ISBN: 978-81-970675-6-3

9. Advancing Agriculture: Nanotechnology Mediated Agronomic Biofortification for Sustainable Crop Enhancement

Pinaj Yadav

Department of Biotechnology,
Chaudhary Devi Lal University,
Sirsa, Haryana.

Mahanthi Vasu

Department of Animal Biotechnology,
ICAR-National Dairy Research Institute,
Karnal.

Dr. Mukesh Kumar

Department of Chemistry,
School of Applied Sciences,
Om sterling Global University,
Hisar.

Harshit Yadav

Institute of Management Studies,
Kurukshetra University,
Kurukshetra, Haryana.

Charu Yadav

Department of Biotechnology,
Sharda University, Greater Noida,
Uttar Pradesh.

Abstract:

Biofortification emerges as a potential strategy to prevent and address a variety of malnutrition, significantly improving health outcomes. Employing breeding techniques and agronomic interventions allows for the reduction of anti-nutritional levels, thereby enhancing the bioavailability of essential elements like minerals and vitamins. This approach provides a sustainable solution to nutritional deficiencies, contributing to human development by strategically enhancing key crops. Biofortification stands as a crucial global nutrition strategy, focusing on elevating the nutritional content of vital crops like maize, rice, and wheat. However, in developing nations where hunger and malnutrition are prevalent, these crops do not provide sufficient nutrition for human well-being.

Therefore, micronutrients, vitamins, minerals, and phytochemicals must be added to staple crops in order to enhance their nutritional quality. Integrating nanoscience into agricultural science holds the potential to advance and sustain agricultural practices. Over the past few decades, nanotechnology has demonstrated its capability to enhance agricultural systems and management techniques. Ongoing exploration of nanoscience in agriculture presents innovative prospects for cultivating more productive and eco- friendly farming methods. Encapsulated nanoparticles like nano clays, zeolites, and nano gypsum hold promise in boosting fertilizer efficiency, enhancing soil fertility, fostering plant health, and minimizing environmental impact. This underscores their contribution to the progression of sustainable agricultural practices. Phyto nanotechnology integrates nanotechnology into agronomic practices, revolutionizing agriculture by transforming conventional production systems to enhance efficiency and innovation. This interdisciplinary approach harnesses the unique properties of nanomaterials, offering novel solutions for crop improvement, resource optimization, and sustainable farming practices. By seamlessly incorporating nanotechnology into agriculture, Phyto nanotechnology aims to revolutionize the field and address the challenges of modern food production in a more effective and sustainable manner. This chapter primarily discusses recent progress and improvements in the nutritional characteristics of crop plants, achieved through the utilization of nanoparticles, nano fertilizers, nano sensors, and similar technologies. In addition, it offers valuable perspectives on the changing dynamics of agricultural practices, underscoring the significance of nanotechnology in enhancing the nutritional composition of crops.

Keywords:

Biofortification, nanoparticles, nano fertilizers, nano sensors, Phyto nanotechnology.

9.1 Introduction:

Biofortification is a critical global nutrition strategy that concentrates on increasing the nutritional value of essential crops such as maize, rice, and wheat. These grains, integral to the diets of billions globally, are subject to specific improvements to combat prevalent micronutrient deficiencies, promoting a more robust and nutritious food source for diverse populations (Kiran et al., 2022).

However, these crops prove insufficient in providing the necessary nutrition for human well-being, especially in developing nations where hunger and malnutrition are prevalent. Malnutrition has serious hazards, including the potential for serious problems like mental and physical damage, shortened growth in children, worst circumstances, and death. To address this worldwide issue, comprehensive approaches are needed to provide sufficient nutrition and avoid negative health consequences.

In the world, approximately 800 million individuals are undernourished, according to a report by the Food and Agriculture Organization of the United Nations and other organizations. Whereas approximately 25% of the world undernourished population is found in India, highlighting the massive effect due to lack of nutrition. Moreover, a number of individuals consuming high energy but nutritionally poor quality, which can lead to obesity, overweight and cardiovascular diseases. Such interventions can address nutritional deficiencies and contribute to fostering healthier diets, ultimately promoting better public health outcomes and mitigating the risks associated with inadequate nutrition. Therefore, enhancing the nutritional quality of staple crops is imperative, involving the incorporation of micronutrients, vitamins, minerals, and phytochemicals. This strategy is important in addressing widespread nutritional deficiencies and promoting overall health through fortified and enriched food sources (Ele mike et al., 2019).

Biofortification emerges as a powerful strategy in preventing and treating diverse range of malnutrition, significantly enhancing the health. It is possible to reduce the anti-nutritional level, by employing breeding techniques along with agronomic interventions, consequently enhancing the bioavailability of minerals, vitamins, etc. It offers a long-term solution to nutritional deficiencies and the development of human achievement through focused improvements in essential crops (Ram et al., 2020). Its versatility enables innovations ranging from advanced electronic components to cutting-edge medical treatments, showcasing the broad spectrum of benefits derived from manipulating materials at the nanoscale. While nanotechnology holds significant promise for the future of agriculture. However, there remains a shortage of extensive research in this field. Exploring and expanding the understanding of nanotechnology applications in agriculture is crucial for unlocking its full potential in enhancing crop productivity and sustainability (Pramanik et al., 2020).

The application of nanoscience in agricultural science might contribute to the advancement and sustainability of agricultural science. Nanotechnology has proven over the last few decades to be able to improve agricultural systems and management techniques. The continued investigation of nanoscience in agriculture holds forth creative possibilities for more productive and environmentally friendly farming methods (Saritha et al., 2020). By applying fertilizer at the proper stage of crop growth is one of the important management techniques that affects yield of crops. When compared to conventional fertilizer sources, nanoparticles are proven to be a desirable replacement for use in the production of nano fertilizers, with higher agronomic efficiency. Nanotechnology can solve this problem by creating nano fertilizers that can be absorbed by the soil faster and improve its quality, which helps the plant grow faster and improve the nutrient-use efficiency (Mahanta et al., 2019). Encapsulated nanoparticles such as nano clays, zeolites and nano gypsum are potential to enhance fertilizer efficiency, improve soil fertility, promote plant health, and mitigate environmental impact, showcasing their role in advancing sustainable agricultural practices. Among the nanoparticles Al_2O_3, Silica, FeO_2, CeO_2, TiO_2, and ZnO are commercially available to enhance the crop productivity and increases the micronutrient content (Panakkal et al., 2021).

Phyto nanotechnology involves the integration of nanotechnology into agronomic applications to improve efficiency and innovation in agriculture by altering traditional production systems. In contrast to traditional methods, Phyto nanotechnology demands requires less input and minimizes waste, leading to a more efficient and sustainable approach to agriculture. This cutting-edge technology advances agriculture by combining nano pesticides, nano sensors, and nano fertilizers to reduce agrochemical inefficiencies and enhance crop stress management.

Crops are susceptible to diverse conditions, encompassing both biotic and abiotic stressors, including plant diseases, salinity, drought, and extreme temperatures. Understanding and reducing these challenges are crucial for enhancing agricultural resilience and ensuring sustainable food production. Phyto nanotechnology is now being investigated for its potential in enhancing crop tolerance to salinity. Seed priming is a method employed to enhance seed germination and vitality. This technique involves exposing seeds to a specific solution for a defined duration, followed by a drying period.

This innovative approach showcases the evolving strategies within Phyto nanotechnology to address agricultural challenges and improve crop resilience under adverse environmental conditions such as salinity. This chapter predominantly elucidates recent advancements and enhancements in the nutritional profile of crop plants through the application of nanoparticles, nanofertilizers and nanosensors, etc. It provides insights into the evolving landscape of agricultural practices, emphasizing the role of nanotechnology in augmenting crop nutritional content.

9.2 Nanotechnology in Agronomic Biofortification:

Nanotechnology involves the scientific and engineering manipulation of matter at the nanoscale (1-100 nm), unveiling novel properties and phenomena. Nanomaterials are studied at the nanometer level to develop breakthroughs with wide-ranging applications across diverse fields. Agronomic biofortification involves elevating the nutrient content and quality of crops through the application of fertilizers to the soil or foliage. This strategic process aims to optimize the nutritional profile of harvested produce, addressing dietary deficiencies and contributing to improved overall health through enhanced crop nutrient levels (Abbey et al., 2022). Nanotechnology and agronomic biofortification are interconnected through their collaborative pursuit of advancing agricultural practices. Nanotechnology contributes to biofortification by providing innovative tools, such as nano fertilizers and nano sensors, to enhance nutrient delivery and optimize crop health. This synergy promotes sustainable and efficient strategies for improving the nutritional quality of crops. Nanotechnology has the potential to offer innovative and effective nanomaterials that can serve as carriers, translocation of nutrients, enhancers, regulators of nutrients, improve the delivery, reducing the losses and increasing the effectiveness of fertilization (Ele mike et al., 2019). In addition to these advantages, nanotechnology has the capability to regulate the physiological and biochemical processes of plants, thereby enhancing their growth, yield, and quality. Ultimately, it has the potential to mitigate environmental and health risks linked to traditional fertilizers, including issues like soil contamination, groundwater pollution, and human toxicity.

9.2.1 Scientific Aspects of Nanotechnology Mediated Agronomic Biofortification:

Explore the interactions and mechanisms of nanomaterials with soil, plants, and microorganisms, assessing their impacts on nutrient cycles and food webs. The current status of nanotechnology mediated agronomic biofortification is that it has shown promising results in various field crops, such as wheat, maize, soybean, rice and tomato (Kapoor et al., 2022).

A number of nanomaterials, including as zeolite, silicon dioxide, carbon, zinc oxide, iron oxide, copper oxide, titanium dioxide, cerium oxide, and selenium, have been employed for this purpose to increase plant growth, production, and quality, these nanomaterials can be used as nano pesticides, nanocarriers, nano fertilizers, or nano sensors.

Examine the complex interactions to learn about the dynamic interactions that occur between biological components and nanomaterials, creating an in-depth understanding of their impacts on biological systems. Examine the safety and effectiveness of nanomaterials in agronomic biofortification, evaluating their potential risks and benefits for both human health and the environment (Gopinath et al., 2021). This method boosts the nutrient content and bioavailability of crops, presenting a promising solution to the widespread issue of micronutrient deficiency, commonly referred to as hidden hunger. Nanotechnology role in agronomic biofortification is closely tied to innovation, sustainability, and scalability in agriculture. It provides pioneering and economically viable methods to boost nutrient efficiency, crop yield, and food quality (Aithal et al., 2021). Furthermore, nanotechnology aligns with sustainable development goals, aiding in the reduction of hunger, poverty, and environmental degradation. In addition, it can also be integrated with other emerging technologies, such as biotechnology, genomics, and precision agriculture, to create synergistic effects and optimize the agricultural system.

The safety, regulation, and public perception of nanoparticles offer significant challenges to agronomic bio-fortification mediated by nanotechnology. Standardized methods and protocols are currently lacking for the synthesis, characterization, and application of nanomaterials in agriculture. Additionally, there is a requirement for more extensive and prolonged investigations into the environmental fate, transport, and toxicity of nanomaterials, along with their impacts on soil health, chemistry, and microbiology (Javed et al., 2019).

Moreover, there is a gap between the scientific research and the public awareness and acceptance of nanotechnology in agriculture. There is a necessity for improved communication and educational strategies to enlighten stakeholders and consumers about the advantages and potential risks associated with nanotechnology-mediated agronomic biofortification. Yet, numerous challenges and uncertainties must be addressed before widespread acceptance of nanotechnology in agriculture can occur. Further research, regulatory measures, and communication efforts are necessary to guarantee the safety, effectiveness, and sustainability of nanotechnology-mediated agronomic biofortification. Nanotechnology can be used in wheat biofortification in several ways. One of them is to apply nanofertilizers that contain zinc oxide nanoparticles, which can increase the zinc uptake and accumulation in wheat grains. Zinc oxide nanoparticles can also enhance the antioxidant activity of wheat grains by reducing the oxidative stress and increasing the activity of antioxidant enzymes (Shang et al., 2019).

So, by utilizing nano fertilizers, nanocarriers, and nano sensors, wheat biofortification can employ nanotechnology to increase the zinc content and antioxidant activity of wheat grains. By enhancing wheat nutritional efficiency, crop yield, and food quality, these nanotechnologies can help reduce malnutrition and hidden hunger. An alternative approach involves the utilization of nanocarriers designed to deliver zinc and other micronutrients to wheat plants in a precise and targeted manner.

Nanocarriers, including zeolite, carbon nanotubes, and chitosan, offer a safeguard against nutrient degradation and leaching, releasing nutrients based on plant demand or environmental cues. This not only enhances nutrient use efficiency but also mitigates the environmental impact of fertilization (Iqbal et al., 2019). These nanocarriers play a crucial role in sustaining nutrient availability for plants while minimizing the risks associated with nutrient loss and environmental harm caused by traditional fertilization methods. A third approach involves employing nano sensors capable of real-time monitoring of the nutrient status and overall health of wheat plants. Utilizing nano sensors like gold nanoparticles, quantum dots, and nanowires allows for the detection of zinc and other micronutrient presence and concentrations in both plant tissues and soil. These nano sensors are also capable of assessing wheat plants physiological parameters and stress indicators, including photosynthesis, water status, respiration, and reactive oxygen species.

9.2.2 Positive and Negative Effects of Nano-Biofertilizers:

Nano-biofertilizers, derived from biological sources like plants and microbes, represent a subset of nano fertilizers. Employed to augment nutrient availability, uptake, and crop efficiency, they additionally contribute to enhanced plant growth and resilience to diverse stresses. The impact of nano-biofertilizers on soil health, chemistry, and microbial diversity varies based on factors like composition, shape, surface charge, size, and application method (Sharma et al., 2023). Nano-biofertilizers have the potential to elevate crucial components such as soil organic matter, phosphorus, nitrogen, carbon, and potassium, essential for fostering soil fertility and enhancing crop productivity. In addition, nano-biofertilizers can enhance vital aspects including biological activity, soil structure, porosity, enzyme activity, microbial biomass, water holding capacity, and aeration.

These improvements play a crucial role in shaping soil physical properties and fostering the development of plant roots. Moreover, in order to enhance nutrient cycling, plant nutrition, and plant health, nano-fertilizers can promote the proliferation and diversity of advantageous soil microbes, such as phosphate-solubilizing, nitrogen-fixing, and growth-promoting rhizobacteria. Along with they can suppress the growth and activity of harmful soil microorganisms, such as pathogens, nematodes, and weeds, which can reduce the crop yield and quality. However, there are certain drawbacks when employing nano-biofertilizers include alterations in soil pH, electrical conductivity, and cation exchange capacity, influencing soil chemical properties and nutrient accessibility. Accumulation in the soil may lead to the formation of aggregates or complexes with other soil components, diminishing their mobility, bioavailability, and efficacy (Dhaliwal et al., 2019). Leaching into groundwater or surface water can result in environmental pollution and health hazards. Additionally, these nano-biofertilizers have the potential to induce oxidative stress, inflammation, and toxicity in soil microorganisms, plants, animals, and humans, thereby compromising cellular structures, functions, and interactions.

9.2.3 Nanomaterials Used in Agronomic Biofortification:

Nanoparticles offer precise and targeted nutrient delivery to plants, reducing losses from volatilization, leaching and immobilization. It can improve the bioavailability and uptake of nutrients by plants, increasing the efficiency and effectiveness of fertilization. Additionally, nanoparticles contribute to the stability and solubility of nutrients, preventing their degradation or precipitation within soil or plant tissues. By influencing the physiological and biochemical processes of plants, it has the potential to enhance their growth, yield, and quality. Simultaneously, it can mitigate the environmental and health hazards linked to traditional fertilizers, including issues like soil contamination, groundwater pollution, and human toxicity. Various nanoparticles play a pivotal role in enhancing plant nutrition and performance. Zeolite- based nanoparticles serve as carriers for essential micronutrients like zinc, iron, copper, and selenium.

Zinc oxide nanoparticles contribute to elevated zinc levels and enhanced antioxidant activity in wheat grains. Iron oxide nanoparticles improve iron content and photosynthetic efficiency in rice plants, while copper and copper oxide nanoparticles enhance copper levels and bolster disease resistance in tomato plants (Elemike et al., 2019). Titanium dioxide nanoparticles are instrumental in augmenting the calcium content and prolonging the shelf life of lettuce leaves. Cerium oxide nanoparticles positively impact the manganese content and stress tolerance of soybean plants. Noble metal nanoparticles, including gold, silver, and platinum, exhibit the ability to modulate gene expression and enzyme activity in plants. Carbon-based nanoparticles, such as graphene, carbon nanotubes, and fullerenes, influence the growth and metabolism of plants. Silicon dioxide nanoparticles play a crucial role in increasing the silicon content and enhancing drought resistance in maize plants (Rai et al., 2018). These diverse nanoparticles showcase the potential for targeted nutrient delivery, improved physiological processes, and enhanced resilience, collectively contributing to the advancement of agricultural practices and crop quality.

9.2.4 Phytonanotechnology:

Phytonanotechnology integrates nanotechnology into agronomic practices, revolutionizing agriculture by transforming traditional production systems for enhanced efficiency and innovation.

Recent research explores the application of phytonanotechnology to enhance salt tolerance in crops. Seed priming, a method involving the exposure of seeds to a designated solution for a specific duration, followed by a drying phase, is employed to foster seed germination and vigor. This process holds promise for mitigating the impact of salinity stress on crops, showcasing the potential synergy between phytonanotechnology and seed priming in bolstering agricultural resilience. This method stimulates the early phases of germination without causing radicle emergence. It is understood that the priming process can initiate plant stress signaling pathways, thereby priming them to confront and withstand stressors effectively (Marthandan et al., 2020). Recently, nano priming, employing nanomaterials for seed priming, has proven effective in enhancing the growth and stress resilience of seedlings. For example, metal-based nanoparticles (NPs), such as Fe2O3 and Ag nanoparticles have been documented for their ability to boost seed development which achieve this by initiating iron acquisition in wheat and improving starch metabolism in rice. The priming of lupine seeds with ZnO nanoparticles has been identified as a strategy to mitigate the detrimental effects of NaCl. This process enhances photosynthetic pigments while adjusting sodium levels and stress-related antioxidant activities.

The application of ZnO nanoparticles in seed priming demonstrates a promising strategy for mitigating the negative impacts of salt stress, ultimately promoting healthier photosynthetic processes and bolstering antioxidant mechanisms in lupine plants. Additionally, Silver (Ag) nanoparticles was observed to modify the phytohormone balance in wheat, resulting in enhanced seed growth and improved tolerance to salinity. Moreover, Manganese (Mn) plays a crucial role in various plant functions, serving as a cofactor for numerous enzymes like oxalate oxidase, Mn superoxide dismutase, and the Mn protein in photosystem II. Its essentiality underscores its significance in supporting key enzymatic processes vital for plant growth and stress response.

9.2.5 Future Prospectives:

Extensive exploration and refinement of nano priming are essential for establishing it as a viable technique in plant stress mitigation, thereby contributing to sustainable agriculture. However, a more in-depth examination of the biochemical interplay between nanoparticles and biomolecules is imperative. Utilizing additional methodologies such as molecular biology, electron/spectral microscopy, or nanos copy techniques is warranted to comprehensively comprehend the subcellular reactions of plants under diverse abiotic/biotic stressors and to observe the behavior of these nanomaterials. Investigate the interactions and mechanisms of nanomaterials with soil, plants, and microorganisms, along with their impact on nutrient cycles and food webs.

Optimize the synthesis, characterization, and application methods of nanomaterials, and establish standardized protocols and guidelines. Assess the safety and efficacy of nanomaterials for agronomic biofortification, evaluating potential risks and benefits for human health and the environment. Design innovative and multifunctional nanomaterials for delivering various nutrients and beneficial substances to plants. Integrate nanotechnology with other disciplines and technologies, including biotechnology, molecular biology, or remote sensing, to create intelligent and sustainable agricultural systems. Specifically, the investigation of biosynthesized nanoparticles and nano-biofertilizers as potential eco-friendly alternatives for sustainable agriculture should be expanded. This emerging frontier holds the promise of substantial benefits for food production and nutrition, especially in the face of challenges posed by climate change. By tackling the technical, economic, and social hurdles associated with biofortification, we can establish a viable strategy to effectively address micronutrient deficiencies in the foreseeable future.

9.3. Conclusion:

In conclusion, nanotechnology-facilitated agronomic biofortification involves utilizing nanomaterials to enhance the nutrient content and bioavailability of food crops. Leveraging the unique physical, chemical, and biological properties of nanomaterials offers diverse applications in agriculture.

This approach enhances the efficiency of fertilizers, pesticides, and biocontrol agents by minimizing losses, increasing uptake, and directing delivery to specific sites. While nanotechnology-mediated agronomic biofortification holds promise for global food and nutrition security, its sustainable and safe implementation demands careful assessment and management of benefits and risks. Recent advancements and improvements in crop plant nutritional profiles, facilitated by the application of nanoparticles, nano fertilizers, nano sensors, and related technologies, offer valuable insights into the evolving agricultural landscape. These developments underscore the pivotal role of nanotechnology in enhancing crop nutritional content. The innovative use of nanomaterials contributes to a progressive shift in agricultural practices, presenting opportunities to address nutritional deficiencies and optimize food production. Phytonanotechnology integrates nanotechnology into agronomic practices, revolutionizing agriculture by transforming traditional production systems for enhanced efficiency and innovation. Diverging from conventional methods, phytonanotechnology necessitates fewer inputs and reduces waste, offering a more efficient and sustainable approach to agriculture. This evolving paradigm emphasizes the potential of nanotechnology to significantly impact crop quality, laying the foundation for more resilient and nutrient-enriched agricultural systems in the future.

9.4 References:

1. Kiran, A., Wakeel, A., Mahmood, K., Mubaraka, R., Hafsa, & Haefele, S. M. (2022). Biofortification of staple crops to alleviate human malnutrition: contributions and potential in developing countries. *Agronomy*, *12*(2), 452.
2. Elemike, E. E., Uzoh, I. M., Onwudiwe, D. C., & Babalola, O. O. (2019). The role of nanotechnology in the fortification of plant nutrients and improvement of crop production. *Applied Sciences*, *9*(3), 499.
3. Ram, S., Narwal, S., Gupta, O. P., Pandey, V., & Singh, G. P. (2020). Anti-nutritional factors and bioavailability: Approaches, challenges, and opportunities. *Wheat and barley grain biofortification*, 101-128.
4. Pramanik, P., Krishnan, P., Maity, A., Mridha, N., Mukherjee, A., & Rai, V. (2020). Application of nanotechnology in agriculture. *Environmental Nanotechnology Volume 4*, 317-348
5. Saritha, G. N. G., Anju, T., & Kumar, A. (2022). Nanotechnology-Big impact: How nanotechnology is changing the future of agriculture? *Journal of Agriculture and Food Research*, 100457.
6. Mahanta, N., Dambale, A., Rajkhowa, M., Mahanta, C., & Mahanta, N. (2019). Nutrient use efficiency through nano fertilizers. *Int J Chem Stud*, *7*(3), 2839-2842.
7. Panakkal, H., Gupta, I., Bhagat, R., & Ingle, A. P. (2021). Effects of different metal oxide nanoparticles on plant growth. *Nanotechnology in Plant Growth Promotion and Protection: Recent Advances and Impacts*, 259-282.
8. Abbey, L., Okoli, C., Martin-Clarke, D., Ijenyo, M., Abbey, J., Anku, K., & Abbey, P. A. (2022). The Role of Nanomaterials in Plant Production and Fortification for Food and Nutrition Security. *Emerging Challenges in Agriculture and Food Science; BP International: Hong Kong, China*, *4*, 18-54.
9. Kapoor, P., Dhaka, R. K., Sihag, P., Mehla, S., Sagwal, V., Singh, Y., ... & Kumar, U. (2022). Nanotechnology-enabled biofortification strategies for micronutrients enrichment of food crops: Current understanding and future scope. *NanoImpact*, *26*, 100407.
10. Gopinath, K. P., Rajagopal, M., Krishnan, A., & Sreerama, S. K. (2021). A review on recent trends in nanomaterials and nanocomposites for environmental applications. *Current Analytical Chemistry*, *17*(2), 202-243.

11. Javed, Z., Dashora, K., Mishra, M., Fasake, V. D., & Srivastva, A. (2019). Effect of accumulation of nanoparticles in soil health-a concern on future. *Front. Nanosci. Nanotechnol*, *5*(2), 1.
12. Aithal, S., & Aithal, P. S. (2021). Green nanotechnology innovations to realize UN sustainable development goals 2030. *International Journal of Applied Engineering and Management Letters (IJAEML)*, *5*(2), 96-105.
13. Shang, Y., Hasan, M. K., Ahammed, G. J., Li, M., Yin, H., & Zhou, J. (2019). Applications of nanotechnology in plant growth and crop protection: a review. *Molecules*, *24*(14), 2558
14. Iqbal, M., Umar, S., & Mahmooduzzafar. (2019). Nano-fertilization to enhance nutrient use efficiency and productivity of crop plants. *Nanomaterials and plant potential*, 473-505.
15. Sharma, B., Tiwari, S., Kumawat, K. C., & Cardinale, M. (2023). Nano-biofertilizers as bio- emerging strategies for sustainable agriculture development: Potentiality and their limitations. *Science of The Total Environment*, *860*, 160476.
16. Dhaliwal, S. S., Naresh, R. K., Mandal, A., Singh, R., & Dhaliwal, M. K. (2019). Dynamics and transformations of micronutrients in agricultural soils as influenced by organic matter build-up: A review. *Environmental and Sustainability Indicators*, *1*, 100007.
17. Rai, P. K., Kumar, V., Lee, S., Raza, N., Kim, K. H., Ok, Y. S., & Tsang, D. C. (2018).
18. Nanoparticle-plant interaction: Implications in energy, environment, and agriculture. *Environment international*, *119*, 1-19.
19. Marthandan, V., Geetha, R., Kumutha, K., Renganathan, V. G., Karthikeyan, A., & Ramalingam,
20. J. (2020). Seed priming: a feasible strategy to enhance drought tolerance in crop plants. *International journal of molecular sciences*, *21*(21), 8258.
21. Kalia, A., & Kaur, H. (2019). Nano-biofertilizers: Harnessing dual benefits of nano-nutrient and bio-fertilizers for enhanced nutrient use efficiency and sustainable productivity. *Nanoscience for sustainable agriculture*, 51-73.