# Chapter-31
# Applications of Nanotechnology in Agriculture

**Amit Babasaheb Ghadge**
Department of Microbiology
Smt. Ratnaprabhadevi Mohite Patil College of Home Science for Women, Akluj
Email: amitghadge9921@gmail.com

**Abstract:**

Nanotechnology has rapidly emerged as one of the most powerful modern tools in agriculture and is expected to significantly influence the agricultural economy in the coming years. By utilizing innovative chemical compounds and advanced delivery platforms, nanotechnology enhances crop productivity while reducing the reliance on conventional bulk agrochemicals. It offers promising and efficient solutions to several persistent challenges in agriculture.In many developing nations, agriculture remains the primary livelihood source for over 60% of the population. However, the sector faces numerous issues such as climate variability, unsustainable resource use, and excessive application of chemical fertilizers. Nanotechnology provides several direct applications in agriculture, including targeted delivery of nutrients and pesticides, nano-carriers, intelligent packaging systems, nanosensors, veterinary and aquaculture applications, and detection of nutrient deficiencies.Nanomaterials are generally produced through two major approaches: top-down techniques, which involve reducing larger materials into nanoscale forms, and bottom-up techniques, which build materials from atomic or molecular units. Nano-fertilizers are now increasingly preferred over traditional fertilizers because they help decrease soil and water contamination caused by agrochemicals. Their slow-release nature ensures a gradual supply of nutrients, minimizing nutrient loss and enhancing nutrient-use efficiency. Nanotechnology therefore improves fertilizer efficiency, decreases environmental protection costs, and provides an effective alternative to water-soluble fertilizers.This work highlights the significant role of nanotechnology in advancing agricultural systems, particularly in improving plant nutrition and plant protection.

**Keywords:** Nanotechnology, Agriculture, Crop Protection, Fertilizers, Smart Packaging

## Introduction

Nanotechnology has rapidly become one of the most influential modern tools in agriculture and is projected to play a major role in driving the agricultural economy in the near future. By incorporating innovative chemical compounds and advanced delivery mechanisms, nanotechnology enhances crop productivity while lowering the dependence on conventional bulk agrochemicals. This emerging field offers more precise and efficient solutions to many long-standing agricultural challenges.Agriculture remains the foundation of most developing nations, providing a livelihood for more than 60% of their populations. However, the sector is continuously affected by issues such as climate change, irrational resource use, and excessive reliance on chemical fertilizers [1]. Nanotechnology, often described as “the art and science of manipulating matter at the nanoscale," involves designing, characterizing, producing, and applying materials, devices, and systems by controlling their structure at nanometer dimensions [2].

Recognized as the sixth major technological revolution, nanotechnology has expanded across numerous scientific fields and is expected to become a key contributor in agriculture and food science in the coming decades. Despite its vast potential, scientific research on the agricultural applications of nanotechnology remains limited worldwide [3]. Since plant nutrition plays a critical role in crop yield and quality and nearly 40% to 60% of global food production depends on fertilizer use [4] nanotechnology provides new possibilities for improving agricultural efficiency.By working with particles at extremely small scales, nanotechnology aims to address problems that conventional methods cannot solve, ultimately supporting better management of agricultural inputs. Nanoparticles possess unique physicochemical properties, including large surface area, high reactivity, and customizable pore sizes, making them promising tools for future advancements in plant nutrition to meet the demands of a growing population.

**Nanotechnology:**

Nanotechnology is an advanced scientific field that involves using materials and devices capable of exploiting the physical and chemical properties of matter at molecular and atomic levels. It enables exploration and manipulation of biological and material systems at the nanometer scale for applications ranging from medicine to agriculture [5]. It deals with materials smaller than 100 nm—where 1 nanometer equals $10^{-9}$ meters—and integrates principles from solid-state physics, chemistry, chemical engineering, biophysics, biochemistry, and materials science.

**Nanoparticles:**

Nanoparticles are defined primarily by their size, at which they exhibit properties significantly different from those of their bulk counterparts. Their dimensions overlap with colloidal particles, typically ranging from 1 nm to 1 mm in diameter [6]. Because of their extremely high surface-to-volume ratio, nanoparticles also display physical behaviors that differ considerably from larger materials [7].

**Production Methods of Nanoparticle**

Nanomaterials are generally synthesized using two major approaches: top-down and bottom-up techniques (as described by the Royal Society and the Royal Academy of Engineering).

**1 Top-down approach**

This method reduces larger bulk materials into nanoscale particles through physical and mechanical processes such as milling, grinding, or crushing. It is commonly used to produce nanocomposites and nano-grained metals or ceramics, typically generating particles within a broad size range (10–1000 nm), as illustrated in Figure 1.

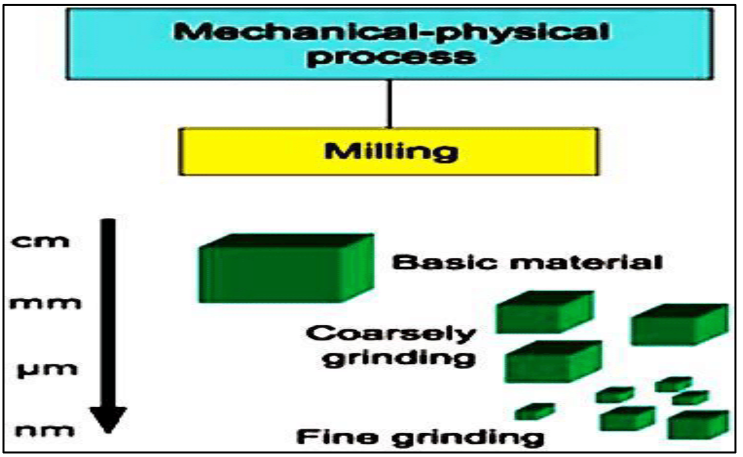


**Figure 1: mechanical process for preparation of nanoparticles (8).**

**2 Bottom-up system:** in **'Bottom-up'** building up, numerous molecules self-assemble in parallel steps, as a function of their molecular recognition characters, this processing produces more complex structures from atoms or molecules, also, this method produce a uniform controlling sizes, shapes and size ranges of nano materials (Figure 2).

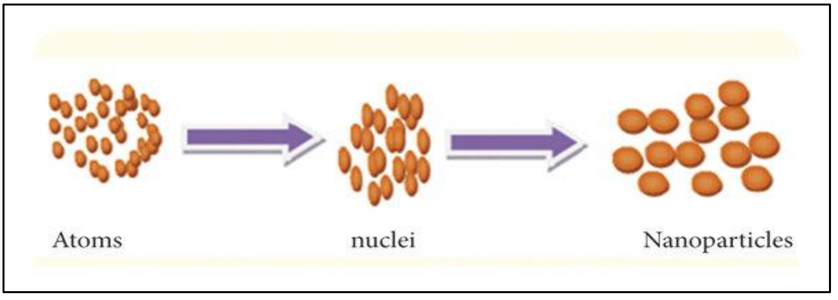


**Figure 2: Nano particle's Structures chemically fabricated (9)**

In the bottom-up approach, nanomaterials are generated by assembling atoms or molecules into organized structures through self-assembly. This process relies on molecular recognition properties, enabling molecules to spontaneously arrange themselves into more complex formations. Such techniques allow precise control over particle size, shape, and distribution (Figure 2). This method is widely used to produce most nanomaterials within the 1–100 nm range and plays a critical role in fabricating nanoscale structures. Additional synthesis techniques include attrition, pyrolysis, and biological (green) nanoparticle production.

**Unique characters of Nanoparticles**

i. At sizes below 100 nm, materials behave very differently because classical physical rules start giving way to quantum effects. Nanotechnology takes advantage of these unique properties, which include:

ii. High surface charge and enhanced reactivity due to extremely small particle size [10].

iii. Greater surface area-to-volume ratio, causing surface atoms to be far more active than internal atoms.
iv. Improved mechanical strength, increased thermal stability, reduced melting point, and altered magnetic properties because of nanoscale clustering.
v. Variations in exposed surface structures lead to differences in atomic arrangement across nanoparticles, influencing electron-transfer kinetics between nanoparticles and the molecules bound to them.
vi. Superior catalytic efficiency, especially in tetrahedral nanoparticles, followed sequentially by cubic and spherical forms, due to highly reactive corners and edges [11].

**Nanomaterials in Agriculture**

Nanomaterials possess chemical, physical, and biological characteristics that differ significantly from their larger counterparts, which may also introduce unique safety considerations. Their potential has drawn major interest in agriculture and food systems, as they can enhance the quality and efficiency of agricultural inputs. With rapid technological progress since the late 20th century, controlled synthesis of nanomaterials with specific shapes and sizes, along with new conceptual approaches, has provided strong foundations for addressing longstanding challenges in nutrient uptake. Nanotechnology in agriculture includes applications such as targeted delivery of agrochemicals, understanding plant disease mechanisms, and improving plant genomes [12].

**Positive approaches of nanomaterials in the agriculture**

i. Nanomaterials offer several advantages because of their nanoscale properties:
ii. Higher solubility when dispersed in solutions.
iii. Larger surface area and small particle size, enhancing their ability to penetrate seed coats and root tissues.
iv. Improved molecular bioavailability to seed radicals, supporting early plant growth [13].

**Aspects of nanomaterials in agricultural applications:**

i. Ideal nanomaterials intended for agricultural use should exhibit the following characteristics:
ii. Controlled and precise release of fertilizers or pesticides under specific conditions—for example, $TiO_2$ nanoparticles used to enhance Mung bean growth [14].
iii. Enhanced target specificity, ensuring better delivery and reduced wastage [15].
iv. Lower environmental toxicity, combined with safe and user-friendly handling and transport.

**Nanomaterials practise in agriculture**

Nanotechnology is applied across multiple stages of agricultural production through various forms and techniques, such as:

i. Nano-fertilizers for balanced nutrient supply [16,17]
ii. Crop enhancement (e.g., zinc nano-fertilizers improving Pennisetum americanum yield) [18]

iii. Nano-formulated pesticides, fungicides, and herbicides for plant protection [19]
iv. Weed management
v. Nano-pesticide formulations [20]
vi. Nano-enabled sensors for soil and crop monitoring [21]
vii. Post-harvest preservation and packaging technologies [22]
viii. Bio-synthesized nanoparticles for agricultural applications [18]
ix. Biosensors in aquaculture [23]
x. Nanobiotechnology tools for gene expression and regulation studies [24]
xi. Tracking and verifying the quality and identity of agricultural produce [25]
xii. Precision agriculture to increase yield while minimizing soil and water damage, reducing nutrient losses from leaching, and boosting long-term nutrient retention by soil microbes (Figure 3)
xiii. Seed technology
xiv. Water purification and improved irrigation systems [27]
xv. Nano-based plant growth regulators [28]
xvi. Soil improvement and management [29]
xvii. Applications in agricultural engineering [30]
xviii. Nanotechnology in food processing and food safety [31]

**10. Some applications of Nanotechnology in Agriculture**

a. Crop improvement
b. Enhanced efficiency of fertilizers and pesticides
c. Soil quality improvement
d. Early detection of plant diseases
e. Improved water resource management
f. Gene expression and regulatory studies

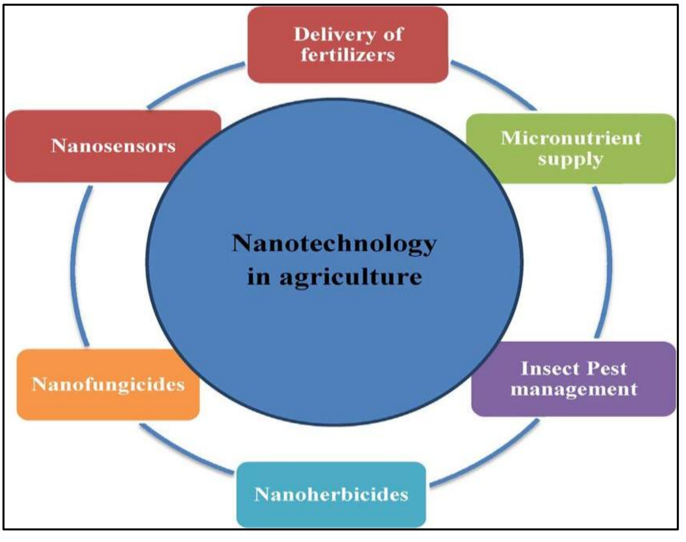


**Figure: Role of nanotechnology [33]**

## Potential Risks of Nanotechnology

Certain nanomaterials can pose risks to living organisms and the environment. For instance, exposure to high levels of silver nanoparticles may result in toxic effects on edible plants. In addition, some nanoparticles are capable of producing reactive oxygen species within biological tissues, which can lead to DNA damage. Because of these potential hazards, it is essential to thoroughly assess the safety of nano-based agricultural materials before their widespread application [32].

## Conclusion

Nanotechnology is emerging as a significant tool for enhancing agricultural productivity by improving nutrient-use efficiency and strengthening plant protection strategies. It offers promising solutions to numerous agricultural challenges, including the development of improved crop varieties, disease detection, and real-time monitoring of plant growth. With its advanced applications, nanotechnology holds considerable potential for transforming the agricultural sector and increasing global food production in the coming decades. Current progress in areas such as nano-nutrients, crop productivity enhancement, plant protection (including herbicides and pesticides), nano-packaging, and nanosensors demonstrates its growing impact on modern agriculture.

## References:


1. Raliya, R., et al. (2017). Nano fertilizer for precision and sustainable agriculture: Current state and future perspectives. Journal of Agricultural and Food Chemistry.
2. British Standards Institution. (2005). The Royal Society, 6–9 Carlton House Terrace, London SW1Y 5AG.
3. Mousavi, S. R., & Rezaei, M. (2011). Nanotechnology in agriculture and food production. Journal of Applied Environmental and Biological Sciences, 1(10), 414–419.
4. Roberts, T. L. (2009). The role of fertilizer in growing the world's food. Better Crops Plant Food, 93, 12–15.
5. Fakruddin, M., et al. (2012). Prospects and applications of nanobiotechnology: A medical perspective. Journal of Medical Biotechnology, 10, 31.
6. Banfield, J. F., & Zhang, H. (2001). Nanoparticles in the environment. In J. F. Banfield & A. Navorotsky (Eds.), Nanoparticles and the environment (pp. 1–58). Mineralogical Society of America.
7. Buffle, J. (2006). The key role of environmental colloids/nanoparticles for the sustainability of life. Environmental Chemistry, 3(3), 155–158.
8. Laboratory for Micro and Nanotechnology, Paul Scherrer Institut. (n.d.).
9. Kumar, R., et al. (2015). Bionanoparticles: A green nanochemical approach. PharmaTutor, 3(9), 28–35.
10. Yang, L., & Watts, D. J. (2005). Particle surface characteristics may play an important role in phytotoxicity of alumina nanoparticles. Toxicology Letters, 158(2), 122–132.
11. Adhikari, T., et al. (2010). Nanofertilizer: A new dimension in agriculture. Indian Journal of Fertilisers, 6(8), 22–24.

12. Abobatta, W. F. (2017). Nanotechnology: A new key for agricultural sector development. International Conference in Nanotechnology, Biotech and Spectroscopy (ICNBS).
13. Dehner, C. A., et al. (2011). Size-dependent bioavailability of hematite (α-$Fe_2O_3$) nanoparticles to a common aerobic bacterium. Environmental Science & Technology, 45, 977–983.
14. Raliya, R., et al. (2015). $TiO_2$ nanoparticle biosynthesis and its physiological effect on mung bean (Vigna radiata L.). Biotechnology Reports, 5, 22–26.
15. Lu, C. M., et al. (2002). Research on the effect of nanometer materials on germination and growth enhancement of Glycine max and its mechanism. Soybean Science, 21(3), 168–171.
16. Janmohammadi, M., et al. (2016). Impact of foliar application of nano micronutrient fertilizers and titanium dioxide nanoparticles on the growth and yield components of barley under supplemental irrigation. Acta Agriculturae Slovenica, 107(2), 265–276.
17. Abobatta, W. F. (2017). Different impacts of nanotechnology in agricultural sector development. Nano Technology Science and Application – The Creative Researchers First Scientific Annual Conference.
18. Tarafdar, J. C., et al. (2014). Development of zinc nanofertilizer to enhance crop production in pearl millet (Pennisetum americanum). Agricultural Research, 3(3), 257–262.
19. Park, H. J., et al. (2006). A new composition of nanosized silica-silver for control of various plant diseases. Plant Pathology, 22(3), 295–302.
20. Corradini, E., et al. (2010). A preliminary study of the incorporation of NPK fertilizer into chitosan nanoparticles. eXPRESS Polymer Letters, 4(8), 509–515.
21. Mukal, D., et al. (2009). Emerging trends of nanoparticles application in food technology: Safety paradigms. Nanotoxicology, 3(1), 10–18.
22. Meetoo, D. (2011). Nanotechnology and the food sector: From the farm to the table. Emirates Journal of Food and Agriculture, 23(5), 387–403.
23. Kumar, S. R., et al. (2008). Potential use of chitosan nanoparticles for oral delivery of DNA vaccine in Asian sea bass (Lates calcarifer) to protect from Vibrio (Listonella) anguillarum. Fish and Shellfish Immunology, 25(1–2), 47–56.
24. Galbraith, D. W. (2007). Nanobiotechnology: Silica breaks through in plants. Nature Nanotechnology, 2(5), 272–273.
25. Rameshaiah, G. N., et al. (2015). Nano fertilizers and nanosensors: An attempt for developing smart agriculture. International Journal of Engineering Research and General Science, 3(1), 314–320.
26. Duhan, J. S., et al. (2017). Nanotechnology: The new perspective in precision agriculture. Biotechnology Reports, 15, 11–23.
27. Bharathi, P., et al. (2016). Improvement of membrane system for water treatment by synthesized gold nanoparticles. Journal of Environmental Biology, 37, 1407–1414.
28. Choy, J. H., et al. (2007). Clay minerals and double-layered hydroxides for novel biological applications. Applied Clay Science, 36(1–3), 122–132.

29. Klingenfuss, F. (2014). Testing of TiO2 nanoparticles on wheat and microorganisms in a soil microcosm (Master's thesis). University of Gothenburg.
30. Gonzalez-Melendi, P., et al. (2008). Nanoparticles as smart treatment delivery systems in plants: Assessment of different techniques of microscopy for their visualization in plant tissues. Annals of Botany, 101(1), 187–195.
31. Yata, V. K., et al. (2018). Nanoscience in food and agriculture: Research, industries and patents. Environmental Chemistry Letters, 16(1), 79–84.
32. Dekkers, S., et al. (2016). Towards a nanospecific approach for risk assessment. Regulatory Toxicology and Pharmacology, 80, 46–59.
33. Duhan, J. S., Kumar, R., Kumar, N., Kaur, P., Nehra, K., & Duhan, S. (2017). Nanotechnology: The new perspective in precision agriculture. Biotechnology Reports, 15, 11–23.