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Review

# Nanotechnology: The new perspective in precision agriculture

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ABSTRACT

Nanotechnology is an interdisciplinary research field. In recent past efforts have been made to improve agricultural yield through exhaustive research in nanotechnology. The green revolution resulted in blind usage of pesticides and chemical fertilizers which caused loss of soil biodiversity and developed resistance against pathogens and pests as well. Nanoparticle-mediated material delivery to plants and advanced biosensors for precision farming are possible only by nanoparticles or nanochips. Nanoencapsulated conventional fertilizers, pesticides and herbicides helps in slow and sustained release of nutrients and agrochemicals resulting in precise dosage to the plants. Nanotechnology based plant viral disease detection kits are also becoming popular and are useful in speedy and early detection of viral diseases. In this article, the potential uses and benefits of nanotechnology in precision agriculture are discussed. The modern nanotechnology based tools and techniques have the potential to address the various problems of conventional agriculture and can revolutionize this sector.

## 1. Introduction

Nanotechnology has been used in many fields of science like physics, chemistry, pharmaceutical science, material science, medicine and agriculture. The promising results in other fields opened up a lot of scope in the agriculture field also. According to the Directorate-General for internal policies of the European Union; precision agriculture is a farming management concept of measuring and responding to inter and intra-field varying in crops to form a decision support system for whole farm management and to reap the maximum output from the available resources. Now a day, nanotechnology is extensively used in modern agriculture to make true the concept of precision agriculture. Nanotechnology includes nanoparticles having one or more dimensions in the order of 100 nm or less [1]. Nanomaterials find applications in plant protection, nutrition and management of farm practices due to small size, high surface to volume ratio and unique optical properties [2]. A wide range of materials are used to make nanoparticles like metal oxides, ceramics, magnetic materials, semiconductor, quantum dots, lipids, polymers (synthetic or natural), dendrimers and emulsions [3]. Chitosan nanoparticles are being used in agriculture in seed treatment and as biopesticide which helps the plants to fight off fungal infections. The uptake efficiency and effects of nanoparticles on the growth and metabolic functions vary among plants. The concentration of nanoparticles affects processes like germination and growth of the plant [4]. Nanoencapsulation play a vital role in the protection of environment by reducing leaching and evaporation of harmful substances.

The worldwide consumption of pesticides is about two million tonnes per year; out of which 45% is used by Europe alone, 25% is consumed in the USA and 25% in the rest of the world [5]. Careless and haphazard pesticide usage increases pathogen and pest resistance, reduces soil biodiversity, kills useful soil microbes; causes bio magnification of pesticides, pollinator decline and destroys natural habitat of farmer friends like birds [6]. The potential uses and benefits of nanotechnology are enormous. These include insect pest management via formulations of nanomaterial based pesticides and insecticides, increase in agricultural productivity using nanoparticles encapsulated fertilizers for slow and sustained release of nutrients and water. Nanoparticles mediated gene or DNA transfer in plants for the development of insect pest resistant varieties and use of nanomaterial for preparation of different kinds of biosensors would be useful in remote sensing devices required for precision farming are some of the boon of this modern nanotechnology [7]. Traditional strategies such as integrated pest management used in agriculture are insufficient and application of chemical pesticides has adverse effects on animals, useful soil microbes and declines the fertility of soil as well. To combat this problem, development of more effective and non-persistent pesticides such as controlled release formulation is needed [8]. Tools like quantum dots are commonly used in plant pathology successfully for

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routine monitoring of pathogens and beneficial organisms in a wide range of microorganisms and substrates due to gene profiling of wide microorganisms [9]. Advances in micro fabrication and nanotechnology now play an important role in viral detection and improving the detection limit, operational simplicity and cost-effectiveness of viral diagnostics [10].

## 2. Biosynthesis of nanoparticles and their use in agriculture

Many chemical methods are available for synthesis of nanoparticles, which use toxic chemicals so the need of the hour is to use environmentally benign, greener and ecofriendly routes. Researchers are looking forward for various biological entities like bacteria, fungi, higher plants, actinomycetes and viruses for nanoparticles synthesis as they can also reduce the salts to corresponding nanoparticles. Different biological sources have been used for the synthesis of nanoparticles and are being used in agriculture for precision farming [11]. Some of them are as follows: silver nanoparticles, zinc oxide nanoparticles, titanium dioxide nanoparticles.

### 2.1. Silver nanoparticles

Silver nanoparticles have a high surface area and fraction of surface atoms; as a result have high antimicrobial effect as compared to the bulk silver [12]. Antimicrobial property of silver nanoparticles has been used against a broad range of human pathogens [13–16]. However, the full potential is still to be explored for crop protection. Therefore, there is a growing interest to utilize antimicrobial property of silver nanoparticles for plant disease management [17]. Silver nanoparticles have been experimenting as pesticides to reduce burden of pests from crops. Silver nanoparticles can be synthesized from physical, chemical and biological methods. Owing to requirement of extreme conditions and toxic chemicals in physical and chemical methods, biological methods are widely used. Being single step synthesis and ecofriendly, different researchers have synthesized silver nanoparticles from different sources (plants, bacteria, fungi etc.). These silver nanoparticles have been used to get rid of harmful microorganisms in plants.

Biological synthesis of silver nanoparticles in sizes ranging from 6 to 38 nm from white radish (*Raphanus sativus* var. *aegyptiacus*) has been documented. The exposure of the snails and soil matrix to silver nanoparticles in a laboratory experiment reduced the activity and the viability of the land snail (20% of silver nanoparticles treated snails died) as well as the frequency of fungal population in the surrounding soil [18]. Spherical shaped silver nanoparticles in size range of ∼10 to 20 nm using culture supernatant of *Serratia* sp. BHU-S4 and their effective application for the management of spot blotch disease in wheat have been experimented. Silver nanoparticles exhibited strong antifungal activity against *Bipolaris sorokiniana*, the spot blotch pathogen of wheat [17]. Effect of silver nanoparticles with diameters of 20 nm on seeds of Fenugreek (*Trigonella foenum-graecum*) has been carried out. [19]. Different concentrations of silver nanoparticles (0, 10, 20, 30 and 40 $\mu g\ mL^{-1}$) were used and results showed that maximum seed germination (76.11%), speed of germination (4.102), root length (76.94 mm), root fresh weight (2.783) and root dry weight (1.204) at a concentration of 10 $\mu g\ mL^{-1}$. These results revealed that application of silver nanoparticles could be used to significantly enhance seed germination potential, mean germination time, seed germination index, seed vigor index, seedling fresh weight and dry weight.

### 2.2. Zinc oxide nanoparticles

Zinc deficiency is a most common micronutrient problem that adversely affects agricultural production in alkaline soils with calcium carbonate [20]. The soils with calcium carbonate are a major source of agriculture in arid or Mediterranean environments of the world [21]. The parameters that limit zinc availability to plants in calcium carbonate soils are the alkaline pH, which reduces zinc solubility and the high calcium carbonate ($CaCO_3$) content, which can absorb and precipitate zinc [22,23]. Zinc oxides (ZnO) and zinc sulphates ($ZnSO_4{\cdot}H_2O$) or ($ZnSO_4{\cdot}7H_2O$) are commonly used as zinc fertilizers to correct deficiency of zinc in soils [24]. However, their applications as fertilizer are limited due to non-availability of zinc to plants. Zinc oxide nanoparticles can overcome this problem by providing more soluble and available form of zinc to plants due to their higher reactivity in comparison to micron- or millimeter-sized zinc particles present in bulk. The use of zinc oxide nanoparticles as zinc fertilizers may increase zinc dissolution and its bioavailability in soils with calcium carbonate. Diffusion of dissolved zinc is the main mechanism for the movement of zinc from fertilizer to the plant roots following the dissolution process [25]. Zinc oxide nanoparticles have shown much better antimicrobial activity than large zinc particles, since the small size less than 100 nm and high surface-to-volume ratio of nanoparticles allows better interaction with bacteria [26]. Zinc oxide nanoparticles have the ability to induce reactive oxygen species (ROS) generation, which can lead to cell death when the antioxidative capacity of the cell is exceeded [27–31]. Generation of reactive nitrogen species (RNS) and hydrogen peroxide ($H_2O_2$) upon exposure to silver and zinc oxide engineered nanoparticles on the duckweed (*Spirodela punctuta*) suggested that the toxicity of silver and zinc oxide nanoparticles predominantly caused by both the particulates and ionic forms [32]. Zinc nanoparticles have shown to induce free radical formation in wheat, resulting in increased malondialdehyde and lower levels of reduced glutathione [33] and reduced chlorophyll contents [34].

Zinc oxide nanoparticles can be synthesized by chemical and biological methods. Since chemical methods require toxic chemicals, biological methods are becoming popular. Synthesis of zinc oxide nanoparticles from plants is cost effective and eco-friendly. Plant leaf extract has been used commonly for synthesis of zinc oxide nanoparticles. For synthesis of zinc oxide nanoparticles, appropriate concentration of either zinc sulfate heptahydrate ($ZnSO_4{\cdot}7H_2O$) or zinc acetate dehydrate ($Zn(CH_3COO)_2{\cdot}2H_2O$) is dissolved in water. Plant leaf extract can be prepared in solvents such as water, ethanol or methanol. By mixing plant extract and zinc sulfate heptahydrate or zinc acetate dehydrate solution at desired pH, zinc oxide nanoparticles are synthesized.

Zinc oxide nanoparticles have been tested in the laboratory as bactericide and fungicide. Zinc oxide nanoparticles using leaf extract of *Moringa oleifera* in size range from 16 to 20 nm has been synthesized and antimicrobial activity against bacterial strains such as *Staphylococcus aureus*, *Bacillus subtilis*, *Pseudomonas aeruginosa*, *Proteus mirabilis*, *Escherichia coli* and fungal strains such as *Candida albicans* and *Candida tropicalis* using the agar disc diffusion method has been tested. The maximum zone of inhibition was observed in *Staphylococcus aureus* (23.8 ± 0.76) as compared to others [35]. Spherical and hexagonal zinc oxide nanoparticles from *Parthenium hysterophorus* L. have been synthesized by inexpensive, ecofriendly and simple method using different concentrations of 50% and 25% of *Parthenium* leaf extracts with size 27 ± 5 and 84 ± 2 nm, respectively. These zinc oxide nanoparticles were explored for the size-dependent antifungal activity against plant fungal pathogens i.e. *Aspergillus flavus* and *Aspergillus niger*. A maximum zone of inhibition was observed for 27 ± 5 nm size zinc oxide nanoparticles against *Aspergillus flavus* and *Aspergillus niger*. *Parthenium* mediated zinc oxide nanoparticles proved to be good antifungal agents and environment friendly [36]. Spherical shaped zinc oxide nanoparticles with an average size of 23 to 57 nm were prepared by zinc acetate and sodium hydroxide using leaves of *Catharanthus roseus* (L.) G. Don leaf extracts. The synthesized zinc oxide nanoparticles were evaluated for antibacterial activity against gram negative bacteria *Escherichia coli* (ATCC 25922), *Pseudomonas aeruginosa* (ATCC 15442), gram positive *Staphylococcus aureus* (ATCC 6538) and *Bacillus thuringiensis* (ATCC 10792). *Bacillus thuringiensis* indicated the resistance to zinc oxide nanoparticles followed by *Escherichia coli* whereas