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NANOTECHNOLOGY: SHAPING THE FUTURE OF AGRICULTURE

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INTRODUCTION: NANOTECH AND THE HIDDEN WONDERS WITHIN NANOSCALE

Nanotechnology is a science, which deals with materials ranging from 1 to 100 nm, where matter exhibits distinct physio-chemical properties not observed in its larger bulk counterparts, opening the door to numerous novel application not only in agriculture but a wide spectrum of other scientific and industrial fields (Altammar 2023). Incorporating nanotechnology into agriculture has opened the way for efficient nutrient delivery, identification of plant pathogens, improved pest management and notable gains in overall crop productivity (Figure.1).

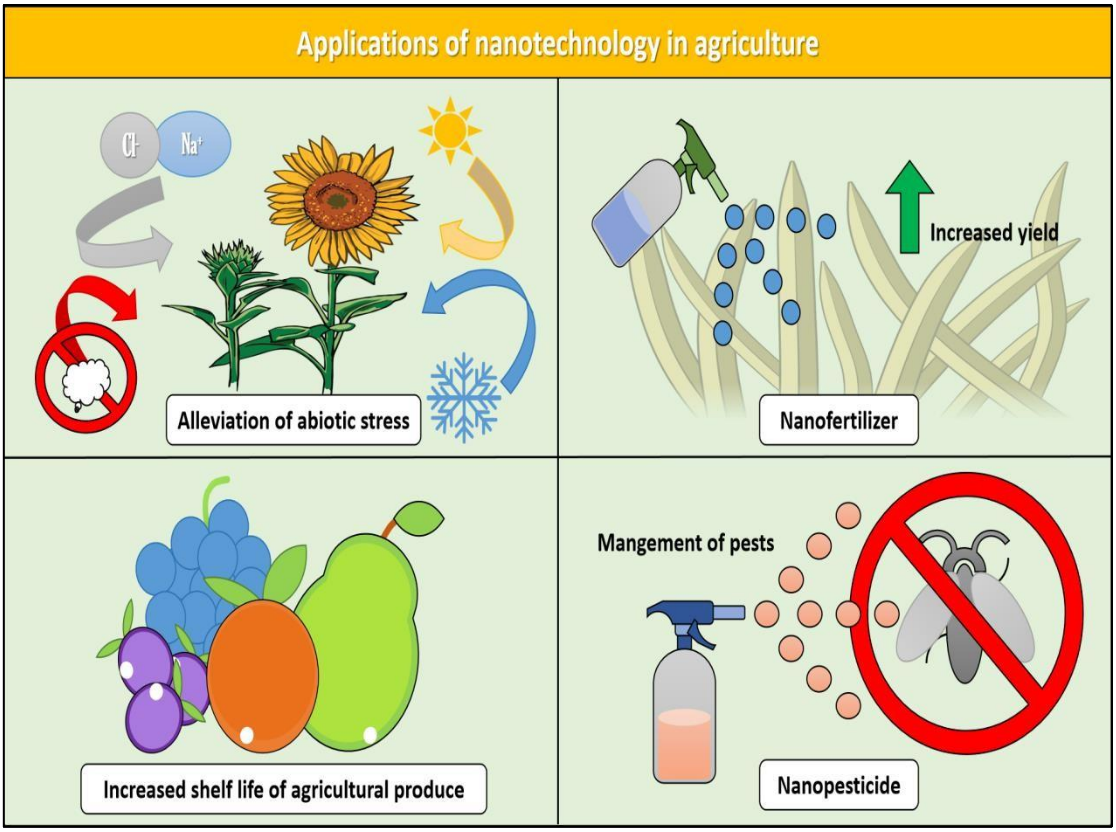

Figure. 1: Applications of nanotechnology in agriculture

1. APPLICATIONS IN AGRICULTURE

1.1 Nanofertilizers

Nanofertilizers out perform conventional fertilizer just as a crushed sugar cube dissolves faster due to its surface is exposed to water, nanofertilizers work better due their extremely small size and high surface area, allowing plants to absorb nutrients more readily with lesser losses as compared to conventional fertilizers as they are prone to leeching, volatilization and run off. Nanofertilizers offer controlled/slow release, high absorption efficiency, better yield, reduced losses and lower dosage requirement (Babu et al. 2022). Although nanofertilizers have not fully replaced conventional fertilizers, their combined use has exhibited reduced fertilizer dosage and significantly enhance crop yields, as reported by Kumar et al. (2020) (Table. 1).

Table.1: Comparative yield under Farmer's Fertilizer Practice (FPP) and Nano-N+ FPP-50% N

Sr. No.	Crop Name (No. Of trials)	FPP Mean yield (Kg/ha^{-1})	FPP-50% N + 2 spray's of Nano-N Mean yield (Kg/ha^{-1})	% Increase over FPP
1.	Wheat (431)	4,354	4,779	9.76
2.	Field pea (26)	2,092	2,270	8.50
3.	Lentil (5)	1,677	1,715	2.26
4.	Amaranthus (3)	2,626	2,927	11.45
5.	Mustard (44)	1,708	1,837	7.55
6.	Potato (127)	32,298	35,414	9.65
7.	Garden pea (12)	9,484	10,247	8.05
8.	Tomato (5)	30,354	35,534	17.07
9.	Cauliflower (4)	32,276	34,521	6.96

Source: Kumar et al. (2020)

1.2 Nanopesticides

Nanopesticides refer to formulations incorporating engineered materials or carriers operating within the nanometre range (1-200 nm). These nanoscale delivery systems-such as polymer-based nanoparticles, nanoemulsions, nanosuspensions, and inorganic metal or mineral nanostructures, offer improved solubility, greater stability, and more precise release of active ingredients than conventional products. By increasing the bioavailability and persistence of the active compounds and by promoting stronger adhesion to plant surfaces and targeted tissues, these formulations often achieve comparable or superior pest suppression at reduced application rates. Their controlled-release behaviour minimizes losses by photodegradation, runoff and spray drift, thereby reducing the overall environmental burden. By facilitating deeper penetration into pest tissues and enhancing the stability of biopesticidal agents. Taken together, these features renders nano-enabled formulations more efficient, sustainable and ecologically compatible options for crop protection within contemporary agricultural systems (Wang et al. 2022, Wei et al. 2025). Commercial nano-formulated pesticides have only recently entered agricultural markets. One example is Pilarquim's PILARTEP, released in early 2022 as a nano-suspension concentrate and among the first publicly marketed nano-enabled plant-protection products. According to the company claims, the nano-formulation exhibits roughly 3.15-fold faster crop absorption, greater active-ingredient uptake and longer residual activity than the conventional version. Field trials also show effective pest and disease control at 25-50% reduced application rates. These improvements are linked to smaller particle sizes (<600 nm), with some variants near 300 nm, which enhance surface area, dispersion, adhesion and rainfastness on plant surfaces. Parallelly, nano based sensors may also support early pest detection and treatment monitoring. Emerging nano-RNAi approaches add a anew route for targeted pest suppression, though further working on environmental and agricultural studies (Mathew et al. 2025).

1.3 Nanoparticles for managing abiotic stress and post harvest applications

Nanoparticles can alleviate stress induced by abiotic environmental factors such as drought, salinity and heavy metal stress, by improving nutrient availability, enhancing antioxidant activity and strengthening the physiological responses. By regulating various reactive oxygen species assisted mechanisms (Dilnawaz et al. 2023). Nanotechnology is also incorporated as edible films and coatings, that can be applied to fresh produce to protect it by reducing moisture loss, slowing respiration, maintaining texture and suppressing microbial growth. These nano based solutions serves as barriers to gas and moisture exchange, thereby extending the shelf life of processed foods. Pt/DMS (platinum-loaded dendritic mesoporous silica) was employed as an ethylene-scavenging material to extend the shelf life of *Musa nana* bananas, taking advantage of its characteristic central-to-radial pore architecture (Wei et al. 2023).

2. CHALLENGES OF NANOTECHNOLOGY

Several studies have reported clear evidence of nanoparticle-induced toxicity, underscoring the need for careful evaluation before widespread application. Nanotoxicity studies in agriculture remain limited and insisting evidence warns of potential risks to plants, animals, microbes and even human. Moreover, producing nanomaterials at large volumes with acceptable cost continues to be a major challenge (Pathak et al. 2020).

3. CONCLUSION

Nanotechnology is emerging as a transformative approach within agricultural systems, offering advanced strategies to optimize nutrient delivery, enhancing stress tolerance, pest management and over all crop performance. While certain limitations and safety concerns still require careful investigation, its contribution to sustainable and efficient farming practices is increasingly evident. With continued research and the development of safer, economically viable nano-based solutions, nanotechnology has the potential to modernize traditional agricultural knowledge with future ready practices.

REFERENCES

1. Altammar KA. 2023. A review on nanoparticles: characteristics, synthesis, applications, and challenges, *Frontiers in Microbiology.* 14(1155622). 1-20. https://doi.org/10.3389/fmicb.2023.1155622.

2. Babu S, Singh R., Yadav D, Rathore SS, Raj R, Avasthe R, Yadav SK, Das A, Yadav V, Yadav B, Shekhawat K, Upadhyay PK, Yadav DK and Singh VK. 2022. Nanofertilizers for agricultural and environmental sustainability. *Chemosphere*. 292:133451. https://doi.org/10.1016/j.chemosphere.2021.133451.

3. Dilnawaz F, Misra AN and Apostolova E. 2023. Involvement of nanoparticles in mitigating plant's abiotic stress. *Plant Stress*. 10:100280. https://doi.org/10.1016/j.stress.2023.100280.

4. Kumar Y, Tiwari KN, Nayak RK, Rai A, Singh SP, Singh AN, Kumar Y, Tomar H, Singh T and Raliya R. 2020. Nanofertilizers for increasing nutrient use efficiency, yield and economic returns in important winter season crops of Uttar Pradesh. *Indian Journal of Fertilizers*. 22(4):324–335.

5. Mathew JT, Hussaini J, Inobeme A, Adetunji CO and Tanko MS. 2025. Nanocarriers for Delivering Pesticides. *Nanocarriers in Plant Science and Agriculture*. 273–296. https://doi.org/10.4018/979-8-3693-9869-2.ch010.

6. Pathak SO, Pandey BK, Singh S, Hasanain M, Shukla G and Maurya DK. 2020. Nanotechnology in Agriculture: benefits, risks and challenges. *Food and Scientific Reports*. 89–90.

7. Wang D, Saleh NB, Byro A, Zepp R, Sahle-Demessie E, Luxton TP, Ho KT, Burgess RM, Flury M, White JC and Su C. 2022. Nano-enabled pesticides for sustainable agriculture and global food security. *Nature Nanotechnology*. 17(4):347–360. https://doi.org/10.1038/s41565-022-01082-8.

8. Wei H, Li L, Zhang T, Seidi F and Xiao H. 2023. Platinum-loaded dendritic mesoporous silica as novel ethylene scavenger to extend shelf life of banana (*Musa nana*). *Food Chemistry*. 424:136415–136415.

9. Wei Y, Chen J, Dong M, Yin M, Shen J, Gao L and Yan S. 2025. Nano-enabled insecticides for efficient pest management: definition, classification, synergistic mechanism, and safety assessment. *Nanomaterials*. 15(13):1050. https://doi.org/10.3390/nano15131050.