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Application of Nanotechnology in Plant Pathology

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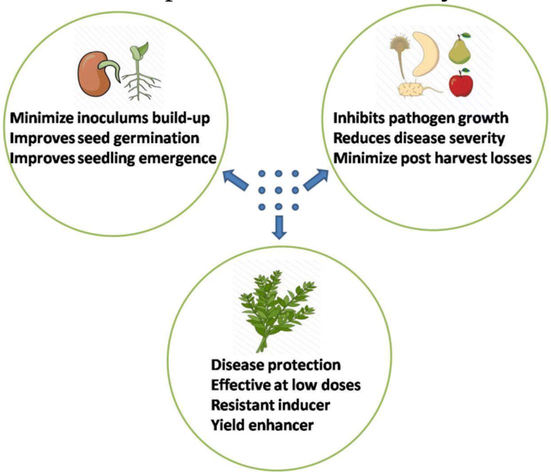
The practice of agriculture also known as "farming" is the process of producing food, feed, fiber and many other desired products by the cultivation of certain plants and the raising of livestock. Agriculture is the backbone of most developing countries and it provides food for humans, directly and indirectly. The world's population will grow to an estimated 8 billion people by 2025 and 9 billion by 2050, and it is widely recognized that global agricultural productivity must increase to feed a rapidly growing world population (Sekhon, 2014).

The challenges faced by plant pathologists and other agriculturalists are daunting. Nanotechnology stands as a new weapon in our arsenal against these mounting challenges in plant health and disease management. The utilization of nanotechnology in plant disease management, diagnosis and genetic transformations is still in its infancy and has only begun to be explored in the plant pathology literature. Nanoparticles remain bound to the cell wall of pathogen and causes deformity due to high energy transfer leading to its death. Nanocomposites fulfil the two most important criteria in disease management: efficacy with minimal ecological impact and less toxicity on humans. While there is no much evidence of harm to people or the environment at present, nanotechnology is a new and evolving area of study where the research and developments are still at bench- top scale. Social and ethical implications of nanotechnology applications in agriculture have to be addressed and toxicity of nanomaterials has to be clearly understood before its commercialization and field application. The potential application of nanomaterials in different agricultural applications needs further research investigation with respect to synthesis, toxicology and its effective application at field level. In the field of agriculture, there are still many possibilities to explore with new nano products and techniques.

Nanoparticles in plant disease management

Different types of organic, inorganic, salts and acids have been used for controlling disease for many years (Talibi *et al*., 2011). Besides, some organic amendments are also used to control plant diseases. Application of nanoparticles in plant disease management is a novel and fancy approach that may prove very effective in near future with the progress of application aspect of nanotechnology. The nanotechnology has effective potential prospects to use in plant disease management in different ways. Direct application of nanoparticles in the soil on seeds or foliage is the most simple and obvious way to protect plants from pathogen invasion. In this way, the NPs may suppress the pathogens growth and development as chemical pesticides could do. When nanoparticles are to be applied directly in soil, non-target organisms especially mineral fixing/solubilizing microorganisms will be effects of the great significance. Secondly, the nanomaterials, carbon tubes, cups, etc., can also be used as a carrier of some fancy chemicals such as pheromones, SAR inducing chemicals, polyamine synthesis inhibitors or (Khan *et al*., 2014) even concentrated active ingredients of pesticides for their controlled release especially under flooded conditions. Hence, the scope and application of nanoparticles in plant disease management, the effects can be discussed through two major point of views i.e. use of nanomaterials in formulating the pesticides i.e., nanopesticides and direct effect of NPs on pathogens. In view of very high degree of reactivity/sensitivity of ultra-small size of the particles, this NPs may also prove very effective in the diagnosis of plant pathogens/diseases and pesticide residue analysis.



Nanoparticles in plant disease management

Effect of nanoparticles on the pathogens/ microorganisms

Since, macroform to its physio chemical properties of nanoforms vary greatly, it becomes important to examine the effect of NPs on microorganisms to harness the benefit of this technology in the plant protection especially against phytopathogens. Because of nanoparticles are in ultra-small size, even smaller than a virus particle and high reactivity, may affect the activity of microorganisms. Silver NPs inhibited the colonization of *Staphylococcus aureus*, *Pseudomonas aeruginosa*, *Escherichia coli* and *Klebsiella pneumonia*. *Solanum tricobatum* and *Ocimum tenuiflorum* leaf extracts was found against *S. aureus* and *E. coli*, respectively has shown highest antimicrobial activity synthesized by silver nanoparticles (30mm).

Effect of nanoparticles on plant pathogenic fungi

Plant pathogens viz., fungi, bacteria, viruses and nematodes are important limiting factors in the production. Number of methods are used to control pathogens but none of them offer perfect control of the plant disease. That's why, a great scope exists for the exploitation of nanotechnology for the management of diseases. The nanoparticles have also been found suppressive to fungi. Among nanoforms of 15 micronutrients reported by Singh *et al*. (2013), $CuSO_4$ and $Na_2B_4O_7$ were found most effective in controlling rust disease of field peas. (Abd El-Hai *et al*., 2009) reported that microelements such as manganese and zinc also suppressed the damping off and charcoal rot diseases in sunflower. *Candida albicans*, *C. krusei*, *C. tropicalis*, *C. glabrata* and *Aspergillus brasiliensis* these different yeasts and molds were tested for fungicidal activity by using Ag NPs/PVP. (Bryaskova *et al*., 2011) The hybrid materials showed strong antifungal effects against the tested microbes. Two postharvest pathogenic fungi, *Botrytis cinerea* and *Penicillium expansum*, have reported fungicidal effect by zinc oxide nanoparticles (ZnO NPs). To study antifungal activities of ZnO NPs and to characterize the changes in morphology and cellular compositions of fungal hyphae were used by traditional microbiological plating, Scanning Electron Microscopy (SEM) and Raman spectroscopy. The ZnO NPs (70±15 nm) at the concentrations greater than 3 mmol L^{-1} significantly inhibited the growth of *B. cinerea* and *P. expansum*, the later fungus was found more sensitive to the treatments. The NP treatments caused deformation in the hyphae of *B. cinerea* and prevented the development of conidiophores and conidia in *P. expansum* which eventually led to the death of fungal hyphae.

Effect of nanoparticles on bacteria

Antibacterial activity of zinc nanoparticles against *P. aeruginosa* has been reported by Jayaseelan *et al*. (2012). The maximum zone of inhibition in the colonization of the bacteria (22±1.8 mm) was recorded at 25 ng mL^{-1} ZnO NPs. The study showed that the ZnO NPs proved to be a novel antimicrobial material. The antibacterial activity of the synthesized AgNPs/PVP (hybrid materials based on polyvinylpyrrolidone with silver nanoparticles) against three different groups of bacteria- *Staphylococcus aureus* (gram positive bacteria), *E. coli* (gram-negative bacteria), *P. aeruginosa* (non ferment gram-negative bacteria), as well as against spores of *Bacillus subtilis* has been studied (Bryaskova *et al*., 2011). The antibacterial activities of CuO NPs has also been reported against *S. aureus*, *Bacillus subtilis*, *P. aeruginosa* and *E. coli* (Azam *et al*., 2012). Guzman *et al*. (2009) found that silver nanoparticles showed high antimicrobial and bactericidal activity against gram positive bacteria such as *E. coli*, *P. aureginosa* and *S. aureus* which are highly methicillin resistant strains. The antibacterial activity of nanoparticles was found to be dependent of NPs concentration, physiology, metabolism, intracellular selective permeability of membranes and the type of microbial cell.

Nanoparticles in disease management

***Biopolymer nanoparticles**:* Development of nanoformulation for field application of agrochemicals requires the use of readily biodegradable, nontoxic, environment friendly, safe and low-cost materials. So, use of biopolymers produced by natural sources with good physical and chemical properties is a fascinating approach to prevent the use of petrochemical and toxic chemical substances in production of nanomaterial.

Chitosan: Chitosan nanoparticles have got various applications in biology due to its biodegradable and nontoxic properties. In acidic condition the free amino groups of chitosan protonate and contributes to its positive charge (Phaechamud and Ritthidej, 2008). In search of natural antimicrobials to avoid harmful synthetic chemicals, chitosan and chitosan nanoparticles are found to be more effective against plant pathogens like *Fusarium solani*.

***Metallic nanoparticles**:* Metallic nanoparticles possess unique chemical and physical properties, small size, huge surface to volume ratio, structural stability and strong affinity to their targets (Kumar et al., 2010). Metal nanoparticles can be used as new antimicrobial agents and an alternative to synthetic fungicide to delay or inhibit the growth of many pathogens' species because of its multiple mode of inhibition.

Silver nanoparticle: Silver in ionic or nanoparticle forms has a high antimicrobial activity and is therefore widely used for various sterilization purposes including materials of medical devices and water sanitization. Relatively few studies were reported on the applicability of silver in controlling various plant pathogens in a relatively safer way c compared to synthetic fungicides (Park et al. ,2006). Since nanoparticles efficiently penetrate into microbial cells lower concentrations of silver nanoparticles are sufficient for microbial control. This would be effective, especially for those organisms that are less sensitive to antibiotics because of poor penetration of some antibiotics into microbial cells (Samuel and Guggenbichler, 2004). Lamsal et al. (2011) showed the effective us age of silver nanoparticles instead of commercial fungicides. They evaluated the effect of silver nanoparticles against six *Colletotrichum* species associated with pepper anthracnose under different culture conditions and found that, application of 100 ppm concentration of silver nanoparticles inhibited the growth of fungal hyphae as well as conidial germination in vitro when compared to the control. A recent study on in vitro and in vivo efficacy of silver nanoparticles against powdery mildew before and after disease outbreak in plants under different cultivation conditions, showed maximum inhibition of fungal hyphae and conidial germination with less concentration of nanoparticle on cucumbers and pumpkins (Lamsal et al., 2011).

Silica nanoparticle: Silicon (Si) increases disease resistance and stress resistance in plants (Brecht et al., 2004). It also stimulates the physiological activity and growth of plants (Carver et al., 1998). Torney et al. (2007) used honeycomb mesoporous silica nanoparticle (MSN) system with 3nm pores to deliver DNA and chemicals into plant cells and intact leaves. They loaded the gene and its chemical inducer into the MSN system and capped the ends with gold nanoparticles and studied the release pattern of chemicals and induction of gene expression in the plants under controlled-release conditions. Their study showed an application of silica nanoparticles in target-specific delivery of proteins, nucleotides and chemicals in plant biotechnology.

Copper nanoparticle: Copper-based fungicides produce highly reactive hydroxyl radicals which can damage lipids, proteins, DNA, and other biomolecules. It plays an important role in disease prevention and treatment of large variety of plants (Borkow and Gabbay, 2005). Complexation of copper with chitosan nanogels was shown to have strong synergistic effect between chitosan and copper in inhibiting the growth of phytopathogenic fungus *Fusarium graminearum.* Because of its bio-compatibility, these nanohydrogels are included as a new generation of copper-based bio-pesticides and it could also be developed into an efficient delivery system for copper-based fungicides for plant protection (Brunel et al., 2013).

Zinc nanoparticle: Mechanism of action of zinc nitrate derived nano-ZnO on important fungal pathogen Aspergillus fumigatus showed hydroxyl and superoxide radicals mediated fungal cell wall deformity and death due to high energy transfer (Prasun Patra. and Goswami, 2012). Zinc oxide nanoparticles (ZnO NPs) could be used as an effective fungicide in agricultural and food safety applications.

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