www.journalworlds.com
AGRI JOURNAL WORLD
VOL. 6 ISSUE 2 APRIL-JUNE, 2026

NANOBIOCHAR: A NEXT-GENERATION SOIL AMENDMENT FOR SUSTAINABLE AGRICULTURE

Tejaswini Chandrakar*, Kamsali Sukeswara Achari, Sanjeev Kumar

Agronomy Section, ICAR-National Dairy Research Institute, Karnal-132001

**Corresponding author email*: tejaswinichandrakar1999@gmail.com

ABSTRACT

Agriculture today faces a complex set of challenges, including declining soil fertility, nutrient losses, water scarcity, and contamination from heavy metals and agrochemicals. Farmers and researchers are therefore exploring innovative materials that can improve soil health while supporting sustainable crop production. One such emerging material is nanobiochar, a nanoscale form of biochar with enhanced physicochemical properties and wide agricultural potential. Derived from biomass and engineered into extremely fine particles, nanobiochar is gaining attention as a multifunctional amendment capable of improving nutrient use efficiency, soil structure, water retention, and environmental quality.

KEYWORDS: Biochar, Nanobiochar, Soil health, Sustainable Agriculture

WHAT IS NANOBIOCHAR?

Biochar is a carbon-rich material produced by heating biomass such as crop residues, wood chips, manure, or other organic wastes under limited oxygen conditions, typically at temperatures ranging from about 300 to 700°C. When this biochar is further processed into particles ranging roughly between 1 and 100 nanometers, it is referred to as nanobiochar. The drastic reduction in particle size transforms ordinary biochar into a highly reactive material with unique characteristics.

Compared with conventional biochar, nanobiochar possesses a much larger specific surface area, smaller particle size, higher reactivity, and a greater abundance of oxygen-containing functional groups. These properties enable nanobiochar to interact more efficiently with soil particles, nutrients, and microorganisms. In addition, nanobiochar typically exhibits a negative surface charge, which improves its ability to retain positively charged nutrients such as ammonium, potassium, calcium, and micronutrients. Because of these advantages, nanobiochar is increasingly being considered a next-generation soil amendment with applications in crop production, soil remediation, and climate-smart agriculture.

PREPARATION OF NANOBIOCHAR

The production of nanobiochar generally involves two main steps. First, biomass is converted into bulk biochar through thermochemical processes such as pyrolysis. Second, the bulk biochar is further processed to reduce particle size to the nanoscale. Several methods are used for this size reduction (Chausali et al., 2021).

1. BALL MILLING METHOD

Ball milling is one of the most widely used techniques for producing nanobiochar. In this process, bulk biochar is placed in a milling chamber containing hardened balls that rotate at high speed. The mechanical impact and friction break down larger particles into nanosized fragments. During milling, longitudinal pores and channels are compressed, creating new micro- and nano-pores (Ramanayaka et al., 2020). This results in increased surface area and improved adsorption capacity. Ball milling can be performed in dry or wet conditions. In dry milling, biochar is ground without any liquid medium, whereas in wet milling, water or another solvent is added. This method is considered environmentally friendly, relatively low-cost, and reproducible, making it suitable for large-scale preparation.

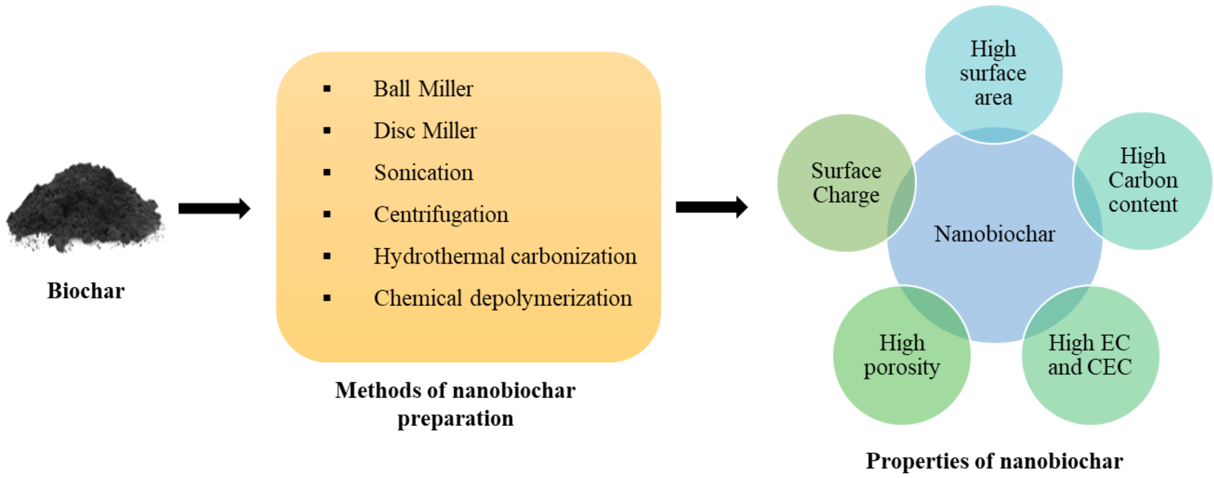

Fig 1. Methods of preparation and properties of nanobiochar

2. ULTRASONICATION METHOD

Ultrasonication involves dispersing biochar in a liquid medium and exposing it to high-frequency ultrasound waves. These waves generate microbubbles that collapse violently, producing shockwaves and microjets. The resulting forces break apart biochar particles and exfoliate graphite-like structures within the material. This process opens blocked pores, creates new micropores, and enhances surface reactivity. Ultrasonication is efficient because it often requires only one step and minimal chemical inputs. The resulting nanobiochar typically exhibits improved dispersion and higher adsorption capacity.

3. CENTRIFUGATION AND OTHER APPROACHES

Centrifugation is often used after milling or ultrasonication to separate nanosized particles from larger fractions. Other emerging approaches include microwave-assisted methods and chemical modifications, which further tailor nanobiochar properties for specific agricultural applications.

KEY PROPERTIES OF NANOBIOCHAR

Nanobiochar exhibits distinctive physicochemical properties that make it particularly useful in agricultural systems (Pathak et al., 2024).

- *HIGH SURFACE AREA AND POROSITY:* Nanobiochar contains abundant nano-pores that greatly increase its surface area. This large surface provides numerous sites for adsorption of nutrients, water, and pollutants. Higher pyrolysis temperatures often enhance pore development, further improving adsorption capacity.
- *HIGH ADSORPTION CAPACITY:* The porous structure and active functional groups allow nanobiochar to efficiently adsorb nutrients, heavy metals, and organic contaminants. This property makes it suitable for slow nutrient release and immobilization of toxic elements in soil.
- *IMPROVED WATER-HOLDING CAPACITY:* Nanobiochar can retain water within its pore network, enhancing soil moisture availability. This feature is especially beneficial under drought or rainfed conditions, where maintaining soil moisture is critical for crop growth.
- *ABUNDANT FUNCTIONAL GROUPS:* The surface of nanobiochar contains oxygen-containing functional groups such as carboxyl (–COOH), hydroxyl (–OH), and carbonyl (C=O). These groups improve nutrient retention, increase cation exchange capacity, and support microbial colonization.
- *ALKALINE NATURE:* Most nanobiochar materials are neutral to alkaline, which helps reduce soil acidity. This can improve nutrient availability and create a more favorable environment for plant growth.
- *HIGH CARBON CONTENT AND STABILITY:* Nanobiochar is rich in stable aromatic carbon structures. This contributes to long-term carbon sequestration, improved soil aggregation, and enhanced soil structure.

- *NEGATIVE SURFACE CHARGE:* Nanobiochar typically carries a negative surface charge, improving its ability to adsorb positively charged nutrients and metals. This also enhances colloidal stability and dispersion in soil.
- *SMALL PARTICLE SIZE AND HIGH REACTIVITY:* Because of its nanoscale size, nanobiochar can interact closely with plant roots and soil microorganisms. This increases nutrient exchange and improves soil biological activity.

APPLICATIONS OF NANOBIOCHAR IN AGRICULTURE

1. *NUTRIENT RETENTION AND SLOW RELEASE:* One of the major limitations of conventional fertilizers is nutrient loss through leaching, volatilization, and runoff. Nanobiochar can adsorb nutrients and release them gradually, improving nutrient use efficiency. When applied with fertilizers, nanobiochar acts as a carrier that reduces nutrient losses and enhances availability to plants.
2. *SOIL STRUCTURE IMPROVEMENT:* Nanobiochar enhances soil aggregation by binding soil particles together. Improved aggregation leads to better aeration, root penetration, and water infiltration. Over time, this improves soil fertility and productivity.
3. *ENHANCEMENT OF MICROBIAL ACTIVITY:* The porous structure of nanobiochar provides a habitat for beneficial soil microorganisms. These microbes play a vital role in nutrient cycling, organic matter decomposition, and plant growth promotion. Increased microbial activity also contributes to improved soil health.
4. *WATER CONSERVATION:* Nanobiochar improves soil water retention by storing moisture in its pores. This helps crops withstand short dry spells and reduces irrigation requirements. In sandy soils, nanobiochar significantly enhances water-holding capacity.
5. *HEAVY METAL IMMOBILIZATION:* Nanobiochar has strong adsorption capacity for heavy metals such as cadmium, lead, and copper (Jiang et al., 2023). By binding these metals, nanobiochar reduces their mobility and bioavailability. This makes it useful for reclaiming contaminated soils and protecting crop safety.
6. *REMOVAL OF ORGANIC POLLUTANTS:* Nanobiochar can adsorb pesticides, herbicides, and other organic pollutants. It reduces their movement in soil and water systems and may even facilitate degradation through catalytic processes. This contributes to cleaner agricultural environments.
7. *CARBON SEQUESTRATION AND CLIMATE MITIGATION:* Because nanobiochar is composed of stable carbon, it helps store carbon in soil for long periods. This reduces atmospheric carbon dioxide and contributes to climate change mitigation. At the same time, improved soil fertility supports

sustainable crop production.

8. *USE IN NANO-FERTILIZER DEVELOPMENT:* Nanobiochar can serve as a carrier material for nano-fertilizers. Nutrients loaded onto nanobiochar particles can be released slowly and efficiently near plant roots. This approach reduces fertilizer requirements and minimizes environmental pollution.

ADVANTAGES OF NANOBIOCHAR IN AGRICULTURE

- Improves nutrient use efficiency
- Enhances soil water retention
- Promotes microbial activity
- Reduces heavy metal toxicity
- Improves soil structure and aggregation
- Acts as a slow-release nutrient carrier
- Supports carbon sequestration
- Reduces environmental pollution

CHALLENGES AND FUTURE PROSPECTS

Despite its promising potential, nanobiochar use in agriculture is still emerging. Large-scale production methods need optimization to ensure cost-effectiveness. There is also a need to evaluate long-term effects on soil ecosystems and crop productivity. Standardized guidelines for safe application rates are required, particularly because nanoscale materials may behave differently from conventional amendments (Bhandari et al., 2023).

Future research is focusing on combining nanobiochar with fertilizers, microbial inoculants, and organic amendments. Such integrated approaches may enhance sustainability and improve crop yields while reducing environmental risks.

CONCLUSION

Nanobiochar represents a promising innovation for sustainable agriculture. Its nanoscale size, large surface area, and high reactivity make it more effective than conventional biochar in improving soil fertility, nutrient retention, water availability, and pollutant immobilization. By enhancing soil health and reducing nutrient losses, nanobiochar can contribute to improved crop productivity and environmental protection. With continued research and careful field evaluation, nanobiochar has the potential to become an important component of climate-smart and resource-efficient farming systems.

REFERENCES

Bhandari, G., Gangola, S., Dhasmana, A., Rajput, V., Gupta, S., Malik, S., and Slama, P. (2023). Nano-biochar: recent progress, challenges, and opportunities for sustainable environmental remediation. *Frontiers in Microbiology* Volume 14 - 2023.

Chausali, N., Saxena, J., and Prasad, R. (2021). Nanobiochar and biochar-based nanocomposites: Advances and applications. *Journal of Agriculture and Food Research* 5**,** 100191.

Jiang, M., He, L., Niazi, N.K., Wang, H., Gustave, W., Vithanage, M., Geng, K., Shang, H., Zhang, X., and Wang, Z. (2023). Nanobiochar for the remediation of contaminated soil and water: challenges and opportunities. *Biochar* 5**,** 2.

Pathak, H.K., Seth, C.S., Chauhan, P.K., Dubey, G., Singh, G., Jain, D., Upadhyay, S.K., Dwivedi, P., and Khoo, K.S. (2024). Recent advancement of nano-biochar for the remediation of heavy metals and emerging contaminants: Mechanism, adsorption kinetic model, plant growth and development. *Environmental Research* 255**,** 119136.

Ramanayaka, S., Vithanage, M., Alessi, D.S., Liu, W.-J., Jayasundera, A.C.A., and Ok, Y.S. (2020). Nanobiochar: production, properties, and multifunctional applications. *Environmental Science: Nano* 7**,** 3279-3302.

How to cite:

Chandrakar, T., Achari, K. S. and Kumar, S. (2026). Nanobiochar: A next-generation soil amendment for sustainable agriculture. Leaves and Dew Publication, New Delhi 110059. *Agri Journal World* 6 (2): 119-124.

*********XXXXX**********