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Editorial: Agro-nanotechnology: advancements and challenges in nanofertilizers for sustainable agriculture

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Editorial on the Research Topic
Agro-nanotechnology: advancements and challenges in nanofertilizers for sustainable agriculture

The increase in the global population has led to food security issues, putting pressure on agricultural productivity to meet the heightened food demand (Meng et al., 2025). These heightened demands for food around the world, along with a number of environmental factors and natural calamities, resulted in the need to adopt sustainable agricultural practices and the adaptation of advanced technologies in the agricultural fields. Besides, to meet the increased food demand around the world, the use of chemical fertilizers to boost crop yields has been adopted rapidly (Meng et al., 2025). This uncontrolled use of chemical fertilizers has resulted in adverse effects on the environment, soil, as well as on the health of human beings, which not only endanger sustainable agriculture but also have an intense negative impact on the overall environment. Considering this, it is imperative to adopt the most advanced and ecologically suitable agricultural techniques and fertilizers to conserve the soil integrity and promote sustainable healthy agricultural practice.

Thus, to tackle these global sustainability challenges, forward-thinking technology like nanotechnology is considered an advanced tool to deliver effective, reasonable, and eco-friendly solutions for a better agricultural practice by boosting yield, guaranteeing food security, and improving agricultural flexibility to climate change (Babu et al., 2022; Khundi et al., 2025). Agriculture-based nanotechnology integrates nanotechnology with agricultural science and offers several ground-breaking applications and resolutions to improve crop yield and sustainability (Lallawmkimi et al., 2025). This technology has revolutionized agricultural practices by enhancing crop yields and providing protection to the food crops, and among them, the utilization of nano-fertilizers, nano-based pesticides, and disease, stress, and pest management skills has gathered noteworthy consideration for sustainable agriculture and reducing environmental effects (Lallawmkimi et al., 2025; Yadav et al., 2023). Besides, the advanced agro-nanotechnology is highly useful in fertilizer applications, genetic modifications of crops, stress tolerance, and pest control (Meng et al., 2025). Recent

advancements and extraordinary inventiveness in the field of agro-nanotechnology have fundamentally changed the fertilizers for developing agro-based technology (Mim et al., 2025). Additionally, nanofertilizers also improve the nutrient effectiveness of the soil, with most specifically targeted and smart delivery of the fertilizers, improved stress and pest resistance of the crops with higher yields (El-Saadony et al., 2021; Khundi et al., 2025; Mim et al., 2025; Mustafa et al., 2024). These nanofertilizers are able to improve crop productivity by promoting the nitrogen metabolism, photosynthesis, stress tolerance, and germination of seeds (Ahanger et al., 2021). The emphasis towards nanofertilizers is mainly due to their properties to enhance the uptake of nutrients, fewer side effects to the environment, and implementation of a sustainable agricultural practice.

However, apart from its advantages, there are some specific restrictions and challenges of using nanomaterials or nano fertilizers, such as nanotoxicity, high reactivity with non-targeted organisms, permeability to food crops, scalability, and regulatory hurdles (Alam et al., 2024; Lallawmkimi et al., 2025). Understanding these drawbacks is vital for harnessing the full potential of nanofertilizers in enhancing agricultural productivity and sustainability (Alam et al., 2024). The effectiveness of nanofertilizers in enhancing the yield of crops with less adverse effect on the soil quality has been proved; however, there are many other aspects, such as effect on the environment, toxicity to human beings, etc., that need to be addressed before their full-scale application in agriculture. Presently, much effort is on understanding the relation between the environment and the nanofertilizers, but there are some hurdles in translating the laboratory-based research into the actual field, and thus, much in-depth research is required on sustainable manufacture, their characterization, and the use of nanofertilizers in the agricultural field. Their ecological risk assessment and proper regulation framework need to be developed for managing their use, production, disposal, and impact on the environment and human health (Alam et al., 2024; Chavez-Hernandez et al., 2024).

Regardless of numerous advances in the field of nanotechnology applications in the agricultural field, substantial research gaps continue in the long-term application, sustainability, scalability, and economic feasibility of these materials. This Research Topic aimed to discover the progress and limitations connected with the application of sustainable nanofertilizers commercially. This objective has been achieved to some extent with four articles published under this Research Topic on the topics related to the use of graphene oxide in the constituent of nanofertilizers, effect of selenium nanoparticles on growth of *Amaranth microgreens*, impact of nano fertilizers on yield of maize crop, its profitability and soil nitrogen condition, and a review article on the plant metabolite-mediated synthesis of nanoparticle and their applications in horticultural crops (Gomathi et al.; Gopinath etal.; Lakhani et al.; Saraiva et al.). All these manuscripts improve our understanding of nano fertilizers and their applications, which form a basis for future research.

Author contributions

JP: Visualization, Methodology, Validation, Investigation, Formal Analysis, Resources, Conceptualization, Writing – original draft, Writing – review and editing. KC: Investigation, Conceptualization, Visualization, Methodology, Writing – review and editing, Resources, Project administration, Formal Analysis. SK: Conceptualization, Writing – review and editing, Visualization.

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