https://doi.org/10.1007/s13762-020-03060-w>
7. Amdeha E. Biochar-based nanocomposites for industrial wastewater treatment via adsorption and photocatalytic degradation and the parameters affecting these processes, *Biomass Conversion and Biorefinery*; 2023 Jul 4:1-26. <https://doi.org/10.1007/s13399-023-04512-2>
8. Ayaz M, Feizienė D, Tilvikienė V, Feiza V, Baltrėnaitė-Gedienė E, Ullah S. Biochar with Inorganic Nitrogen Fertilizer Reduces Direct Greenhouse Gas Emission Flux from Soil, *Plants*; 2023 Feb 22; 12(5):1002. <https://doi.org/10.3390/plants12051002>
9. Bolan S, Hou D, Wang L, Hale L, Egamberdieva D, Tammeorg P, Li R, Wang B, Xu J, Wang T, Sun H. The potential of biochar as a microbial carrier for agricultural and environmental applications,

- Science of the Total Environment*; 2023 May 8:163968. <https://doi.org/10.1016/j.scitotenv.2023.163968>
10. Chausali N, Saxena J, Prasad R. Nanobiochar and biochar based nanocomposites: Advances and applications, *Journal of Agriculture and Food Research*; 2021 Sep 1; 5:100191. <https://doi.org/10.1016/j.jafr.2021.100191>
 11. Chen M, Alim N, Zhang Y, Xu N, Cao X. Contrasting effects of biochar nanoparticles on the retention and transport of phosphorus in acidic and alkaline soils, *Environmental pollution*; 2018 Aug 1; 239:562-70. <https://doi.org/10.1016/j.envpol.2018.04.050>
 12. Cheng F, Li X. Preparation and application of biochar-based catalysts for biofuel production, *Catalysts*; 2018 Aug 24; 8(9):346. <https://doi.org/10.3390/catal8090346>
 13. Chugh P, Kapoor R, Batra L, Singh R. Role of biochar and modified biochar for effective removal of heavy metals. In *Integrative Strategies for Bioremediation of Environmental Contaminants*, Volume Two 2023 Jan 1 (pp. 17-30); Academic Press. <https://doi.org/10.1016/B978-0-443-14013-6.00006-8>
 14. Das R, Panda SN. Preparation and applications of biochar based nanocomposite: A review, *Journal of Analytical and Applied Pyrolysis*; 2022 Sep 5:105691. <https://doi.org/10.1016/j.jaap.2022.105691>
 15. Dhuldhaj UP, Malik N, Sirsat S. Microbial Synthesis of Nanomaterials: Future prospects and challenges In: Shende SS, Rajput VD, Gorovtsov AV, Minkina TM, Sushkova SN (Eds.), *Microbial Synthesis of Nanomaterials*, Nova Science Publisher, New York, 2021; pp. 337-357.
 16. Do MH, Ngo HH, Guo W, Chang SW, Nguyen DD, Sharma P, Pandey A, Bui XT, Zhang X. Performance of a dual-chamber microbial fuel cell as biosensor for on-line measuring ammonium nitrogen in synthetic municipal wastewater, *Science of The Total Environment*; 2021 Nov 15; 795:148755. <https://doi.org/10.1016/j.scitotenv.2021.148755>
 17. Enaime G, Baçaoui A, Yaacoubi A, Lübken M. Biochar for wastewater treatment—conversion technologies and applications, *Applied Sciences*; 2020 May 18; 10(10):3492. <https://doi.org/10.3390/app10103492>
 18. Goswami L, Kushwaha A, Singh A, Saha P, Choi Y, Maharana M, Patil SV, Kim BS. Nano-biochar as a sustainable catalyst for anaerobic digestion: a synergetic closed-loop approach, *Catalysts*; 2022 Feb 1; 12(2):186. <https://doi.org/10.3390/catal12020186>
 19. Guo F, Bao L, Wang H, Larson SL, Ballard JH, Knotek-Smith HM, Zhang Q, Su Y, Wang X, Han F. A simple method for the synthesis of biochar nanodots using hydrothermal reactor, *MethodsX*; 2020 Jan 1; 7:101022. <https://doi.org/10.1016/j.mex.2020.101022>
 20. Hamidzadeh Z, Ghorbannezhad P, Ketabchi MR, Yeganeh B. Biomass-derived biochar and its application in agriculture, *Fuel*; 2023 Jun 1; 341:127701. <https://doi.org/10.1016/j.fuel.2023.127701>

21. Hassan AZ, Mahmoud AW, Turkey GM, Safwat G. Rice husk derived biochar as smart material loading nano nutrients and microorganisms, *Bulgarian Journal of Agricultural Science*; 2020 Mar 1; 26(2).
22. Hossain MZ, Bahar MM, Sarkar B, Donne SW, Ok YS, Palansooriya KN, Kirkham MB, Chowdhury S, Bolan N. Biochar and its importance on nutrient dynamics in soil and plant, *Biochar*; 2020 Dec; 2:379-420. <https://doi.org/10.1007/s42773-020-00065-z>
23. Abed Hussein B, Mahdi AB, Emad Izzat S, Acwin Dwijendra NK, Romero Parra RM, Barboza Arenas LA, Mustafa YF, Yasin G, Thaeer Hammid A, Kianfar E. Production, structural properties nano biochar and effects nano biochar in soil: a review, *Egyptian Journal of Chemistry*; 2022 Dec 1; 65(12):607-18. <https://doi.org/10.21608/ejchem.2022.131162.5772>
24. Ippolito JA, Cui L, Kammann C, Wrage-Mönnig N, Estavillo JM, Fuertes-Mendizabal T, Cayuela ML, Sigua G, Novak J, Spokas K, Borchard N. Feedstock choice, pyrolysis temperature and type influence biochar characteristics: a comprehensive meta-data analysis review, *Biochar*; 2020 Dec; 2:421-38. <https://doi.org/10.1007/s42773-020-00067-x>
25. Jiang C, Yao M, Wang Z, Li J, Sun Z, Li L, Moon KS, Wong CP. A novel flower-like architecture comprised of 3D interconnected Co-Al-Ox/Sy decorated lignosulfonate-derived carbon nanosheets for flexible supercapacitors and electrocatalytic water splitting, *Carbon*; 2021 Oct 30; 184:386-99. <https://doi.org/10.1016/j.carbon.2021.08.044>
26. Dong M, He L, Jiang M, Zhu Y, Wang J, Gustave W, Wang S, Deng Y, Zhang X, Wang Z. Biochar for the removal of emerging pollutants from aquatic systems: a review, *International Journal of Environmental Research and Public Health*; 2023 Jan 17; 20(3):1679. <https://doi.org/10.1007/s42773-022-00201-x>
27. Jiang SF, Ling LL, Xu Z, Liu WJ, Jiang H. Enhancing the catalytic activity and stability of noble metal nanoparticles by the strong interaction of magnetic biochar support, *Industrial & Engineering Chemistry Research*; 2018 Sep 11; 57(39):13055-64. <https://doi.org/10.1021/acs.iecr.8b02777>
28. Khalid A, Khushnood RA, Mahmood A, Ferro GA, Ahmad S. Synthesis, characterization and applications of nano/micro carbonaceous inerts: A review, *Procedia Structural Integrity*; 2018 Jan 1; 9:116-25. <https://doi.org/10.1016/j.prostr.2018.06.019>
29. Kharlamova MV, Kramberger C. Cytotoxicity of Carbon Nanotubes, Graphene, Fullerenes, and Dots, *Nanomaterials*; 2023 Apr 25; 13(9):1458. <https://doi.org/10.3390/nano13091458>
30. Kianfar E. Comparison and assessment of zeolite catalysts performance dimethyl ether and light olefins production through methanol: a review, *Reviews in Inorganic Chemistry*; 2019 Aug 27; 39(3):157-77. <https://doi.org/10.1515/revic-2019-0001>

31. Kianfar E, Mahler A. Zeolites: properties, applications, modification and selectivity, *Zeolites: advances in research and applications*; 2020; 1.
32. Kianfar E, Salimi M. A review on the production of light olefins from hydrocarbons cracking and methanol conversion, *Advances in chemistry research*; 2020; 59:1-81.
33. Kianfar E, Salimi M, Koohestani B. Zeolite CATALYST: a review on the production of light olefins, LAP LAMBERT Academic Publishing; 2020.
34. Kianfar E, Cao V. Polymeric membranes on base of PolyMethyl methacrylate for air separation: a review, *Journal of Materials Research and Technology*; 2021 Jan 1; 10:1437-61. <https://doi.org/10.1016/j.jmrt.2020.12.061>
35. Kim HB, Kim SH, Jeon EK, Kim DH, Tsang DC, Alessi DS, Kwon EE, Baek K. Effect of dissolved organic carbon from sludge, Rice straw and spent coffee ground biochar on the mobility of arsenic in soil, *Science of the Total Environment*; 2018 Sep 15; 636:1241-8. <https://doi.org/10.1016/j.scitotenv.2018.04.406>
36. Kim HB, Kim SH, Jeon EK, Kim DH, Tsang DC, Alessi DS, Kwon EE, Baek K. Effect of dissolved organic carbon from sludge, Rice straw and spent coffee ground biochar on the mobility of arsenic in soil, *Science of the Total Environment*; 2018 Sep 15; 636:1241-8. <https://doi.org/10.3390/app12084051>
37. Lian F, Wang Z, Xing B. Nano-black carbon (biochar) released from pyrogenic carbonaceous matter as a super suspending agent in water/soil environments, *Biochar*; 2021 Mar; 3:1-3. <https://doi.org/10.1007/s42773-020-00075-x>
38. Li J, Cai X, Liu Y, Gu Y, Wang H, Liu S, Liu S, Yin Y, Liu S. Design and synthesis of a biochar-supported nano manganese dioxide composite for antibiotics removal from aqueous solution, *Frontiers in Environmental Science*; 2020 May 22; 8:62. <https://doi.org/10.3389/fenvs.2020.00062>
39. Li Y, Zhang F, Yang M, Zhang J, Xie Y. Impacts of biochar application rates and particle sizes on runoff and soil loss in small cultivated loess plots under simulated rainfall, *Science of the Total Environment*; 2019 Feb 1; 649:1403-13. <https://doi.org/10.1016/j.scitotenv.2018.08.415>
40. Lian F, Yu W, Zhou Q, Gu S, Wang Z, Xing B. Size matters: nano-biochar triggers decomposition and transformation inhibition of antibiotic resistance genes in aqueous environments, *Environmental science & technology*; 2020 Jun 19; 54(14):8821-9. <https://doi.org/10.1021/acs.est.0c02227>
41. Lian F, Yu W, Wang Z, Xing B. New insights into black carbon nanoparticle-induced dispersibility of goethite colloids and configuration-dependent sorption for phenanthrene, *Environmental science & technology*; 2018 Dec 12; 53(2):661-70. <https://doi.org/10.1021/acs.est.8b05066>
42. Liu B, Li H, Ma X, Chen R, Wang S, Li L. The synergistic effect of oxygen-containing functional groups on CO₂ adsorption by the glucose-potassium citrate-derived

- activated carbon, *RSC advances*; 2018; 8(68):38965-73.
<https://doi.org/10.1039/C8RA05523H>
43. Liu G, Zheng H, Jiang Z, Zhao J, Wang Z, Pan B, Xing B. Formation and physicochemical characteristics of nano biochar: insight into chemical and colloidal stability, *Environmental science & technology*; 2018 Aug 24; 52(18):10369-79.
<https://doi.org/10.1021/acs.est.8b01481>
44. Liu M, Linna C, Ma S, Ma Q, Song W, Shen M, Song L, Cui K, Zhou Y, Wang L. Biochar combined with organic and inorganic fertilizers promoted the rapeseed nutrient uptake and improved the purple soil quality, *Frontiers in Nutrition*; 2022 Sep 14; 9:997151.
<https://doi.org/10.3389/fnut.2022.997151>
45. Lopes RP, Guimarães T, Astruc D. Magnetized biochar as a gold nanocatalyst support for p-nitrophenol reduction, *Journal of the Brazilian Chemical Society*; 2021 Jul 28; 32:1680-6.
<https://doi.org/10.21577/0103-5053.20210056>
46. Majdi HS, Latipov ZA, Borisov V, Yuryevna NO, Kadhim MM, Suksatan W, Khlewee I, Kianfar E. Nano and Battery Anode: A Review, *Nanoscale Res Lett*; 2021; 16: 177.
<https://doi.org/10.1186/s11671-021-03631-x>
47. Molina Delgado L, Segura A. Biochemical and metabolic plant responses toward polycyclic aromatic hydrocarbons and heavy metals present in atmospheric pollution.
<http://dx.doi.org/10.3390/plants10112305>
48. Mukherjee S, Sarkar B, Aralappanavar VK, Mukhopadhyay R, Basak BB, Srivastava P, Marchut-Mikołajczyk O, Bhatnagar A, Semple KT, Bolan N. Biochar-microorganism interactions for organic pollutant remediation: Challenges and perspectives, *Environmental Pollution*; 2022 Sep 1; 308:119609.
<https://doi.org/10.1016/j.envpol.2022.119609>
49. Murtaza G, Ahmed Z, Eldin SM, Ali I, Usman M, Iqbal R, Rizwan M, Abdel-Hameed UK, Haider AA, Tariq A. Biochar as a green sorbent for remediation of polluted soils and associated toxicity risks: A critical review, *Separations*; 2023 Mar 13; 10(3):197.
<https://doi.org/10.3390/separations10030197>
50. Neupane D. Biofuels from Renewable Sources, a Potential Option for Biodiesel Production, *Bioengineering*; 2022 Dec 25; 10(1):29.
<https://doi.org/10.3390/bioengineering10010029>
51. Novotný M, Marković M, Raček J, Šipka M, Chorazy T, Tošić I, Hlavínek P. The use of biochar made from biomass and biosolids as a substrate for green infrastructure: A review, *Sustainable Chemistry and Pharmacy*; 2023 May 1; 32:100999.
<https://doi.org/10.1016/j.scp.2023.100999>
52. Osman AI, Fawzy S, Farghali M, El-Azazy M, Elgarahy AM, Fahim RA, Maksoud MA, Ajlan AA, Yousry M, Saleem Y, Rooney DW. Biochar for agronomy, animal farming, anaerobic digestion, composting, water treatment, soil remediation,

- construction, energy storage, and carbon sequestration: a review, *Environmental Chemistry Letters*; 2022 Aug; 20(4):2385-485. <https://doi.org/10.1007/s10311-022-01424-x>
53. Palansooriya KN, Shaheen SM, Chen SS, Tsang DC, Hashimoto Y, Hou D, Bolan NS, Rinklebe J, Ok YS. Soil amendments for immobilization of potentially toxic elements in contaminated soils: A critical review, *Environment international*; 2020 Jan 1; 134:105046. <https://doi.org/10.1016/j.envint.2019.105046>
54. Pratap T, Patel M, Pittman CU, Nguyen TA, Mohan D. Nanobiochar: A sustainable solution for agricultural and environmental applications, *In Nanomaterials for Soil Remediation* 2021 Jan 1; 501-519. <https://doi.org/10.1016/B978-0-12-822891-3.00028-1>
55. Rajput VD, Minkina T, Ahmed B, Singh VK, Mandzhieva S, Sushkova S, Bauer T, Verma KK, Shan S, van Hullebusch ED, Wang B. Nano-biochar: A novel solution for sustainable agriculture and environmental remediation, *Environmental Research*; 2022 Jul 1 ;210:112891. <https://doi.org/10.1016/j.envres.2022.112891>
56. Ramanayaka S, Vithanage M, Alessi DS, Liu WJ, Jayasundera AC, Ok YS. Nanobiochar: production, properties, and multifunctional applications. *Environmental Science: Nano*. 2020;7(11):3279-302. <https://doi.org/10.1039/DOEN00486C>
57. Rawat J, Saxena J, Sanwal P. Biochar: [a sustainable approach for improving plant growth and soil properties](#), *Biochar-an imperative amendment for soil and the environment*; 2019 Jan 8;1-7.
58. Sajjadi B, Zubatiuk T, Leszczynska D, Leszczynski J, Chen WY. Chemical activation of biochar for energy and environmental applications: a comprehensive review, *Reviews in Chemical Engineering*; 2019 Oct 1; 35(7):777-815. <https://doi.org/10.1515/revce-2018-0003>
59. Sciarria TP, Oliveira AC, Mecheri B, D'Epifanio A, Goldfarb JL, Adani F. Metal-free activated biochar as an oxygen reduction reaction catalyst in single chamber microbial fuel cells, *Journal of Power Sources* 2020; 462: 228183 <https://doi.org/10.1016/j.jpowsour.2020.228183>
60. Sonowal S, Koch N, Sarma H, Prasad K, Prasad R. A Review on Magnetic Nanobiochar with Their Use in Environmental Remediation and High-Value Applications, *Journal of Nanomaterials*; 2023 Jan 5; 2023. <https://doi.org/10.1155/2023/4881952>
61. Sugiarto Y, Sunyoto NM, Zhu M, Jones I, Zhang D. Effect of biochar in enhancing hydrogen production by mesophilic anaerobic digestion of food wastes: The role of minerals, *International Journal of Hydrogen Energy*; 2021 Jan 19; 46(5):3695-703. <https://doi.org/10.1016/j.ijhydene.2020.10.256>
62. Sun B, Zhang Y, Chen W, Wang K, Zhu L. Concentration dependent effects of bovine serum albumin on graphene oxide colloidal stability in aquatic environment, *Environmental science & technology*; 2018 Jun 12; 52(13):7212-9.

- <https://doi.org/10.1021/acs.est.7b06218>
63. Syah R, Zahar M, Kianfar E. Nanoreactors: properties, applications and characterization, *International Journal of Chemical Reactor Engineering*, 2021; 19(10): 981-1007. <https://doi.org/10.1515/ijcre-2021-0069>
64. Tomczyk A, Sokołowska Z, Boguta P. Biochar physicochemical properties: pyrolysis temperature and feedstock kind effects, *Reviews in Environmental Science and Bio/Technology*; 2020 Mar; 19:191-215. <https://doi.org/10.1007/s11157-020-09523-3>
65. Venkatesh R, Karthi N, Kawin N, Prakash T, Kannan CR, Karthigairajan M, Bobe K. Synthesis and adsorbent performance of modified biochar with ag/MgO nanocomposites for heat storage application, *Adsorption Science & Technology*; 2022 Sep 29; 2022. <https://doi.org/10.1155/2022/7423102>
66. Wu L, Wei C, Zhang S, Wang Y, Kuzyakov Y, Ding X. MgO-modified biochar increases phosphate retention and rice yields in saline-alkaline soil, *Journal of Cleaner Production*; 2019 Oct 20; 235:901-9. <https://doi.org/10.1016/j.jclepro.2019.07.043>
67. Yaashikaa PR, Kumar PS, Varjani S, Saravanan A. A critical review on the biochar production techniques, characterization, stability and applications for circular bioeconomy, *Biotechnology Reports*; 2020 Dec 1; 28:e00570. <https://doi.org/10.1016/j.btre.2020.e00570>
68. Yadav AP, Dwivedi V, Kumar S, Kushwaha A, Goswami L, Reddy BS. Cyanobacterial extracellular polymeric substances for heavy metal removal: a mini review, *Journal of Composites Science*; 2020 Dec 23; 5(1):1. <https://doi.org/10.3390/jcs5010001>
69. Yadav SP, Bhandari S, Bhatta D, Poudel A, Bhattarai S, Yadav P, Ghimire N, Paudel P, Paudel P, Shrestha J, Oli B. Biochar application: A sustainable approach to improve soil health. *Journal of Agriculture and Food Research*. 2023 Jan 6:100498. <https://doi.org/10.1016/j.jafr.2023.100498>
70. Yang F, Zhang S, Sun Y, Du Q, Song J, Tsang DC. A novel electrochemical modification combined with one-step pyrolysis for preparation of sustainable thorn-like iron-based biochar composites, *Bioresource technology*; 2019 Feb 1; 274:379-85. <https://doi.org/10.1016/j.biortech.2018.10.042>
71. Yang Z, Yang R, Dong G, Xiang M, Hui J, Ou J, Qin H. Biochar nanocomposite derived from watermelon peels for electrocatalytic hydrogen production, *ACS omega*; 2021 Jan 14; 6(3):2066-73. <https://doi.org/10.1021/acsomega.0c05018>
72. Yang Z, Zhang L, Zhou Y, Wang H, Wen L, Kianfar E. Investigation of effective parameters on SAPO-34 nanocatalyst in the methanol-to-olefin conversion process: a review, *Reviews in Inorganic Chemistry*; 2020 Sep 25; 40(3):91-105. <https://doi.org/10.1515/revic-2020-0003>

73. Yao RJ, Li HQ, Yang JS, Wang XP, Xie WP, Zhang X. Biochar Addition Inhibits Nitrification by Shifting Community Structure of Ammonia-Oxidizing Microorganisms in Salt-Affected Irrigation-Silting Soil, *Microorganisms* 2022; 10(2): 436. <https://doi.org/10.3390/microorg-anisms10020436>
74. Yogalakshmi KN, Sivashanmugam P, Kavitha S, Kannah Y, Varjani S, AdishKumar S, Kumar G. Lignocellulosic biomass-based pyrolysis: A comprehensive review, *Chemosphere*; 2022 Jan 1; 286:131824. <https://doi.org/10.1016/j.chemosphere.2021.131824>
75. Yue L, Lian F, Han Y, Bao Q, Wang Z, Xing B. The effect of biochar nanoparticles on rice plant growth and the uptake of heavy metals: Implications for agronomic benefits and potential risk, *Science of the Total Environment*; 2019 Mar 15; 656:9-18. <https://doi.org/10.1016/j.scitotenv.2018.11.364>
76. Zhang Z, Ding H, Li Y, Yu J, Ding L, Kong Y, Ma J. Nitrogen-doped biochar encapsulated Fe/Mn nanoparticles as cost-effective catalysts for heterogeneous activation of peroxymonosulfate towards the degradation of bisphenol-A: Mechanism insight and performance assessment, *Separation and Purification Technology*, 2022; 283: 120136. <https://doi.org/10.1016/j.seppur.2021.120136>
77. Zhou B, Chen X, Wang Q, Wei W, Zhang T. Effects of nano carbon on soil erosion and nutrient loss in a semi-arid loess region of Northwestern China, *International Journal of Agricultural and Biological Engineering*; 2018 Jan 31; 11(1):138-45. [10.25165/j.ijabe.20181101.2775](https://doi.org/10.25165/j.ijabe.20181101.2775)

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