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Efficacy of nanoparticles in plant disease control and their phytotoxicity

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Abstract: Every year approximately 20 to 40 percent crop yield lost due to disease which is caused by pathogenic fungi, bacteria, virus etc. the plant disease management totally dependent on chemical pesticides, herbicides which are harmful for human life and may be cause severe diseases. Nanotechnology play a significant role in agriculture, especially in disease resistance crop production, enhancement of quality of crop, high yield production, resistance from biotic as well as abiotic stresses. In this review, we have not included all the plant diseases but we have tried to include all the newest information related to role of nanotechnology in disease resistance in plants.

Keywords: : *Nano-sensors, Nano-emulsion, Carbon-nanotubes, Nanocomposites, Biosensor.*

In 1974, 'Nanotechnology' term was coined by Taniguchi. The science that deals with particles of nano size (10^{-9}). When we reduce material at nano scale, their physical and chemical properties are also change. Nanoparticles exhibit smaller size than bacterial cell. It may be less than size of influenza virus or tobacco mosaic virus. In future, Nanomaterials will reduce the use of chemical pesticides, herbicides etc. Today, loss of crop yield due to diseases is major concern of agriculture scientist and farmers. Most of the cultivars suffer from this problem. Nanocomposites (Bioengineered chitosan-iron nanocomposite, BNCs) plays significant role in crop yield and production of disease free crop plants. E.g. Inhibit rice crop against bacterial leaf blight (BLB) disease which is caused by *Xanthomonas oryzae* and improve crop nutrition. Nano-enabled agrochemicals are good alternatives of pest control methods. Ni-chitosan nanoconjugate play an important role as an antifungal agent for combating fusarium rot of wheat (Chouhan et al., 2022). Copper-based nanopestisides have efficiency for Solanum lycopersicum disease control (Liu et al., 2022). TiO_2 nanoparticles obtained by shell extract of *Caricaceae* used as antifungal (Saka et al., 2022). Sulfur nanoparticles (SNPs) enhance disease resistance in Tomatoes (Cao et al., 2021). Fluorescent silica nanoprobes used for diagnosis of plant disease (Banik and Sharma 2011). Another way, nanosensor paly significant role in disease management, crop production (Banerjee et al., 2021). However, unregulated use of nanoparticles causes several severe problems such as lack of soil fertility. In this review article, recent scenario of nanotechnology in plant disease management, application, synthesis of nanoparticles and phytotoxic effect of nanoparticles have been discussed. We try to include the use of various type of nanoparticles in plant disease control.

Synthesis of nanoparticles

Nanoparticles can be synthesized by various types of methods such as chemical, biological and physical method. Nanoparticles are eco-friendly, biodegradable and reproducible, have less toxicity, more effective, and have antimicrobial, antifungal, antibacterial as well as antiviral properties. These properties depend on method of synthesis (Fig.1). The green synthesis of nanoparticles from plants extract is a good approach. It is pollutant less, eco-friendly and production of harmful waste in low quantity (Banerjee et al., 2021). Recently, TiO_2 NPs synthesized by using *Carica papaya* (Saka et al., 2022). Microorganism such as fungi, bacteria known as "Bio factories" for nanoparticle production (Banik and Sharma 2011).

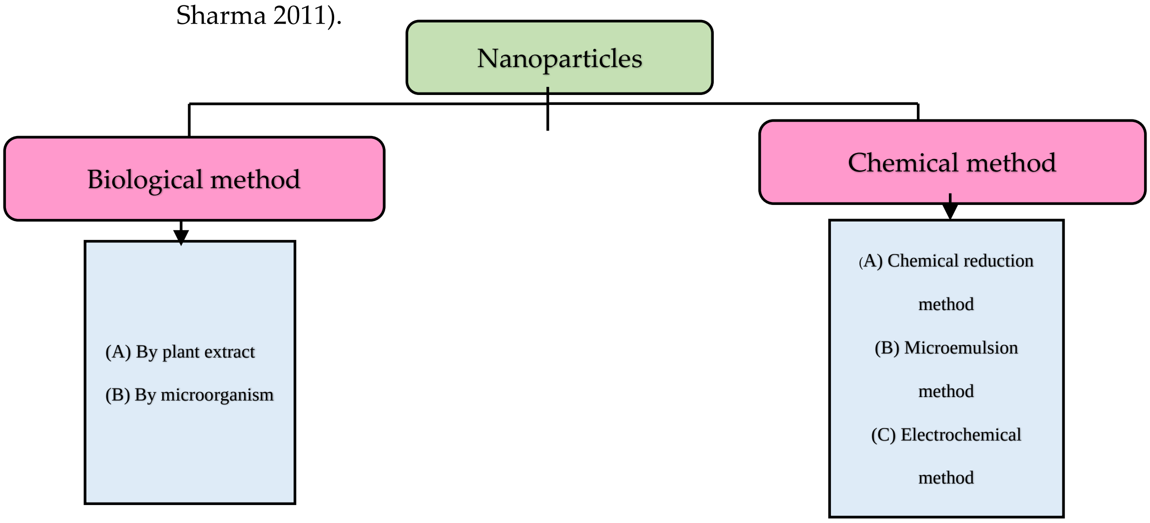

Figure 1. Different types of methods using for synthesis of nanoparticles (Khan and Rizvi, 2014**).**

Biological method

A. By plant extract

Recently, different types of approaches have been developed to synthesize nanoparticles from extract of plants (Makarov et al., 2014). Nanoparticles extracted from plants play more significant role in biological application. Copper nanoparticles (Cu NPs) can be biosynthesized by using *Magnolia* , *Syzygium aromaticum* and *Zinziber officinale* plants extract (Lee et al., 2011; Subhankari and Nayak, 2013). *Azadirachta indica* and *Citrus lemon* has been used in the synthesis of gold nanoparticles (AuNPs) and silver nanoparticles (AgNPs) (Table 1)..

B. By microorganism:

Some fungi are used in biosynthesis of silver nanoparticles (Ag NPs) such as *Verticillium sp, Phoma sp., Fusarium oxysporum, Phaenerochaete chrysosporium, Aspergilus flavus* (Sastry et al., 2003; Chen et al., 2003; Duran et al., 2005; Vigneshwaran et al., 2006). On the otherhand, some bacteria also used for silver nanoparticles (Ag NPs) biosynthesis e.g. *Clostridium versicolor, Bacillus subtilis* (Sanghi and Preetiverma, 2009; Saifuddin et al., 2009). Plant virus capsids are also used as bio-templates for nanoparticles synthesis e.g. Tobacco mosaic virus (TMV) used in the biosynthesis of Ag and Ni nanoparticles (Dujardin et al., 2003).

Table 1 Biosynthesized Nanparticles by using plant extract.

Bio-Synthesized Nanoparticles	Plant extract	Activity	Reference
Cu NPs	*Magnolia*, *Syzygium aromaticum* and *Zinziber officinale*	Antibacterial	(Lee et al., 2011; Subhankari and Nayak, 2013).
Au NPs	*Eclipta alba*, *Nepenthes khasiana* leaf	Antibacterial	(Ahmed et al., 2016; Ibrahim, 2015)
Ag NPs	*Azadirachta indica*, *Musa acuminate peel*	Antibacterial	(Vijayakumar et al., 2020; Bhau et al., 2015)
TiO_2 NPs	*Caricaceae*	Antifungal	(Saka et al., 2022)
Fe_2O_3 NPs	*Mentha spicata*	Antifungal	(Khan et al., 2022)

Chemical method:

It is a commercial method of synthesis of nanoparticles. There are many types of chemical methods which can be used in the synthesis of nanoparticles such as chemical reduction method, microemulsion method, electrochemical method etc (Khan and Rizvi, 2014). The chemical reduction method was firstly discovered by Michael Faraday in 1857. This method is useful for the synthesis of nanosized copper nanoparticles (Cu NPs) (Song et al., 2004). On the otherhand, the electrochemical method used as a metal nenoparticles. It is done by passing electric current between electrodes (Raja et al., 2008).

Nanotechnology in plant disease control

There are different types of pesticides and herbicides have been used for controlling disease for many years (Talibi et al., 2011). Recently, use of nanoparticles in controlling disease in plants, is very effective in future aspect. Nanotechnology have different ways of controlling plant disease. Nanotechnology have major advances in plant disease management. In future prospects, it will be used as a tool of diagnosis of disease caused by bacteria, virus, fungi, insects etc. It will be used as a tool of diagnosis of disease caused by bacteria, virus, fungi, insects etc. Biosensor as a nanoanalytical device (Kumar et al., 2022). Nanoparticles have potential to provide protection against bacteria, virus, insects and fungi. Ag, Cu, ZnO and TiO_2 have antibacterial and antifungal properties. Various types of nanoparticles are used in the management of disease in plants (Fig.2).

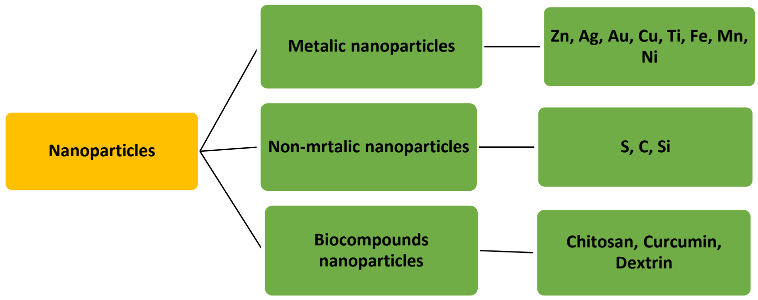

Figure 2. Types of nanoparticles synthesized for disease management.

Metallic NPs have more efficiency than non-metallic and bio compounds nanoparticles.

Zinc NPs

Zinc nanoparticles (Zn NPs) have low toxicity so it can be used in various disease management. It has viricidal, antibacterial properties (Abdelkhalek et al., 2020). It had been reported that Zinc nanoparticles (Zn NPs) effective against several pathogenic fungi *Mucor plumbeus, Botrytis cinerea, Penicillium expansum* (Banerjee et al., 2021).

Silver NPs

It is a most effective NP. It has antibacterial, antiviral, nematocidal and antifungal activity. It has been resulted that Silver nanoparticles (Ag NPs) have viricidal activity, it protects faba bean plant from BYMV (Rajani et al., 2022). Foliar application of Silver nanoparticles (Ag NPs) spray has efficacy to provide resistance against Tomato mosaic virus (ToMV) and Potato mosaic virus (PMV) (Noha et al., 2018). It has been also reported that AgNPs have viricidal activity against banana bunchy top virus (BBTV) (Mahfouze et al., 2020) when banana plants treated with AgNPs it reduces viral infection. It has antibacterial activity against *Staphylococcus aureus, E. coli, P. aeruginosa* and *Bacillus subtilis* (Brayskova et al., 2011). It shows antibactericidal and antimicrobial activity against *Staphylococcus aureus, E. coli,* and *P. aeruginosa* (Guzman et al., 2009).

Iron NPs

Iron nanoparticles (Fe_2O_3 NPs) have less toxic effect so it can be used in ordinary use (Abbaszadeh and Hejazi et al., 2019). It is a highly reactive and shows antiviral activity against tobacco mosaic virus (TMV) (Rajani et al., 2022). Khan et al., 2022 have been reported that Fe_2O_3 NPs have potential to inhibit the growth of *Phytophthora infestance*.

Nickel NPs

When cucumber plant treated with Ni NPs it shows antiviral activity and after the treatment leaf number and dry weight are also increases (Derbalah et al., 2019). It shows antimicrobial activity against Methicillin-resistant *Staphylococcus aureus* infection (Zarenezhad et al., 2022). Ni NPs have antimicrobial activity against *E. coli, Bacillus subtilis* which is synthesized by using plant extract of *Ocimum sanctum* (Pandian et al., 2016).

Titanium NPs

It has ability to oxidize biomolecules due to this it has high antiviral activity. It has been resulted that when *Viccia faba* L. treated with TiO2 NPs it shows reduction in viral infection caused by broad bean stain virus (BBSV) (Elsharkawy et al., 2019).

Gold NPs

Due to their physiochemical properties it shows great antimicrobial activity. Au NPs have been used as biosensor components for diagnosis of plant disease (Biju, 2014). Au NPs play a significant role for detection of pathogen of karnal bunt disease of wheat by surface plasmone resonance (SPR) method and late blight of potato and tomato (caused by *Phytophthora infestance*) by using Au NPs based lateral flow biosensor (Singh et al., 2010; Zhan et al., 2018). Au NPs have been used as the detection label (Lee et al., 2021).

Copper NPs

It has excellence potential of plant disease control and antimicrobial activity. Fungicides developed by Cu NPs has potential to inhibit growth of *Phytophthora infestance* in tomato plant (Giannousi et al., 2013). Bordeax mixture produced by Cu NPs suppress the *Xiphinema index* (Elmer et al., 2018). (Varympopi et al., 2022) reported that Cu NPs shows antibacterial activity against *Xanthomonas compestris pv. vesicatoria,* in Tomato. CuO NPs have most effective antifungal activity against root rot disease in cucumber which is caused by *Phomopsis sclerotioides* (Kamel et al., 2022).

Mg NPs

It shows effective antibacterial activity against Gram-positive and Gram-negative bacteria. It had been demonstrated that MgO NPs shows antibacterial activity against *Ralstonia solanacearum* (Imada et al., 2016). Recently, some studies hypothesized that MgO NPs has antibacterial activity against bacterial wilt in tomato caused by *Ralstonia solanacearum.*

Table 2 Nanoparticles in bacterial disease management.

Nanoparticles	Activity	Effect against	Reference
ZnO NPs	Antibacterial	*P. aeruginosa*	(Jayaseelan et al., 2012).
Ag NPs	Antibacterial	*Staphylococcus aureus,* *E. coli,* *P. aeruginosa* *Bacillus subtilis*	(Brayskova et al., 2011).
		Fusarium oxysporum	(Birla et al., 2013)
CuO NPs	Antibacterial	*Staphylococcus aureus,* *E. coli,* *P. aeruginosa* *Bacillus subtilis*	(Azam et al., 2012).
Ag NPs	Antimicrobial, Antibactericidal	*Staphylococcus aureus,* *E. coli,* *P. aeruginosa*	(Guzman et al., 2009).

Table 3. Nanoparticles against pathogenic fungi.

Nanoparticles	Pathogenic fungi	Disease	Reference
$CuSO_4$, $Na_2B_4O_7$	*Uromyces viciae-fabae*	Rust disease of field peas	(Singh et al., 2013).
Mn and Zn NPs	*Pythium spp., Fusarium spp.*	Damping off and charcoal rot diseases in sunflower	(Abd El-Hai et al., 2009).
ZnO NPs	*Botrytis cinerea,*	Grey mould of strawberry	(Khan, A.R and Rizvi T.F., 2014)
	Penicillium expansum	Blue mold disease in fruits and vegetables	

Phytotoxic effect of nanoparticles

There are many studies on interaction between nanoparticles and plant which reported their negative as well as positive impacts on plant. It has been reported that nanoparticles show toxic effect on plants (Table 3). Phytotoxicity depends upon physicochemical property of plant. Konotop et al., 2014 observed that colloidal solution of nanoparticles supress the growth of root of *Allium cepa* (L.). However, some metal-nanoparticles show more toxic than other such as Cu NPs more toxicity than Fe NPs (Cu>Zn>Ag>Fe). CuO NPs inhibit root and shoot elongation of *Hordeum sativum* (Rajput et al., 2018). Nano Zn and ZnO NPs have inhibitory effect on seed germination in ryegrass and corn, respectively. It has been reported that Ag NPs damage the cells of root tip of Allium cepa (Parthasarathi, 2011).

Table 4 Phytotoxic effect of various type of nanoparticles on plants

Nanoparticles	Plant species	Toxic effect	Reference
CuO NPs	*Hordeum sativum,*	Inhibition of shoot and root elongation	(Rajput et al., 2018)
Ag NPs	Tobacco	Retardation of plant growth and crop yield	(Liu et al., 2016)
Fe_2O_3 NPs	*Lactuca sativa*	Retardness in root elongation	(Liu et al., 2016)
ZnO NPs	*Allium cepa*	Effect on cell-cycle progresion	(Sun et al., 2019)
TiO_2 NPs	*Lactuca sativa*	Decrease in CO_2 fixation	(Madanayake and Adassooria, 2020)

Future aspects of nanotechnology in plant disease control

To provide necessary amount of food for this fast-growing world, we are Using so many chemicals as fungicides, pesticides and insecticides which cause damage to living organisms. There is a need to adapt Chemical less farming. The best way for chemical less disease management is Nanotechnology. Which plays crucial role in current agriculture practices like high yield crops, hormone delivery, seed germination, transfer of desired gene nanobarrcoding, decrease the usage of chemical fertilizer. Some of the researches on metal nanoparticles shows antiviral, antifungal and antibacterial properties. Metal nanoparticles like Silver (Ag), Copper (Cu), Zinc oxide (ZnO) and Titanium oxide (TiO) Are used to supress the Activities of paint pathogens like *Alternaria aleternata*, *Sclerotinia sclerotiorum*, *Macrophomina phaseolina* etc (Lamsal et al., 2011). In the Silver, Copper, Zinc and Titanium, Silver nanoparticles showed hopefully results against Powdery mildew, late blight in tomato by it's host defense mechanism. Silver nanoparticles shows Activities like disturbing cell membrane of pathogen, prevent H+ ATPase activity and blockage of nutrient flow. Silver nanoparticles (AgNPs) are considered as an effective tool for crop disease management. Powdery Mildew is one of such disease which is found in the plant family of cucurbits by fungi. As the studies proved that silver ions are highly reactive in nature. They can decrease the metabolic activities of the bacteria by damaging the bacterial

DNA. The activity of silver nanoparticles was tested against the fungi Ascomycetous which resulted in the 75% inhibition of late blight disease in plants and also experiments concluded that Ag nanoparticles with silica can damage many bacteria like *Pseudomonas syringae* and showed 25% disease resistance. Chitosan is the another widely used nanoparticles which showed antimicrobial activity and prevent viral infection like tobacco mosaic virus, bean mild mosaic virus, tobacco necrosis virus. Chitosan nanoparticles inhibit microbial activities by synthesizing mRNA and protein and distorting the cell membrane of pathogen resulting in control of root rot in tomato and bunch rot in grapes. Some experiments are going on the nanoparticles like TiO2, MnO, CuO and so on which are estimated to show hopeful results to prevent disease caused by many bacteria, fungi and viruses. By the successful application of these methods we can prevent many diseases like powdery milder, root rot, late blight, bunch rot and so on (Elmer and White 2018).

Conclusion

From this review this is concluded that nanoparticles (NP) play a significant role in control of plant disease. Nanoparticles (NP) have antibacterial, antiviral and antifungal properties against plant pathogens which causes various types of disease in plants. These nanoparticles are synthesized from plants extract and by microorganisms. These have potential tool of detect the plant disease. Nanoparticles (NPs) act as nano-herbicides, nanopesticides, nano-fungicides and play a significant role in control of plant disease. Nanoparticles provide unprecedented advantage in the field of plant disease management. In future it will be alternative of fungicides, pesticides and herbicides and become a sustainable tool in agriculture field to control management of plant disease. In another way, nanoparticles also play a significant role in improving crop yields and delivery of plant hormones etc. however, due to inappropriate use of nanoparticles have some phytotoxic effects which retards the growth of plant and also effects physiology of plants.

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Conflict of interest

No conflict of interest.

Authors contribution

Yashwant Sompura provide general concept of manuscript. Yashwant Sompura, Vanshika Sharma, Chayadevi H, Maruthi G R, Jeenat Banu, Tansukh Barupal and Shyam Sunder Meena wrote the manuscript. All authors read and approved it for publication.

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