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Review Article

Bio Nanoparticles as Antimicrobial Agents

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Abstract: One such novel technology is nanotechnology, which has been revolutionized in health care, textile, materials, information and communication technology, and energy sectors too. There are many ways depicted in various literatures to synthesize silver nanoparticles. These include physical, chemical, and biological methods. The physical and chemical methods are numerous in number, and many of these methods are expensive or use toxic substances which are major factors that make them "not so favored" methods of synthesis. An alternate, feasible method to synthesize silver nanoparticles is to employ biological methods of using microbes and plants. Biotechnology has considered a safe agricultural tool to enhance crop protection, subsequently to produce more agricultural products, improve food process, nutritional value, and better flavor. Side by side it has detrimental ecological consequences such as spreading genetically engineered genes to indigenous plants, elevated toxicity, which may transmit through food chain, disrupting nature's system of pest control, developing new weeds or virus strains, biodiversity loss, and insecticidal resistance (Goswami *et al.*, 2010). Hence, it is necessary to bring forth new innovative technology/methods to overcome the above mentioned problems. The potential application of biogenic nanoparticles as antimicrobial agents will be also reviewed. The mechanism of action of nanoparticles as bactericidal and antifungal agents will be highlighted in this chapter.
Keywords: Nanoparticle, Silver, Gold, Chitin.

INTRODUCTION

Nanotechnology research is appearing as a cutting-edge technology which is rap idly growing field in physics, chemistry, biology, materials science, and medicine (Narayanan and Sakthivel 2010) with its application in science and technology for the purpose of manufacturing new materials at the nanoscale level (Albrecht *et al.*, 2006). Their extremely small size and large surface area relative to their volume make them useful for applications in various fields, such as antibacterials (Souza *et al.*, 2004), therapeutics (Wang *et al.*, 2011), cosmetics, microelectronics (Tomsic *et al.*, 2009), and conductive links and adhesives (Akaighe *et al.*, 2011). Different types of nanomaterials like copper, zinc, titanium (Retchkiman Schabes *et al.*, 2006), magnesium, gold (Gu *et al.*, 2003), alginate (Ahmad *et al.*, 2005), and silver are synthesized. Silver nanoparticles (Ag NPs) have proved to be most effective as they have good antimicrobial efficacy against bacteria, viruses, and other eukaryotic microorganisms (Gong *et al.*, 2007). Silver nanoparticles (Ag NPs) are commonly synthesized by chemical reduction (Peterson *et al.*, 2007), irradiation (Shao and Yao 2006), and laser ablation (Tsuji *et al.*, 2002), which are low yield, energy intensive, difficult to scale up, often producing high levels of hazardous wastes, and may require the use of organic solvents and toxic reducing agents (Wani *et al.*, 2013). Biosynthesis of nanoparticles is a kind of bottom-up approach where the main reaction occurring is reduction/oxidation. The microbial enzymes or the plant phyto chemicals with antioxidant or reducing properties are usually responsible for reduction of metal compounds into their respective nanoparticles. In recent times biosynthetic methods employ either microorganisms such as bacteria (Joerger *et al.*, 2000) or fungus (Shankar *et al.*, 2003a) or plants extract (Shankar *et al.*, 2003b; Chandran *et al.*, 2006; Gardea Torresdey *et al.*, 2002). The green synthesis of nanoparticles has gained significant importance in recent years and has become one of the most preferred methods for obtaining biocompatible, cost effective, clean, nontoxic, easily scaled up for largescale synthesis, and ecofriendly size-controlled nanoparticles (Dobrucka and Dlugaszewska 2015).

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Many countries are now being switching over from chemical based agriculture to green agriculture, where the utilization of biopesticides and also biological nano materials has a lots of role to play in pest control (Chakravarthy *et al.*, 2011, 2012a, b; Chandra *et al*., 2013; Christofoli *et al.*, 2015; De *et al*., 2014; Debnath *et al*., 2011; Christofoli et al. 2015). Meliaceae (*Azadirachta indica* A. Juss), Annonaceae (*Asimina triloba*, *Annona muricata*, and *Annona squamosa*), Compositae [*Tanacetum cinerariifolium* (Trev.) Schultz Bip., *Pyrethrum cinerariifolium* (Trev.), and *Chrysanthemum cinerariifolium* (Trev.) Vis.], Leguminosae [*Pongamia pinnata* (L.) Pierre.] Have been utilized worldwide for various pestiferous insects management.

Nanotechnology has revolutionized the whole world with marked advancements in many arenas of sciences like biotechnology, bioengineering, agriculture as well as analytical chemistry and their use in crop protection is just in its infancy (Arumugam *et al*., 2015). Nanomaterials measure between approximately 1 and 100 nm. Over many decades, nanotechnology and nanomaterials have been employed successful and safely in various fields like medicine, environmental science, and food processing. However, the use of nanomaterials in agriculture, especially for plant protection and production, is an underexplored research area (Barik *et al*., 2008). It has been used as conductors and semiconductors, medical devices, sensors, coatings, catalytic agents, and as pesticides (Bhattacharyya *et al*., 2010).

The medical properties of silver have been known for over 2000 years. Since the nineteenth century, silver-based compounds have been used in many antimicrobial applications. Silver nanoparticles are being used as antimicrobial agents in many public places, such as railway stations and elevators in China, and they are said to show good antimicrobial action. It is a well-known fact that silver ions and silver-based compounds are highly toxic to microorganisms which include 16 major species of bacteria.

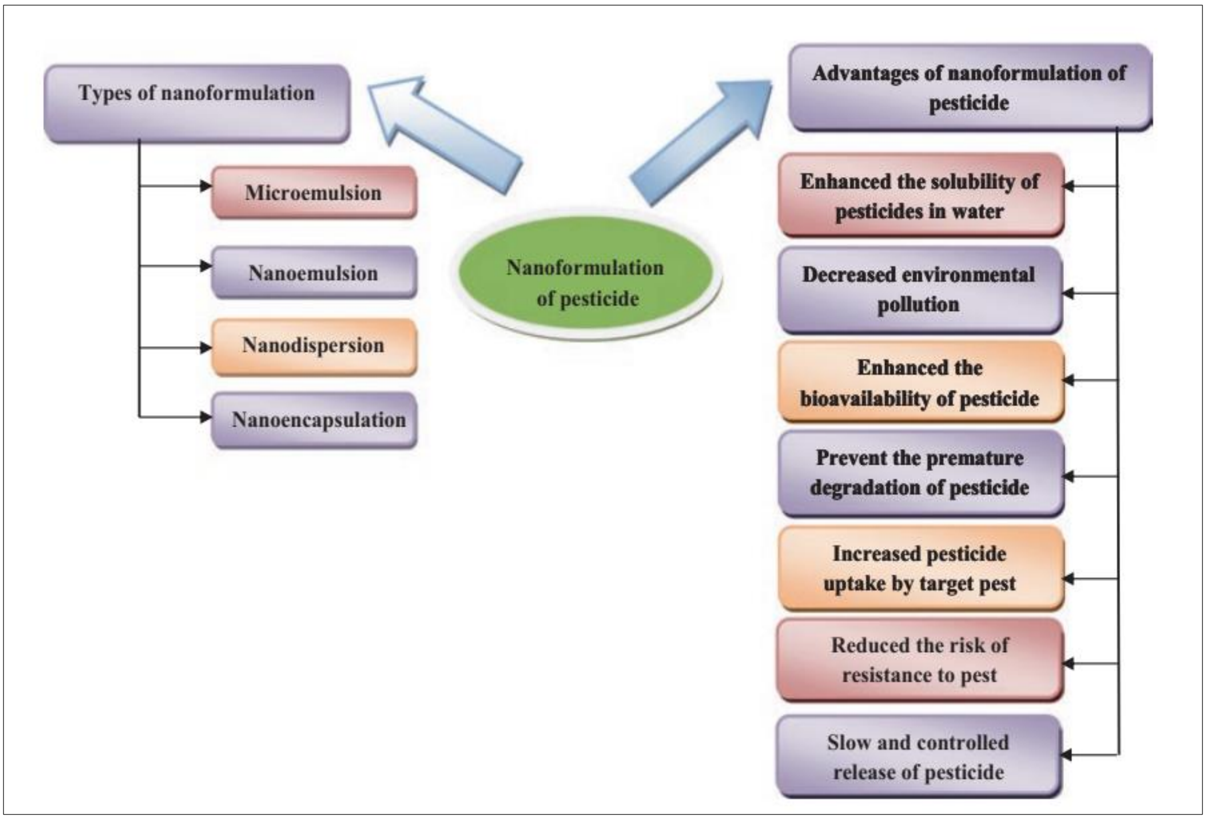
Synthesis

Various nanoparticles (aluminum, titanium, zinc, etc.) are utilized for the synthesis of pesticides. Barik *et al*., (2008) used nanosilica to control pests. The effects of nanoparticles like aluminum oxide, zinc oxide, titanium dioxide, and silver were studied against insect pests (Goswami *et al*., 2010). Sarlak *et al.*, (2014) encapsulated zineb and mancozeb pesticides into multiwall carbon nanotubes graft poly (citric acid) (MWCNTg PCA) hybrid material. This encapsulation converts bulk pesticide into pesticide nanoparticles and increases their solubility in water. Carbendazim and propiconazole pesticides were encapsulated into graphene graft poly (citric acid) (GOgPCA) hybrid materials and show toxic effect on *Rhizoctonia solani* fungi (Sarlak and Poorhadi 2016).

Formulation

The conventional pesticide formulations include wettable powder (crushed powder pesticide), oil dispersions in the form of soluble, emulsifiable suspension concentrates (Ramadass and Thiagarajan 2017). Conventional pesticide formulation has several disadvantages like the use of harmful solvents, reduced dispersion rate, environmental leaching through the dust and spray drift (Zhao *et al*., 2018). In recent years, nanotechnology is being used to develop new pesticide formulations that remain active and stable in sun, heat, and rain. Nano formulation of pesticide enhances the solubility of poorly water-soluble pesticides, has slow and controlled pesticide release, prevents premature degradation, enhances bioavailability, reduces the risk of pest resistance, increases uptake by target pest, and decreases environ mental pollution (Balaure *et al*., 2017)

Microemulsion, nano emulsion, and nano dispersion are novel types of pesticide nano formulations. Microemulsions are droplets of size less than 50 nm that are thermodynamically stable water based formulations consisting of the dis solved active ingredient in oil, surfactant, and cosurfactant. Microemulsions contain a high amount of surfactant. Nano emulsions are emulsions of droplet size 20–200 nm and with dimensions that overlap with microemulsions. Nano emulsions are meta stable possess lower amount of surfactants (5–10%) than microemulsions (20%) (Kah *et al*., 2013). Oil in water nano emulsion is prepared in multistep at 25 °C (Wang *et al*., 2007). Song *et al*., (2009) synthesized nano emulsions by adding water to the triazophos mixture and surfactant at 25 °C. Nano emulsion protects triazophos from hydrolysis and remains stable in neutral and acidic solutions. Nano dispersions are nanocrystals dispersed in liquid medium. The nano dispersion enhances the solubility of poorly water-soluble active ingredients (Kah *et al*., 2013). A solid nano dispersion of lambdacyhalothrin was synthesized by melt emulsification and highspeed shearing. The solid nano dispersion method increases the stability and bioavailability of pesticide (Cui *et al*., 2015). The solid nano dispersion of emamectin benzoate was synthesized based on solidifying nano emulsion method. Nano dispersion of pesticide emamectin benzoate enhances its bioavailability, thus decreasing the pesticide pollution (Yang *et al.*, 2017). A nano formulation of mancozeb and acephate pesticides was synthesized by encapsulated complex using poly propylene glycol. This nano formulation is ecofriendly in nature and creates less environmental impact (Venugopal and Sainadh 2016; Venugopal and Sainadh).



Types and advantages of nano formulation of pesticide. (From Balaure *et al.*, 2017)

A sodium alginate chitosan based nano etofenprox formulation was synthesized by entrapping pesticides in chitosan and sodium alginate matrix. The pesticide nano formulation was developed against *Spodoptera litura* and found more toxic to the pests compared to commercial pesticide (Ali *et al*., 2017)

Use of Silver Nanoparticles

Silver nanoparticles find use in many fields, and the important applications include their use as catalysts, in textile engineering, in optics, in electronics, as optical sensors of zeptomole (10–21) concentration, and most importantly in the clinical area as bactericidal as well as therapeutic agents. Silver ions are applied for dental resin composites formulation; for coatings of medical devices; as a bactericidal coating in water filters; as an antimicrobial agent in air sanitizer sprays, socks, pillows, respirators, wet wipes, soaps, detergents, shampoos, toothpastes, washing machines, and many consumer products; as cementing agent for bone; and in several wound dressings to name a few. Though there are various benefits of silver nanoparticles, there is also the problem of nanotoxicity of silver. There are various literatures that suggest that the nanoparticles can cause various environmental and health problems, though there is a need for more studies to be conducted to conclude that there is a real problem with silver nano particles. K. Biswas and S. N. Sinha123

Bio Nanoparticles as Antimicrobial Agents
Application of Nanoparticles in Agriculture

DNA tagged gold nano, DNA tagged CdS, nano Ag, and nano TiO2 were developed by Chandrashekharaiah *et al*., (2018) and were tested against third, fourth, and fifth stadium larvae of Spodoptera litura. The results indicated that DNA tagged gold nano showed 30.50, 57.50, and 75.00% mortality, respectively, on third, fourth, and fifth instar larvae of *S. litura*, CdS nanoparticle caused highest larval mortality of 21.41–93.79% at 150 and 2400 ppm, respectively, in *S. litura*. The nanoTiO2 showed maximum of 73.79% *S. litura* larval mortality at 2400 ppm and the least was 18.50% at 150 ppm. Nano Ag caused maximum 56.89% *S. litura* mortality at 2400 ppm followed by 46.89 and 33.44% mortality at 1200 and 600 ppm, respectively. Previously, Chakravarthy *et al*., (2014) also utilized DNA tagged nanogold for *S. litura* management. Further, they developed nanoparticles coated with tebufenozide and halofenozide (ecdysteroid analogues) and tested against *Corcyra cephalonica* (Stainton) (Lepidoptera: Pyralidae). Previously, an experiment in vivo was conducted in the Egyptian cotton leaf worm *Spodoptera littoralis* (Boisd.) (Lepidoptera: Noctuidae) using nanoparticles of novaluron. Results reveal that the toxicity of nanoparticles of novaluron resembled that of the commercial formulation (Lin and Xing 2008). Polyethylene glycolcoated nanoparticles amended with garlic essential oil, against mature *Tribolium castaneum* (Herbst) demonstrated the insecticidal activity of the bio nano polyethylene glycol coated nanoparticles. Likewise, Nano Diatomaceous Earth (NanoDE) in comparison with natural Diatomaceous Earth (DE) showed increased larval mortality with the increase of NanoDE and DE against *Tribolium confusum* (Jacquelin) and *T. castaneum* under laboratory and stored conditions. Larvae of T. confusum was found to be more susceptible to the treatments than the larvae of *T. castaneum*, Nano DE was more effective than natural DE. The fecundity of insects investigated was highly affected with DE and NanoDE. Further, Nano DE strongly suppressed the deposited eggs by *T. confusum* over *T. castaneum* (3.8 ± 1.5, 17.8 ± 7.5, and 26.6 ± 3.5 eggs/female) and (13.8 ± 1.5, 37.8 ± 7.5, and 46.6 ± 3.5 eggs/female) after 20, 90, and 120 storage interval days, respectively. The persistent effect of nanoparticles displayed a number of different modes of action by reducing adult emergence, oviposition, and infestation. The results revealed that DE nanoparticles may be exploited as an important tool in pest management programs of *T. confusum* and *T. castaneum* (Sankar and Abideen 2015). Yang *et al*., (2009) argue that nanoparticles coated with garlic oil then combined with polyethylene glycol (PEG) using melt dispersion method. This nanomaterial caused 100% mortality to *T. castaneum* after 5 months. It was chiefly because of continuous release of the active components from nanoparticles. During the same period control test materials caused only 11% mortality.

Green synthesis of silver nanoparticles was reported using *Euphorbia prostrata* and used to check the adult of *Sitophilus oryzae* (Shiva and Kumar 2015). Silver and lead nanoparticles synthesized utilizing mangrove plants extract of *Avicennia marina* showed pesticidal activity against S. oryzae and the results revealed that treatment caused 100% mortality within 4 days of treatment (Stadler *et al*., 2010). K. Biswas and S. N. Sinha125 of gram-negative bacteria. The phospho tyrosine profile of bacterial peptides is altered by the nanoparticles. It was found that the nanoparticles dephosphorylate the peptide substrates on tyrosine residues, which leads to signal transduction inhibition and thus the stoppage of growth. It is, however, necessary to understand that further research is required on the topic to thoroughly establish the claims (Shrivastava *et al.*, 2007).

Crop Protection

The global population growth rate has increased from 2.1 billion to 6.1 billion from 1950 to 2000, which has raised the threat to global food security (Carvalho 2006). In the previous few decades, the global population growth rate remained at 1.24% per year but is annually growing by 1.10% since 2017. Although the growth rate of the population showed a descending trend, an additional 83 million people are added annually. It is estimated that the world's population will increase by slightly more than 1 billion people over the next 13 years, reaching 8.6 billion in 2030, 9.8 billion in 2050, and 11.2 billion by 2100 (Department of Economic and Social Affairs, Population Division 2017). The world's population is expanding at a faster rate than the planted area of the globe, resulting in unbalance in food demand and supply (Funk and Brown 2009). Implementation of high yielding varieties, fertilizers, synthetic pesticides, hybrid seeds, and transgenic crops is trying to solve the global issue of food security. However, our enhanced dependency on these alternatives has adversely affected the global food supply and caused problems of health risk to nontarget organisms like humans, beneficial microorganisms, beneficial insects, birds, and earthworms, biomagnification, development of pesticide resistance and revival of pesticide resistant pest populations, micronutrient imbalance, nitrate pollution, and eutrophication by using excessive chemical fertilizers. Genetically modified (GM) crops have the potential to reduce the hazardous effects of the agrochemicals (Tabashnik *et al*., 2013; Pandey *et al*., 2016). However, this approach is also failing as the pests are acquiring resistance against GM crops. It is illustrated that 5 population types, out of 13 major populations of pests, have evolved resistance against Bt crops in the field, whereas in 2005 only one pest species was resistant. Therefore, newer approaches are required for effective crop protection. The effective measures of crop protection would pave the solution to global food security issue. Use of nano pesticides in crop protection is one such approach that could augment the effectiveness of crop protection program.

Pest Management

In a report of Food and Agriculture Organization of the United Nations (FAO), the average pre and postharvest losses were estimated around 20–40% caused by pests (weeds, insects, rodents, and diseases) (Savary *et al*., 2012). Insect pests cause great damage in subtropical and tropical regions. Weeds and plant disease damage crops mostly in the temperate climates. Due to the inefficiency of crop protection methods, the highest crop losses occur in Central Africa, which could be 52% of the potential yield (Organization for Economic Cooperation and Development 2010). A study done by the Associated Chambers of Commerce and Industry of India reported worth $500 billion of crop loss by pest and disease infestation, and because of this at least 200 million people go to bed on an empty stomach each night in India (Food Quality and Nutrition 2015). There are several ways to reduce crop damages and to control pests. The methods include biological, cultural, mechanical, and chemical controls. The sustainable crop protection requires the concept of integrated pest management (IPM) in which all suitable methods are used in such a way that the population of damaging organisms remain below the economic injury levels without adversely affecting the ecological balance and the environmental health.

Pesticide falls under the chemical controls for crop protection. Worldwide, about three million metric tons of pesticides are applied annually, holding the value of around $40 billion (Pimentel 2009). However, pesticide usage has a series of major drawbacks.

Nontargeted useful species like insect pollinators, birds, or natural enemies of pests can be threatened by the application of nonselective pesticides. In addition, the deleterious effect of pesticides is a risk to humans and other life forms, ground and surface water contamination and development of pesticide resistance. Moreover, climate change could affect the occurrence and distribution of insect pests and diseases that may cause unpredictable negative impacts on agricultural production worldwide (FAO 2016). Ghormade *et al*., (2011) estimated that up to 90% of the applied pesticides are lost during and after application. However, nano pesticide could remove the drawbacks associated with the traditional pesticide. Nano pesticides have several advantages over chemical pesticides such as increased effectiveness, durability, and a reduction in the amounts of active ingredients (AIs) that are being used in protecting crops against diseases, insects, and weeds (Kah *et al.*, 2013). Several formulations of nano pesticides have been proposed for insecticidal compounds.

Disease Management

Plant pathogens are responsible for huge economic losses in any agriculture-based economies. Nanoparticles have attracted a great attention in plant disease management. Nanoparticles of metals and metal oxides were found promising against serious plant pathogens. Further, the polymers and Ag based nanocomposites were found to be the best alternatives to commercial pesticides.

Plant Disease Management

There is a drastic increase in chemical pesticide usage for control of plant diseases to gain higher productivity and to prevent postharvest losses in economically important crops. Indiscriminate use of these toxic chemicals has led to contamination of soil, water, and air with hazardous chemicals, and residues of these chemicals also cause serious health hazards (Akoto *et al*., 2014).

8.3.1Biopesticides

World Agriculture suffers severely every year due to damages caused by plant diseases. The use of chemical fungicides, virucides, bactericides, and other chemicals was well emphasized during the past decades. In the recent years, several effective fungicides were banned in many countries due to their negative impact on human health and environment. Moreover, development of resistance to fungicides by certain group of plant pathogens has been reported, and use of one fungicide may lead to severe outbreak of another disease (Prakasam *et al*., 1998). So, in recent years, the use of biocontrol agents and plant products (botanicals) for managing the plant dis eases is given importance and several commercial formulations are being developed and successfully used throughout the world. The fungal biocontrol agents, viz., *Trichoderma viride* and *T. harzianum*, and bacterial biocontrol agents, viz., *Pseudomonas fluorescens* and *Bacillus subtilis* are commonly used against plant diseases management in several crops and improve the growth and yield.

Application of biopesticides for disease management is gaining momentum with the availability of many biocidal compounds from plants, microbes, and other bio originated materials. These biomaterials can be exploited in management of plant diseases besides enhancing the plant defense system to overcome biotic and abiotic stresses. One such compound is chitosan, a polysaccharide, naturally occurring in cell walls of some fungi and produced by deacetylation of chitin and known for its antimicrobial activity. Chitosan acts as an immune stimulant, helps in enhancing the innate immune response of the plant to biotic stresses. Chitosan active biopesticides represent a new tier of cost-effective biological control systems which can be used in agricultural and horticultural crops. Chitosan enhances plant growth by improving plant nutrient uptake and boosts plant vigour.

8.3.2 Nano Biopesticides

Nanoparticles of chitosan exhibit unique physical and chemical characteristics and have enormous potential in biomedical applications such as drug carrier and as crop protection agents in agriculture. The bioactivity of chitosan based nano materials varies with molecular weight, polymerization, and degree of deacetylation of chitin (Huang *et al*., 2009; Choudhary *et al*., 2017). Chitosan nanoparticles (ChNP) exhibit higher antibacterial activity compared to conventional chitosan formulations (Sekhar *et al*., 2013). Silver metal ion loaded ChNPs show enhanced antibacterial properties with a low minimum inhibiting concentration (MIC) of 3 μg/ml toward Escherichia coli and 6 μg/ml toward Staphylococcus aureus (Du *et al*., 2008). In another study, chitosan nanoparticles showed impaired growth of microsclerotia and reduced mycelial growth of *Macrophomina phaseolina* and *Fusarium oxysporum* in comparison with normal chitosan (Sekhar *et al*., 2013). Similarly, when Cu chitosan nanocomposites were used for control of post flowering stalk rot (PFSR) disease of maize caused by *F. verticillioides*, a minimum concentration of 0.06% caused 34% less disease incidence in comparison with untreated control under field conditions (Choudhary *et al.*, 2017).

Nowadays, green synthesized metal nanomaterials are gaining importance in disease management. Fungi are one of the well-studied biological systems exploited for the synthesis of metal nanoparticles due to their ability to tolerate high metal concentrations and to bioaccumulate them (Prasad *et al*., 2016). When compared to bacteria and actinomycetes, fungi can secrete more enzymes required for bio synthe sis of nanoparticles (Bhattacharyya *et al*., 2016; Kamaraj *et al*., 2018). *Trichoderma* is a versatile fungus known to have the ability to control numerous foliar, root, and fruit pathogens and even invertebrate parasites such as nematodes. *Trichoderma* has been studied for its ability to biosynthesize metal nanoparticles and act as an efficient biocatalyst (Mishra *et al.*, 2014a). In a study performed by Kamaraj *et al.*, 2018, titanium dioxide nanoparticles (TDNPs) were synthesized using *T. viride* and tested for their bio efficacy against larvae and pupae of *Helicoverpa armigera*. TDNPs showed 100% larval mortality in I, II and III instar larvae of *H. armigera* at a concentration of 100 ppm when compared to fungal cell free extract (16–52%), TiO (OH) (2–8%), and chemically synthesized TiO (33–74%). Highest antifeedant activity (100%) and pupal mortality (100%) were observed when treated with *Trichoderma* biosynthesized TDNPs in comparison with fungal cell free extract, TiO $(OH)_2$, and azadirachtin. Similarly, synthesis of metal detoxifying enzymes (βglycosidase and carboxyl esterase) by *H. armigera* larval gut was significantly less when treated with *Trichoderma* biosynthesized TDNPs (Kamaraj *et al.*, 2018). Another study was performed by Mishra *et al.*, (2014a) with *T. viride* and *Hypocrea lixii* for biosynthesis of gold nanoparticles and testing for their antimicrobial activity. Rapid biosynthesis of gold nanoparticles took place within 10 min at a reaction temperature of 30 °C using cell free extract of *T. viride*, whereas no synthesis was observed with cell free extract of *H. lixii* at similar temperature. Biogenic gold nanoparticles exhibited improved antimicrobial activity and inhibited the growth of *E. coli*, *Shigella sonnei*, and *Pseudomonas syringae* up to 53%, 47%, and 55%, respectively. Silver nanoparticles (AgNP) synthesized extracellularly using bacterium, *Serratia* sp. BHUS4, showed inhibitory effect on fungus, *Bipolaris sorokiniana*. Biogenic AgNPs showed 100% inhibition of conidial germination on media as a well as on wheat leaves artificially inoculated fungal conidia. Similar effect was observed under glass house conditions where fungus *B. sorokiniana* development was completely inhibited on wheat plants besides improving the plant growth (Mishra *et al.*, 2014b).

Using botanicals is one of the ecofriendly managements of plant diseases, and their nano formulations are much more effective than conventional botanical pesticides. Nano emulsions of many plant essential oils were studied for their efficacy against plant pathogens. Neem and citronella EO based nano emulsions exhibited high antifungal activity against *Rhizoctonia solani* and *Sclerotium rolfsii*. In vitro experiments revealed that both neem and citronella based nano emulsions exhibited high toxicity toward both the pathogens' low ED 50 values (Ali *et al.*, 2017). In another study, the fungicidal activity of EO combination of clove and lemon grass was enhanced when developed into nano emulsions. These nano emulsions showed 1.2–1.7fold higher fungistatic effect against *F. oxysporum* f. sp. *lycopersici* compared to their unformulated combination of essential oils (Sharma *et al.*, 2018). Noveriza *et al.*, (2018) observed 8–23% less incidence of vascular streak dieback in cocoa when nano emulsion of citronella EO was used.

Silver Nanoparticles

Silver nanoparticles (AgNPs) are the most used antimicrobial agents. Nanosized silica silver NPs are prepared by combining AgNO3, sodium silicate, and a water soluble polymer, and silica silver nanoparticles are used to control powdery mildew of pumpkin in field and greenhouse at 0.3 ppm (Park *et al.*, 2006). It was further observed that a higher concentration of silica silver nanoparticles (10 ppm) did not cause any adverse effect on a few beneficial bacteria. The sheath blight of rice (*Oryza sativa* L.), caused by *Rhizoctonia solani*, is responsible for a huge loss in crop yield. This causal organism remains ineffective against the application of fungicides azoxystrobin and flutolanil. However, the application of AgNPs (4–8 nm) significantly inhibits the hyphal growth of *R. solani* (Min *et al.*, 2009). The AgNPs (10–50 nm) prepared using Acalypha indica leaf extract also show inhibitory action against *Alternaria alternata*, *Macrophomina phaseolina*, *Botrytis cinerea*, and *Curvularia lunata* at 15 mg/10 μL concentration (Krishnaraj *et al.*, 2012).

Titanium Dioxide Nanoparticles

The titanium dioxide nanoparticles (TiO2NPs) are reported more effective than AgNPs against *X. perforans* (Strayer *et al.*, 2016). The combinations of Zn and TiO NPs (TIO NPs/Zn) were also found effective against a newly found *Xanthomonas* sp., responsible for bacterial leaf spot of rose (Paret *et al.*, 2013).

Zinc Oxide Nanoparticles

Thiram is an antifungal agent used to inhibit *Phytophthora capsici* growth, but simultaneously it also causes necrosis of fibroblasts cells and adversely affects reproduction and immune functions of birds (LopezAntia *et al.*, 2015). It has been reported by Xue *et al.*, (2014) that the use of composite ZnO thiram antifungal system efficiently inhibits *Phytophthora capsici*. In addition, zinc oxide nanoparticles (ZnONPs) completely degrade under simulated sunlight irradiation within 6 h. Practical use of such composites could be the effective along with moderate quantity of pesticide agents in disease control thus impacting the environment in less severe ways.

Copper Nanoparticles

Plant pathogenic bacteria, *Xanthomonas axonopodis* pv. *punicae*, cause the blight of pomegranate (*Punica granatum*), leading to a great economic loss. The copper oxychloride treatment is moderately effective against the disease. Mondal and Mani (2012) observed that the application of copper nanoparticles (CuNPs) suppresses *Xanthomonas axonopodis* pv. *punicae* growth at 0.2 ppm, which has 10,000 times lower concentration than of commercial copper oxychloride.

Chitosan Nanoparticles

Chitosan, a natural polymer, induces systemic resistance in plants. However, there is a lesser attraction toward chitosan use for plant disease control because of its insolubility in aqueous media and lower antifungal activity (Saharan *et al*., 2013). In addition, it is required in bulk amount for the treatment of fungal plant disease. However, it was reported that 0.10% and 0.12% application of copper chitosan nanoparticle composite (CuCSNPs) decreases the mycelial growth and spore germination of *Alternaria solani* and *Fusarium oxysporum* (Saharan *et al*., 2015). Therefore, it was confirmed that nanoparticle is required in less amount for the fungal disease treatment. Similar kind of other nanocomposites can be developed for wide antifungal agent application in field.

Postharvest Management

The management of crop product delivery, place of harvest, and consumption with minimum loss and maximum efficiency is called as a postharvest system (Hodges *et al*., 2011). According to the Food and Agriculture Organization of the United Nations estimate, about 1.3 billion tons of food are globally wasted or lost annually due to improper management of post harvesting (Gustavsson *et al*., 2011). Yadollahia *et al*., (2010) reported that there were higher rates of return on investment in post-harvest research and infrastructure than on farm production investment. The reduction in food postharvest could enhance global food security. Therefore, there are many nanoparticles that can protect foods from different infections. With proper research, NPs and their composites could aid in reducing the food loss in the near future.

CONCLUSION

The use of nanoproducts with commercial value is directly manifested by the numerous compounds present in the market. The values of these products are considered as a source of new mechanisms and their consequent incorporation into high output screens is hard to evaluate. Nowadays, some works have been done and enlarged for shelf life efficient in field and dependability, biological scheme, immediate death and lastly effect cost of living system the effect of cost of living systems and there have been some notable successes in situations where some disruption to the microbes is acceptable.

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