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Uptake, translocation, and nutrient efficiency of nano-bonechar as a plant growth regulator in hydroponics and soil systems

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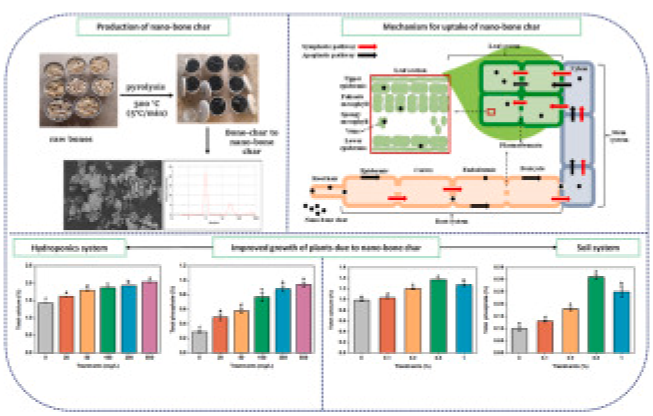
Highlights

- Translocation of nano-bonechar particles was visually observed in the *Syngonium podophyllum* plant.
- Plant productivity was significantly improved with nano-bonechar application in hydroponics and soil systems.
- Nano-bonechar also enhanced the plant's nutrient efficiency in both systems.

Abstract

The use of nanotechnology in terms of nanoparticles, carbon nanotubes, and quantum dots, when exposed to the plants, helps increase their productivity. It is worth the effort to comprehend the fate of these nanoparticles in plants. Bonechar derived from bones is a rich source of C, P, Ca^{2+}, and Mg^{2+} nutrients, which can significantly contribute to the growth of the plants. This study focused on the uptake of nano-bonechar (NBC) in the *Syngonium podophyllum* plant, and its effects on plant growth under hydroponics and soil systems. The compound microscopy and SEM-EDX results confirmed the presence of NBC in the leaves and roots of the plants in hydroponics and soil systems. The FTIR spectra reflected the presence of functional groups of the NBC in the leaves of the *Syngonium podophyllum* plant. The plant's growth parameters showed an increase in fresh weight, dry weight, shoot length, chlorophyll content, leaf count, total Ca^{2+}, total PO_4^{3-}, and total organic carbon of plants in both systems. The NBC not just improved plant physiochemical parameters but also built up the soil quality in terms of bioavailable Ca^{2+}, PO_4^{3-}, water holding capacity, and soil organic matter. It is concluded that the production of carbon-based NBC not only helps manage bone waste but also their efficient uptake in plants significantly improving plant productivity.

Graphical abstract



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Introduction

Nanomaterial-based technologies have been widely incorporated in agricultural research for efficient plant nutrient supply, enhanced crop viability under stressed conditions, and increased plant productivity (Vithanage et al., 2023). Recent research has demonstrated that nanoparticles can enter the plant through roots or cell walls if their size is smaller than that of the pores in these structures (Su et al., 2019). From roots, these specific-sized nanoparticles can travel to shoots via phloem tissues (Ahmed et al., 2021). Carbon-based nanoparticles are of utmost significance in environmental applications among the many nanomaterials. These carbon nanomaterials possess unique physiochemical characteristics, such as a large surface area, heightened chemical reactivity, and an increased capacity to enter living cells and alter normal cell morphology (Wang et al., 2018).

Biochar has the potential for enhanced nutrient retention, controlling undesirable algal growths in the nutrient medium, and supporting plant yield (Awad et al., 2017). A recent assessment highlighted the potential for changing the properties of bulk biochar to nano-biochar to ultimately increase agricultural production (Shafiq et al., 2023). Biochar having a particle size of less than 100 nm is categorized as “nano-biochar” (Liu et al., 2018). Different methods are available in the literature to produce nano-biochar from bulk biochar (Guo et al., 2020; Kumar et al., 2020). According to Naghdi et al. (2017), the ball milling technique for the formation of nano-biochar from bulk char is one of the most efficient technologies. Nano-biochar, in comparison to bulk biochar materials, possesses more attractive effectiveness for environmental management for specific purposes due to their distinctive nano-enable properties, including small size, bioavailability, mobilization, and outcomes on soil and plant systems (Rajput et al., 2022). Hence, action research is required to explore the potential of nano-biochar, particularly originating from specific feedstocks, in improving plant productivity. Animal bones could be a promising feedstock for the production of nano-bonechar due to their richness in carbon, phosphorus, and calcium. Bonechar is suggested as a green remediation agent with multiple advantages, including nutrient rich fertilizer, heavy metal immobilizer, and bone recycler (Mei et al., 2022). The nano-bonechar could enhance the uptake of essential nutrients by plants. Recent research has reported the application of bonechar as a fertilizer to enhance plant productivity (Liang et al., 2023; Mei et al., 2022; Carella et al., 2021).

Soil is one of the most significant and readily available media for plant growth. It is responsible for providing nutrients, air, and water and holds the key to the successful growth of plants (Sardare and Admane, 2013). Nowadays, the soil is no longer actively available for crop cultivation in many areas of the world as more land is being turned into urban or metropolitan territory. Additionally, certain regions are not geographically or topographically conducive to agriculture. In this scenario, the soil-less method “the hydroponics system,” a technique for growing plants without soil in a nutrient solution, may be useful (Cifuentes-Torres et al., 2021). In a hydroponics system, plants are grown with their roots suspended in a nutrient solution (Maharana et al., 2011). The nutrient deficiency, toxicity symptoms, and other corresponding mechanisms of crops are easy to observe in hydroponics system (Zhang et al., 2020).

The aim of this study was to evaluate the uptake and translocation of nano-bonechar particles and their effects on the productivity and availability of nutrients to the *Syngonium podophyllum* plant in hydroponics and soil systems. The two systems were used in this study to compare the effectiveness of nano-bonechar on plant productivity in different growing media. To our knowledge, no study has been reported on the application of nano-bonechar in hydroponics and soil systems to improve plant growth. The evidence of nano-bonechar particles' existence in different parts of the plant (root, stem, and leaf) was assessed through compound microscopy, scanning electron microscopy, and energy dispersive X-ray spectroscopy. Moreover, effects of nano-bonechar on plants’ physiochemical parameters (shoot length, leaf count, chlorophyll contents, fresh and dry weights, organic carbon, Ca^{2+}, and PO_4^{3-}) were also observed.

Section snippets

Synthesis of nano-bonechar

Cow bones were collected from a slaughterhouse within the jurisdiction of Rawalpindi, Pakistan. The bones were extensively washed with hot water and later with distilled water to remove flesh and fiber from the bones. The bones were then oven-dried at 110°C. The dried metatarsal bones were ground into small particles using a mechanical grinder. The bone powder was then pyrolyzed in a muffle furnace (Vulcan D-550, Germany) at a temperature of 500 °C for 2 h with a ramping time of 5 °C min^{-1}.…

Physiochemical characteristics

The temperature of 500 °C for nano-bonechar production was selected because at >500 °C, charring may cause the de-hydroxylation of the hydroxyapatite structure (Patel et al., 2015). The results of the chemical and proximate analysis of NBC are given in Table S1 (supplementary material). The yield of NBC obtained through pyrolysis was 76.00±0.25%. NBC produced through pyrolysis showed a high yield due to inorganic minerals present in the bone powder (Tomczyk et al., 2020). The moisture…

Conclusions

Exposure to the NBC under hydroponics and soil systems showed a positive effect on its uptake, translocation, and accumulation in the *Syngonium podophyllum* plants, which was confirmed by the compound and SEM microscopic images of different parts of the plants. The NBC improved the growth of plants in both systems as compared to the control. The NBC mainly comprised of C, Ca, P, K, and Mg, which were taken up by the plants through the roots, thereby improving their growth. The fresh weight, dry…

CRediT authorship contribution statement

Saher Shahid: Writing – original draft, Methodology, Formal analysis, Data curation, Conceptualization. **Hina Imtiaz:** Writing – review & editing, Visualization, Investigation, Data curation. **Jamshaid Rashid:** Writing – review & editing, Visualization, Funding acquisition, Formal analysis. **Ming Xu:** Writing – review & editing, Visualization, Funding acquisition, Formal analysis. **Meththika Vithanage:** Writing – review & editing, Validation, Investigation, Data curation. **Mahtab Ahmad:** Writing – review …

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.…

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Recommended articles

References (58)

Y.M. Awad *et al.*
Biochar, a potential hydroponic growth substrate, enhances the nutritional status and growth of leafy vegetables
J. Clean. Prod. (2017)

K.C. Bedin *et al.*
Bone char prepared by CO_2 atmosphere: preparation optimization and adsorption studies of Remazol Brilliant Blue R
J. Clean. Prod. (2017)

L.D. Burrell *et al.*
Long-term effects of biochar on soil physical properties
Geoderma (2016)

K.B. Cantrell *et al.*
Impact of pyrolysis temperature and manure source on physicochemical characteristics of biochar
Bioresour. Technol. (2012)

X. Cao *et al.*
Properties of dairy-manure-derived biochar pertinent to its potential use in remediation
Bioresour. Technol. (2010)

X. Cao *et al.*
Double-edged sword effect of nano-biochar for Cd^{2+} adsorption on zeolite
J. Environ. Chem. Eng. (2023)

F. Carella *et al.*
Thermal conversion of fish bones into fertilizers and biostimulants for plant growth–A low tech valorization process for the development of circular economy in least developed countries
J. Environ. Chem. Eng. (2021)

G. Ghoshal *et al.*
Characterization of silver nano-particles synthesized using fenugreek leave extract and its antibacterial activity
Mater. Sci. Energy Technol. (2022)

F. Guo *et al.*
A simple method for the synthesis of biochar nanodots using hydrothermal reactor
MethodsX (2020)

M. Kumar *et al.*
Ball milling as a mechanochemical technology for fabrication of novel biochar nanomaterials
Bioresour. Technol. (2020)

A. Liang *et al.*
Micro/nanoscale bone char alleviates cadmium toxicity and boosts rice growth via positively altering the rhizosphere and endophytic microbial community
J. Hazard Mater. (2023)

C. Lin *et al.*

Studies on toxicity of multi-walled carbon nanotubes on *Arabidopsis* T87 suspension cells

J. Hazard Mater. (2009)

H. Mei *et al.*

One stone two birds: bone char as a cost-effective material for stabilizing multiple heavy metals in soil and promoting crop growth

Sci. Total Environ. (2022)

M. Naghdi *et al.*

Immobilized laccase on oxygen functionalized nanobiochars through mineral acids treatment for removal of carbamazepine

Sci. Total Environ. (2017)

R. Nair *et al.*

Nanoparticulate material delivery to plants

Plant Sci. (2010)

S. Patel *et al.*

Synthesis and characterisation of mesoporous bone char obtained by pyrolysis of animal bones, for environmental application

J. Environ. Chem. Eng. (2015)

J.G. Ramirez-Gil *et al.*

Calcium phosphate nanoparticles improve growth parameters and mitigate stress associated with climatic variability in avocado fruit

Heliyon (2023)

V.D. Rajput *et al.*

Nano-biochar: a novel solution for sustainable agriculture and environmental remediation

Environ. Res. (2022)

C.K. Rojas-Mayorga *et al.*

Optimization of pyrolysis conditions and adsorption properties of bone char for fluoride removal from water

J. Anal. Appl. Pyrol. (2013)

C.K. Rojas-Mayorga *et al.*
Breakthrough curve modeling of liquid-phase adsorption of fluoride ions on aluminum-doped bone char using micro-columns: effectiveness of data fitting approaches
J. Mol. Liq. (2015)

M.N.H. Sani *et al.*
Waste-derived nanobiochar: a new avenue towards sustainable agriculture, environment, and circular bioeconomy
Sci. Total Environ. (2023)

M.K. Shahid *et al.*
Synthesis of bone char from cattle bones and its application for fluoride removal from contaminated water
Groundw. Sustain. Dev. (2019)

M. Vithanage *et al.*
Plant nanobionics: Fortifying food security via engineered plant productivity
(2023)

H. Wang *et al.*
Carbon dots promote the growth and photosynthesis of mung bean sprouts
Carbon (2018)

X. Xin *et al.*
Carbon nanoparticles improve corn (*Zea mays* L.) growth and soil quality: comparison of foliar spray and soil drench application
J. Clean. Prod. (2022)

Y. Yin *et al.*
Effect of biochar application on rice, wheat, and corn seedlings in hydroponic culture
J. Environ. Sci. (2024)

K. Zhang *et al.*

Effects of biochar nanoparticles on seed germination and seedling growth

Environ. Pollut. (2020)

X. Zhang *et al.*

Nanobiochar-rhizosphere interactions: implications for the remediation of heavy-metal contaminated soils

Environ. Pollut. (2022)

M. Ahmad *et al.*

Biochar-induced changes in soil properties affected immobilization/mobilization of metals/metalloids in contaminated soils

J. Soils Sediments (2017)

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Cited by (0)

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