Nanotechnology: A Potential Alternative for Plant Disease Management

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Nanotechnology is a growing interdisciplinary science in the past decades that links knowledge of biology, chemistry, physics, engineering, and material science. Application of nanotechnology in crop protection is of relatively recent origin compared with its use in drug delivery and pharmaceuticals. Any material when attenuated at nanometer scale (less than 100 nm) exhibits new properties that are entirely different from its bulk counterpart due to small size and high surface to volume ratio. Material scientists have engineered nanoparticles with desired characteristics, like shape, pore size, and surface properties, so that they can then be used as protectants or for precise and targeted delivery via adsorption, encapsulation, and/or conjugation of an active, such as a pesticide. Nanosensors and other field sensing devices can be used in detection and measurement of crop nutrient status, insects, and pathogens. Nanomaterial is used in plant protection through controlled release of encapsulated pesticide against pests and pathogens. Nanoparticles remain bound to the cell wall of pathogen and causes deformity due to high energy transfer leading to its death. Nanotechnology has tremendous potential in existing and future crop improvement programs through plant protection strategies against pests and diseases, in monitoring pathogens, and in detecting plant diseases. Researchers believe that agricultural production is one of the most important fields for application of nanotechnology.

Application of various nanoparticles for management of plant disease

Silver NPs

Silver (Ag) is known to have antimicrobial activity both in ionic or nanoparticle forms. The powerful antimicrobial effect of silver especially in unicellular microorganisms is believed to be brought about by enzyme inactivation (Kim et al., 1998). Nano silver whose antimicrobial effect has been tested against many disease causing pathogens of animals and plants is the most studied and utilized nanoparticle. Silver is also an excellent plant growth stimulator. Antifungal effect of nano silver colloids (average diameter of 1.5 nm) was studied against the powdery mildew pathogen of rose caused *by Sphaerotheca pannosa* var. *rosae.* Silver is now an accepted agrochemical replacement' and maximum no. of patents are filed for 'nano silver' for preservation and treatment of diseases in agriculture field (Sharon *et al*., 2010). Application of silver in management of plant diseases has been tested by (Jo *et al*., 2009) with reference to two fungal pathogens of cereals viz. *Bipolaris sorokiniana* (spot blotch of wheat) and *Magnaporthe grisea* (rice blast).

In vitro assays indicated that silver both in ionic and nanoparticle forms inhibited colony growth of both the pathogens but M. *grisea* was comparatively more sensitive to silver application. When tested in vivo with perennial ryegrass *(Lolium perenne*) silver ions and nanoparticles brought significant reduction in disease severity when applied 3 hours prior to pathogen inoculation. In another study, silver nano particles synthesized extracellularly by *Alternaria alternata* were found to cause significant enhancement in the antifungal action of the triazole fungicide fluconazole against *Candida albicans, Phoma glomerata* and *Trichoderma* sp. (Gajbhiye *et al*., 2009). However, no significant enhancement was observed with respect to the fungi *Phoma herbarum* and *Fusarium semitectum*. The effect of silver nanoparticles on plant pathogenic fungi and bacteria is given in table 1 and table 2 respectively.

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. Nano-copper was reported to be highly effective in controlling bacterial diseases viz. bacterial blight of rice (*Xanthomonas oryzae pv.oryzae*) and leaf spot of mung (*X. campestris pv. phaseoli*) (Gogoi *et al*., 2009). Copper nanoparticles in soda lime glass powder showed efficient antimicrobial activity against gram positive and gram negative bacteria and fungi.

Table 1. Effect of Ag nanoparticles on plant pathogenic fungi (Khan and Rizi, 2019)

NP size	Plant pathogen	Effect
20–30 nm	*Bipolaris sorokiniana, Magnaporthe grisea*	Inhibited colony formation (in vitro)
7-25 nm	*A. alternate, A. brassicicola, A. solani, B. cinerea, Cladosporium cucumerinum, Corynespora cassiicola, Cylindrocarpon destructans, Didymella bryoniae, F. oxysporum, Fusarium oxysporum* f. sp. *cucumerinum, F. Oxysporum* f. sp. *lycopersici, F. solani, Glomerella cingulata, Monospora scuscannonballus, Pythium aphanidermatum, Pythium spinosum, Stemphylium lycopersici*	Inhibition in the microbial growth
25 nm	*Golovinomyces cichoracearum, Sphaerotheca fusca*	Disrupted the transport systems and ion efflux
5–20 nm	*Trichosporonasahii*	Damaged the cell wall, cell membrane, mitochondria, chromatin, and ribosome
4-8nm	*R. solani, Sclerotium sclerotiorum, S. minor*	Separation of hyphal wall and collapse of hyphae

(Mondal and Mani, 2012) reported that copper nanoparticle effectively contolled *Xanthomonas axonopodis pv. pinicea*, causing blight in pomegranate. (Azam et al. 2012) reported the suppressive effect of CuO nanoparticle on *S. aureus, B. subtilis, P. aeruginosa* and *E. coli.* Effect of copper NPs on some plant pathogenic fungi is given in table 3.

Table 2. Effect of Ag nanoparticle on bacteria (Khan and Rizi, 2019)

NP size	Bacteria	Effect
35 nm	Bacteria	In vitro
35-550 nm	*Bacillus cereus, Listeria monocytogenes, Staphylococcus aureus, Escherichia coli, Salmonella*	Antibacterial Activity
13.8 ± 3.8 nm	*Staphylococcus aureus, E. coli, P. aeruginosa* and spore of *B. subtilis*	Bactericidal and sporocidic activity
300–800 nm	*E. coli, S. aureus, Proteus vulgaris*	Antibacterial Activity

Table 3: Effect of copper nanoparticles on plant pathogenic fungi (Khan and Rizi, 2019)

NP size	Plant pathogen	Effect
11-55 nm	*Phytophthora infestans*	Antifungal activity
3- 30 nm	*F. culmorum, F. oxysporum, F. equiseti*	Antifungal activity
3-10 nm	*F. oxysporum, C. lunata, A. Alternate, P. destructive*	Antifungal activity

Zinc nanoparticle

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

Table 4. Effect of Zn nanoparticles on plant pathogenic fungi (Khan and Rizi, 2019)

Nano particle	NP size (in nm)	Plant pathogen	Effect
Zn	57.72	*A. flavus, A. niger, . albicans*	Antifungal activity
Zn		*Aspergillus niger*	Antifungal activity
ZnO	20- 35	*Erythricium salmonicolor*	Antifungal activity
ZnO	70 ± 15 nm	*B. cinerea, Penicillium expansum*	Prevented the development of conidiophores and conidia

ZnO NPs have also been reported to cause antifungal activity against *Botrytis cinerea* and *Penicillium expansum* at 12 mmol l−1. The ZnO NPs at a concentration of 3 mmol l−1 significantly inhibited the growth of *B. cinerea* and *P. Expansum*, later was more sensitive to the treatment with ZnO NPs than *B. cinerea*. SEM images and Raman spectra indicated that ZnO NPs caused deformation in fungal hyphae and prevented the development of conidiophores and conidia (He *et al.*, 2011). More research outcome of Zn nanoparticles effect on plant pathogenic fungi and bacteria are shown in table 4 and table 5.

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 protonates and contributes to its positive charge (Phaechamud and Ritthidej, 2008). The inhibition mode of chitosan against fungi is defined by the following three mechanisms.

i) The positive charge of chitosan interacts with negatively charged phospholipid components of fungi membrane, which in turn alter cell permeability of plasma membrane and causes the leakage of cellular contents, which consequently leads to death of the cell (García- Rincón *et al*., 2010).

Table 5, Effect of Zn nanoparticle on Bacteria (Khan and Rizi, 2019)

Nano particle	NP size (nm)	Bacteria	Effect
ZnO	**13**	*E. coli, S. aureus*	Inhibited the microbial growth
Zn	**57-72**	*A. hydrophila, E. coli, S. aureus, E. faecalis, S. pyogenes, P. aeruginosa*	Antibacterial activity
Zn	<100 nm	*Campylobacter jejuni*	Change cell morphology to lethal
ZnO suspension	≤50 nm	*Salmonella typhimurium, Staphylococcus aureus*	Antibacterial (in vitro)
ZnO	**50-70**	*S. epidermis, S. pyogenes, Enterococcus faecalis, B. subtilis, E. coli*	Caused higher antibacterial activity on *S. aureus*
ZnO	**19.82**	Methicillin-susceptible *Staphylococcus aureus* (MSSA), methicillin-resistant *S. aureus* (MRSA), methicillin-resistant *S. epidermidis* (MRSE)	Inhibited bacterial growth of MSSA, MRSA and MRSE strains
ZnO	**60-100**	*Streptococcus agalactiae, S. aureus*	Bactericidal action

ii) Chitosan chelates with metal ions, which has been implicated as a possible mode of antimicrobial action (Rabea *et al*., 2003). On binding to trace elements, it interrupts normal growth of fungi by making the essential nutrients unavailable for its development (Roller and Covill, 1999).

iii) It is suggested that chitosan could penetrate fungal cell wall and bind to its DNA and inhibit the synthesis of mRNA and, in turn, affect the production of essential proteins and enzymes (Kong *et al*., 2010).

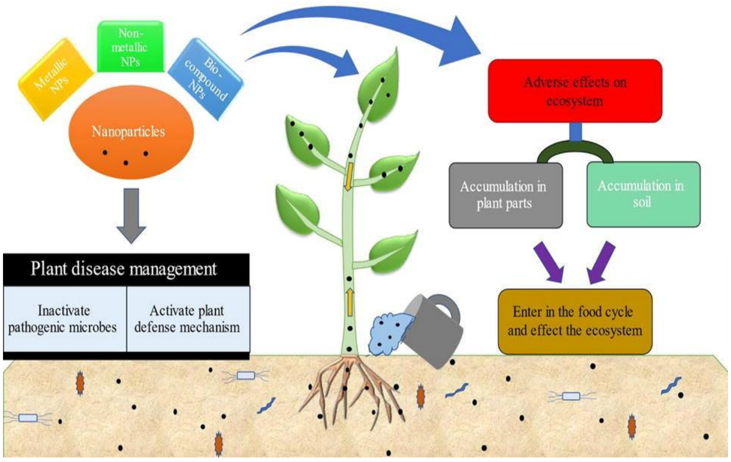

Fig 1: Mechanisim of nanoparticles in disease management (Rajani *et al.* 2022)

chitosan and chitosan nanoparticles are found to be more effective against plant pathogens like *Fusarium solani*. Inhibitory effect was also influenced by particle size and zeta potential of chitosan nanoparticles which plays a significant role in binding with negatively charged microbial membrane. The chitosan therefore could be formulated and applied as a natural antifungal agent in nanoparticles form to enhance its antifungal activity.

Conclusion

Nanotechnology in conjunction with biotechnology has significantly extended the applicability of nanomaterials in crop protection and production. Even though the toxicity of nanomaterials has not yet clearly understood, it plays a significant role in crop protection because of its unique physical and chemical properties. The application of nanomaterials is relatively new in the field of agriculture and it needs further research investigations. Barring the miniscule limitations, nanomaterials have a tremendous potential in making crop protection methodologies cost effective and environmental friendly.

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