AgriCos e-Newsletter
ISSN: 2582-7049
AgriCos e-Newsletter
Open Access Multidisciplinary Monthly Online Magazine
Volume: 04 Issue: 08 August 2023 Article No: 15

# Nanotechnology in Agriculture: Exploring Applications and Future Pathways

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**SUMMARY**

Nanotechnology offers promising applications in agriculture, paving the way for improved crop production and sustainable practices. By utilizing nanoparticles, scientists can develop advanced delivery systems for fertilizers and pesticides, enhancing their efficiency while reducing environmental impact. Nanosensors enable real-time monitoring of soil conditions, water quality, and plant health, aiding in precision agriculture. Additionally, nanomaterials enhance seed quality and increase plant tolerance to environmental stresses. However, ethical and safety concerns regarding nanoparticle release into the environment and their potential effects on ecosystems and human health need to be addressed. Despite these challenges, nanotechnology holds immense potential for revolutionizing agriculture and meeting the global demand for food security in the future.

## INTRODUCTION

Globally, a large proportion of people face daily food shortage due to changing agroclimatic conditions particularly in developing countries. Thus, there is need to develop drought and pest resistant crops with increased minerals uptake to maximize production level. Nanotechnology will increases the crop yield by withstanding environmental conditions (Alfadul *et al*., 2017). Therefore, it is crucial time to use modern technology such as bio and nanotechnology to maintain the ever increasing demand of food and vegetables crops. The essence of nanotechnology is the ability to work at the molecular level, atom by atom, to create large structure with fundamentally new molecular organization. Nanotechnology has the potential to increase crop productivity through genetic improvement of plants, delivery of genes and drug molecules to specific sites at cellular level and nano-array based gene-technologies for gene expressions in plants and animals under stress conditions.

**What is nanotechnology:** It can be defined as the design, characterization, production and application of structures, devices and systems by controlling the shape and size at the nanometer scale (Mousavi and Rezaei, 2011).

**How small nanoscale is:** Nano is a Greek word which means “dwarf” or “very small”; it indicates one billionth ($10^{-9}$) of something. Ex: 1 Nanometer = 1 billion of meter.

**Types of Nano materials:**

**a) Carbon Nanotubes (CNTs):** CNTs, are hallow cylindrical tubes composed of one, two or several concentric graphite layers capped by fullerenic hemisphere, which are refered as single, double and multi-walled CNTs.

**b) Mesoporous silica NPs (MSNs):** NPs that comprises of a honeycomb-like porous structure with pore size and outer particle diameter in the nanometer range. This type of NP has hundreds of empty channels that are capable of encapsulating or absorbing large amounts of agrochemicals or bioactive molecules.

**c) Liposomes:** They are phospholipid vesicles (50–100 nm), they have a bilayer membrane structure similar to that of biological membranes and an internal aqueous phase. Liposomes show excellent circulation, penetration and diffusion properties.

**d) Quantum Dots:** It is a semiconductor nano crystal, are very special because of its size (40,00,000 dots take up 2 cm). Used in several areas such as solar cells, LEDs, medical imaging and quantum computing.

**e) Nanosensors:** They are tiny particles or nanocrystals of a semiconductor material with diameters ranging from 2 to 10 nm. They are any biological or chemical sensory points used to convey information about nano particles to the outside world.

**Properties of nanoparticles:**

- Small size(1-100nm)

- High surface to volume ratio
- Significantly higher hardness, breaking strength and toughness at low temperatures and super plasticity at high temperatures
- Formation of suspensions
- Diffusion properties
- New entry ways (high mobility in human body, plants and environment)
- Optical properties of nanoparticles

**Basic two types of Nanoparticles (NPs) construction:**

**1. Top-down approach (BIG making into SMALL):** Nano objects are created from larger objects. Size reduction is achieved by various chemical and physical treatments such as milling, high pressure homogenization and sonication. Ex: Silicon chips.

**2. Bottom-up approach (SMALL making into BIG):** Large structures are built by linking atom by atom or Building material from atomic level up by arranging or self assembly. Ex: Nano-factories.

**Applications of nanotechnology:**

**1. Nano-genetic manipulation of the plants**

- Properly functionalized nano materials serve as vehicles and could carry a large number of genes as well as substance able to trigger gene expression or to control the release of genetic material throughout timing plants.
- They successfully used nanotechnology to penetrate plant cell walls and deliver a gene and a chemical that triggers its expression.

**2. Nano-biotechnology**

This technique could be applied in improving important crops by organizing and linking carbohydrates, lipids, proteins and nucleic acids to these crystals.

**Nanoparticle mediated gene transfer**

- Gene delivery systems are an important area in the field of genetic engineering and nanomedicine.
- Possible vectors include viral "shells" or lipid spheres (Liposomes), which have properties that allow them to be incorporated into host cells.
- Decreasing the particle size from micro to nano scale, hindrance due to cell wall can be removed
- Cell Damage can be minimized
- The particle can reach the chloroplast and mitochondria easily

**3. DNA micro-arrays and expression profiling:** A DNA microarray (DNA chip or biochip) is a collection of microscopic DNA spots attached to a solid surface. They are used to measure the expression levels of large numbers of genes simultaneously. Microarrays are sensitive, specific, miniaturized devices that may be used to detect selected DNA sequences and proteins, or mutated genes associated with human diseases.

**4. Nano-biosensors:** Nano-sensors with immobilized bio receptor probes that are selective for target analyte molecules are called "Nano-Biosensors. Its applications include detection of analytes like urea, glucose, pesticides etc., monitoring of metabolites and detection of various microorganisms/pathogens (Rai *et al.* 2012), diagnose of soil born diseases via the quantitative measurement of differential oxygen consumption in the respiration of good microbes and bad microbes in the soil (Mengel *et al.* 2001).

**5. Nano-pesticides and nano-herbicides:** Nano-pesticide is an agrochemical combination used to overcome the problems caused by conventional pesticides. Several types of materials *viz*., surfactants, organic polymers and mineral nanoparticles that fall in the nanometer size range are used in formulation of nano-pesticides (Alfadul *et al.*, 2017).

**6. Nano-fertilizers and nano-complexes:** In nano-fertilization, nutrients may be entraped using nano-materials coated with a thin film or delivered as emulsions. The slow release of nutrients from nanoparticles coated fertilizers increase the use efficiency of nutrient by crops. Naderi *et al. (*2011) reported the possible use of nano-fertilizers as an alternative to conventional fertilization processes at low cost and in small quantity.

**7. Pest & disease diagnosis (Nano-phyto pathology):** Nano-phytopathology is a science which uses nanotechnology for detecting, diagnosing and controlling plant disease and their pathogens at an early stage,

owing to crop protection from epidemic diseases. Nanoparticles such as nano sized silica silver have recently been applied as antimicrobial and antifungal agents.
**8. Water treatment and soil remediation:** Nano Membranes for water purification, desalination (salts removing from Sea water) and detoxification. Nano Sensors for the detection of contaminants and pathogens.
**9. Food science and technology:** A key element in this sector is the development of nanocapsules that can be incorporated into food to deliver nutrients. The concept is that thousands of nanocapsules containing flavour or colour enhancers or added nutritional elements (such as vitamins), would remain dormant in the food and only be released when triggered by the consumer.
**10. Post harvest technology:** Horticultural products waste 20-30%, if we manage to reduce this amount for 5-10%, huge saves will be obtained. 70% of the potential lasting quality of horticultural crops is predetermined at harvest and 30% is influenced by post-harvest factors.

**Why we need nanotechnology in post harvest management?**
- To enhance the efficiency of available post harvest techniques.
- To reduce post harvest losses.
- To reduce the microbial decay in post harvest storage

**Nanotechnology strategies to reduce the horticultural produce wastages:**
**A. Nanoemulsion coating:** Nanoemulsion consist of an lipid nanodroplets (between 10 – 100 nm diameter) dispersed in an aqueous solution and each oil droplet surrounded by surfactant molecules with unique physicochemical and functional characteristics (Acosta, 2009).
Advantages of Coatings:1) Reduction of water loss. 2) Retardation of ripening. 3) Reduction of chilling injury. 4) Reduced decay. 5) Added shine or gloss. 6) Carriers of useful ingredients. 7) Anti-ripening compounds. 8) Maintain a good colour of products.
**B. Nanocomposites:** Nanocomposite is a multiphase solid material where one of the phase has nanocomposition of less than 100 nanometers.
Role in food packaging: 1) Reduce weight. 2) Improve mechanical strength. 3) Increase heat resistance. 4) Degradation of ethylene. 5) Improve barrier against oxygen, carbon di oxide, UV radiation, moisture and volatiles.
**C. Chitosan:** A natural antimicrobial compound known to reduce postharvest decay of fruit and vegetables. Chitosan with different molecular weights on gray mold in invitro and invivo in tomato stored at different temperatures was examined. Chitosan treatment significantly reduced fungal decay and concentrations of 2000 and 4000 mg/L showed complete control of the fungus in wound-inoculated tomato fruits.
**D. Nanosensors:** Nanosensors in plastic packaging can detect gases given off by food when it spoils and the packaging itself changes colour to alert (Seval, 2015). Nanotechnology also involves using biological molecules such as sugars or proteins as target-recognition groups for nanostructures that are used.
**Nanosensor applications:** 1) Detection of food pathogenic bacteria. 2) Detection of food-contaminating toxins and adulterants. 3) Detection of food-contaminating pesticides and chemicals. 4) Used for food freshness detection. 5) Food quality assessment due to improper storage.

**11. Precision farming/smart farming:** Precision farming has been a long-desired goal to maximize output (i.e. crop yields) while minimizing input (i.e. fertilizers, pesticides, herbicides, etc.) through monitoring environmental variables and applying targeted action. Bio-Nanotechnology has designed sensors which give increased sensitivity and earlier response to environmental changes and linked into GPS. This will monitor the soil conditions and crop growth over vast areas. Precision farming is measuring and responding to inter and intra-field variability in crops to form a decision support system. About 40–70% of N, 80–90% of P and 50–70% of K of the applied fertilizers is lost to the environment causing pollution. Nanofertilizers helps in slow and sustained release of agrochemicals resulting in precise dosage to the plants.

**Potential risks of nanotechnology:**
- Health and Safety Risks: Inhalation or direct exposure to certain nanoparticles could potentially lead to respiratory issues, organ damage, or other health problems.
- Environmental Impact: Nanoparticles may accumulate in soil, water, or living organisms, potentially disrupting ecosystems and causing harm to wildlife.

- Toxicity and Long-Term Effects: The long-term effects of exposure to nanoparticles are not yet fully understood. Some nanoparticles may possess toxic properties, and their potential cumulative effects over time need to be carefully studied to ensure safety.
- Regulatory Challenges: Nanotechnology poses challenges for regulatory agencies in terms of risk assessment, standardization and safety regulations.

**Limitations of nanotechnology:**

- Expensive (Higher production costs)
- Adverse effects on beneficial microbial flora and fauna
- Biosafety issues not well understood
- Nanotoxicity remains very poorly understood
- Interaction of nanoparticles with the non-target sites, which lead to certain environmental and health issues (Claudia *et al.*, 2014).

**Future prospects:** Focused research is required in use of nanoparticles in preservative solutions and nanopacking to improve the quality and the post harvest life vegetable crops. Focused research is required in use of nanoparticles in food sector so that consumer feel secure to go for it. The efficiency and the economic benefits of applying various techniques in combination with nanotechnology needs to be evaluated in the different crops.

**CONCLUSIONS:**

Nanotechnology has wider uses in biotechnology, genetics, plant breeding, disease control and allied fields etc. All these measures can help in improving genetic makeup of crop plants.Nano-biotechnology could take the genetic engineering of agriculture to the next level down – atomic engineering. Scientists are still seeking new applications of nanotechnology in agri-horticulture based food industry. The agricultural sector and the food industry will indeed see tremendous changes for the better in the coming years.

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