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Review Article
Nano and Bio-nanoparticles for Insect Control

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Abstract
World-wide scientists are providing clean and safe food to all human beings and live-hoods by adapting many green technologies. Considering overall merits of nanomaterials investigators recommend theist application in variously spheres of sustainable agriculture. Because nanotechnology will be helpful to meet the food security challenges; targeted delivery of pesticides, promote the seed germination and plant growth, increase crop yield, improve food quality, control of pestiferous insects that destroy crops and their products in the field as well as in storage. This review provided various research findings of usage of both chemical and bio-nanomaterials for pest management.

Key words: Nanomaterials, bio-nanomaterial, pestiferous insects, post-harvest pests, management

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INTRODUCTION

Friedrich (2015) concludes that in 2050, the expected population is 9.2 billion and the global food production will be about 70%. This could be achieved by adapting safe, abundant, sustainable and nutritious food supply innovative techniques. Some of them are traditional, mobile and vertical farming, cultivation of insect-protected and virus-resistant biotech crop varieties, engineered crops which grows in a places where they would not survive before, herbicide/pesticides-tolerant varieties, nutritionally (high protein, antioxidants and vitamins and lower amounts of fats) enhanced traits; following plant specific protection measures and adapt bio-intensive integrated pest and disease management.

Nanotechnology has revolutionized the world with tremendous advancements in many fields of science like engineering, biotechnology, analytical chemistry and agriculture. Their use in crop protection is just in its infancy (Resham *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, it is an under-explored research area (Khot *et al*., 2012). It has been used as conductors and semi-conductors, medical devices, sensors, coatings, catalytic agents and also as pesticides (Jordan, 2010).

Many countries are now being switching over from chemical-based agriculture to green agriculture, where the utilization of biopesticides and also biological nanomaterials have a lots of role to play in pest control (Bhattacharyya *et al*., 2010; Stadler *et al*., 2010; Watson *et al*., 2011; Gogos *et al*., 2012; Sahayaraj, 2014a, b; De *et al*., 2014). 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.], Leguminaceae (*Pongamia pinnata* (L.) Pierre.) have been utilized world-wide for various pestiferous insects management.

Since, the biogensis of nanomaterials and their characterization was simple and reliable, biogenic silver nanoparticles (AgNPs) for *Pongamia pinnata* (Raut *et al*., 2010; Naik *et al*., 2014), *Azadirachta indica* (Khan *et al.,* 2012; Velusamy *et al.,* 2015), Annona squamosa (Vivek *et al*., 2012), Chrysanthemum (He *et al*., 2013) were prepared and utilized for various biological purposes. However, their utility value was not evaluated against crop pests. Furthermore, a variety of metal nanoparticles silver (Ag), gold (Au), aluminum (Al), silica (Si) and zinc (Zn) and metal oxide-based polymers Zinc oxide (ZnO) and titanium dioxide (TiO_2) are being developed for crop pest management. However, very few studies have been made in the field of nano-material and pest management and a lot more are expected in the near future. Hence, this review planned to provide about the use of nanomaterials and bio-nanomaterials against pestiferous insects and also post-harvest pests.

CROP LOSS AND ITS ASSOCIATES

Crop production loss was mainly caused by weeds (monocots and dicots and parasitic weeds), animal's pests (pestiferous insects, mites, mollusks, rodents, birds, mammals) and phytopathogens (bacteria, fungi, viruses). All these organisms are classified as stand reducers (damping-off pathogens), photosynthetic rate reducers (fungi, bacteria, viruses), leaf senescence accelerators (pathogens), light stealers (weeds, some pathogens), assimilate sappers (nematodes, pathogens, sucking arthropods) and tissue consumers (chewing animals, necrotrophic pathogens) (http://www.agrivi.com/yield-losses-due-to-pests/). They have been managed by practicing different cultivation (cultivar choice, crop rotation) and mechanical weeding methods or utilizing various biological control agents (antagonists, predators, parasitoids etc.) and also using chemicals (pesticides/ insecticides/acaricides/rodenticides/pheromones etc.). Traditional pesticides have many limitations as well as fewer efficacies to control highly devastating pests. Increased use of nanomaterials in agriculture has led to the need to study the impact of nanomaterials on the environment in general and on insect before recommending the same for pest management.

WHY NANOTECHNOLOGY-BASED AGRICULTURE

Biotechnology has considered a safe agricultural tool to enhance crop protection, subsequently to produce more agricultural produce and products, improve food process, nutritional value and better flavor etc. At the same it has harmful ecological consequences like spreading genetically engineered genes to indigenous plants, increasing toxicity, which may move through the food chain, disrupting nature's system of pest control, creating new weeds or virus strains, loss of biodiversity and insecticidal resistance etc. (Wieczorek, 2003). Hence, it is necessary to bring forth new innovative technology/methods to overcome the above mentioned problems.

One such novel technology is nonotechnology, which has been revolutionized in health care, textile, materials, information and communication technology and energy sectors too. With the global population explosion, the demand for increased supply of food has motivated scientists and engineers to design engineered nanoparticles (ENPs) to reduce pestiferous insect infestation subsequently to increase agricultural production. Available literature reveals that both chemical and biological nano materials have also place substantial role in the crop protection as irrigation water filtration, remediation of harmful pesticides/insecticides, preparation of new pesticidal formulations (Barik *et al*., 2008); efficient delivery of pesticides, fertilizers and other agrochemicals, development of organic farming and plant disease control (Prasad *et al*., 2014) etc. Since this field is in infancy stage, by trial and error method, this innovative technology can be utilized in crop protection and production purposes considering their consequences.

PESTIFEROUS INSECT'S MANAGEMENT

Chemical nanomaterials: Initially, Christenson and Foote (1960) compared the effectiveness of colloidal Ca and nano-Ca on infestations of the oriental fruit fly [*Bactrocera dorsalis* (Diptera: Tephritidae: Dacinae)] in fruits and on red scale insects (*Aonidiella aurantii*). Chakravarthy *et al*. (2012b) used inorganic nanoparticles CdS, nano-Ag and nano-TiO_2 against *Spodoptera litura* Fab. (Lepidoptera: Noctuidae) control under laboratory conditions. During the same period, Rouhani *et al*. (2012) proved the bioefficacy of silver and zinc nanoparticles against *Aphis nerii* Boyer De Fonscolombe (Hemiptera: Aphididae). Vinutha *et al*. (2013) suggested to utilize nanotechnology for the management of an economically important polyphagous pest *Helicoverpa armigera* (Hubner). Recently, Hua *et al*. (2015) reported that calcium carbonate nanoparticles can enhance plant nutrition and insect pest tolerance.

Yasur and Rani (2015) studied the impact of silver nanoparticles (AgNPs) on growth and feeding responses of two lepidopteran pests namely Asian armyworm, *S. litura* and castor semilooper, *Achaea janata* L. (Lepidoptera: Noctuidae). The larvae were fed with PVP coated-AgNPs treated castor leaf at different concentrations and their activity was compared to that of silver nitrate ($AgNO_3$) treated leaf diets. Larval and pupal body weights decreased along with the decrease in the concentrations of AgNPs and $AgNO_3$ in both the test insects. Low amounts of silver were accumulated in the larval guts, but major portion of it was eliminated through the feces (Yasur and Rani, 2015). Previously, silica nanoparticle (SNPs) could effectively kill second stadium larvae of *S. litura* (Debnath *et al*., 2012) (Table 1).

BIONANOMATERIALS

***Spodoptera* spp.:** A chitin derivative (N-(2-chloro-6-fluorobenzyl-chitosan), chitosan has been found to showstrong insecticidal activity in some plant pests (Zheng *et al*., 2005; Rabea *et al*., 2005). Chitosan nanoparticle coated fungal metabolite (CNPCFM), Uncoated Fungal Metabolite (UFM) and Fungal Spores (FS) of entomopathogenic fungi *Nomuraea rileyi* (F.) Samson were evaluated against *S. litura* (Chandra *et al*., 2013). Results

Table 1: List of chemical and biological nanoparticles for pestiferous insect management with citations

Metal	Reducing and stabilizing biological agent	Pest(s)	Citations
Chemical nanomaterials			
Ca	-	*Bactrocera dorsalis*	Christenson and Foote (1960)
CdS, Ag and TiO_2	-	*Spodoptera litura*	Chakravarthy *et al*. (2012)
Ag and Zn	-	*Aphis nerii*	Rouhani *et al*. (2012)
calcium carbonate nanoparticles	-		Kuo-Hsun Hua *et al*. (2015)
AgNPs	-	*Spodoptera litura* and *Achaea janata*	Yasur and Rani (2015)
SNPs	-	*Spodoptera litura*	Debnath *et al*. (2012)
AgNPs	Bifenthrin	*Lygus hesperus* and *Acheta domesticus*	Louder (2015)
Bio-nano materials			
Nanoparticle	Chitosan	*Spodoptera litura*	Chandra *et al*. (2013)
Gold, CdS, TiO_2 and Ag	DNA	*Spodoptera litura*	Chandrashekharaiah *et al*. (2015)
Gold	DNA	*Spodoptera litura*	Chakravarthy *et al*. (2012a)
Nanoparticles of novaluron		*Spodoptera littoralis*	Elek *et al*. (2010)
AgNPs	*Aristolochia indica*	*H. armigera*	Siva and Kumar (2015)
PCL nanospheres	*Zanthoxylum rhoifolium*	*Bemisia tabaci*	Christofoli *et al*. (2015)
Chitosan (CS)-g-poly (acrylic acid)		*Aphis gossypii*	Sahab *et al*. (2015)
AgNPs	*Cassia occidentalis*	Crop and human pests	Murugan *et al*. (2016)

showed that among the tested materials, CNPCFM was found to be more effective than UFM and FS. The LC_{50} value for I, II, III and IV instars were 1.67, 1.85, 1.98 and 2.45 µg respectively for CNPCFM, while LC_{50} value for I, II, III and IV instars were1.87, 2.01, 2.38 and 3.97 µg, respectively for UFM. For FS, the LC_{50} values were 2.28×10^8, 2.92×10^6, 4.75×10^{10} and 5.55×10^{10} spores mL^{-1} for I, II, III and IV instars, respectively. The UFM showed better toxicity compared to the FS and less effective than the CNPCFM. When the instars grew older, a decrease in mortality and an increase in LT_{50} were recorded with respect to the concentration of CNPCFM, UFM and FS. Adult longevity (LT_{50}) for CNPCFM, UFM and FS were 2.17 ± 0.2, 4.21 ± 0.2 and 32.7 ± 0.2 h, respectively.

Chandrashekharaiah *et al.* (2015) developed DNA-tagged nanogold, DNA-tagged CdS, nano-TiO_2 and nano-Ag and were tested against *S. litura* third, fourth and fifth stadium larvae. Results revealed that DNA-tagged nanogold caused 30.50, 57.50 and 75.00% mortality respectively on third, fourth and fifth instar *S. litura* larvae, CdS nanoparticle caused highest *S. litura* larval mortality of 21.41-93.79% at 150 and 2400 ppm, respectively. The nano-TiO_2 showed maximum of 73.79% *S. litura* larval mortality at 2400 ppm and the least was 18.50% at150 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.* (2012a) was also utilized DNA-tagged nano gold for *S. litura* management. They further developed nanoparticles coated with ecdysteroid analogues like tebufenozide and halofenozide and tested against *Corcyra cephalonica* (Stainton) (Lepidoptera:Pyralidae). Previously, an *in vivo* experiment was conducted for 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 (Elek *et al.*, 2010).

Other pests: Bionanomaterials were synthesized using plant extracts (Sahayaraj *et al.*, 2014) or microbe's culture or their bioactive principles and protein to enzymes. Antifeedant, larvicidal and cytotoxic activities of synthesized silver nanoparticles (AgNPs) using aqueous leaf extract of *Aristolochia indica* against third instar larvae of *H. armigera* and HeLa cell lines showed that maximum antifeedant and larvicidal efficacy was observed in crude aqueous and synthesized AgNPs against *H. armigera* larvae ($LC_{50} = 127.49$, 84.56 mg L^{-1}, 766.54 and 309.98 mg mL^{-1}, respectively). The extract of *A. indica* and AgNPs elicited low cytotoxic effect with TC_{50} values of >100 and 89 µg mL^{-1}, respectively (Siva and Kumar, 2015). Combining a pyrethroid insecticide bifenthrin with AgNPs was more toxic to *Lygus hesperus*, however, bifenthrin-only mixture was more toxic than the bifenthrin+n-Ag mixture against *Acheta domesticus* under cotton filed condition (Louder, 2015). The treated eggs did not hatch due to arrest of embryonic development. Essential oils from *Zanthoxylum rhoifolium* leaves-containing nanoparticles for control of *Bemisia tabaci* were developed by Christofoli *et al.* (2015) and reported that the a anospheres containing this essential oil exhibited encapsulation efficiency higher than 96%. Chandra *et al.* (2013) confirmed that chitosan nanoparticle coated fungal metabolite (CNPCFM) showed higher pesticidal activity when compared with Uncoated Fungal Metabolite (UFM) and Fungal Spores (FS). Very recently, chitosan (CS)-g-poly (acrylic acid) PAA nanoparticles reduced egg laying of *Aphis gossypii* (20.9 ± 9.1 and 28.9 ± 9.2 eggs/female for laboratory and under semi-field conditions, respectively) than control (97.3 ± 4.9 and 90.3 ± 4.9 eggs/female for laboratory and under semi-field conditions, respectively (Sahab *et al.*, 2015) (Table 1).

POST-HARVEST PEST'S MANAGEMENT

Major post-harvest pests and their consequences: Two major groups of insects such as Coleoptera (beetles) and Lepidoptera (moths and butterflies) comprises the most economically important post-harvest insect pests. Several species of Coleoptera and Lepidoptera attack crops both in the field and in store. They cause physical damage, grain spilling or deterioration, loss of weight and quality, vigor loss, germination reduction, lose value for marketing and consumption or planting (http://www.fao.org/3/a-av013e.pdf). Fumigants and residual insecticides are commonly used to combat stored grain pests. In recent years, consumer awareness of the health hazard from residual toxicity and the growing problem of insect resistance to these conventional insecticides have led the researchers to look for alternative strategies for stored grains protection.

CHEMICAL NANOMATERIALS

***Sitophilus* spp.:** Stadler *et al.* (2010) for the first time studied the insecticidal activity of nanostructured alumina against two insect pest's viz., *Sitophilus oryzae* (L.) (Coleoptera: Curculionidae) and *Rhyzopertha dominica* (F.) and reported significant mortality after 3 days of continuous exposure to nanostructured alumina-treated wheat. Nanostructured alumina was tested against *S. oryzae* L. and *R. dominica* and significant mortality after 3 days of continuous exposure

Table 2: Chemical and biological nanoparticles utilize for the management of post-harvest pests with citations

Metal	Reducing and stabilizing biological agent	Pest(s)	Citations
Chemical nanomaterials			
Alumina	-	*Sitophilus oryzae* and *Rhyzopertha dominica*	Teodoro *et al.* (2010)
Alumina	-	*Sitophilus oryzae* and *Rhyzopertha dominica*	Stadler *et al.* (2010)
SiO_2	-	*Sitophilus oryzae*	Goswami *et al.* (2010)
Silica	-	*Sitophilus oryzae*	Debnath *et al.* (2011)
Al_2O_3 and TiO_2	-	*Sitophilus oryzae*	Sabbour *et al.* (2012)
Octadecylsilane	-		Maddah and Shamsi (2012)
Polyethylene glycols based amphiphilic copolymers	-	*Callosobruchus maculatus*	Loha *et al.* (2012)
Silica	-	*Callosobruchus maculatus*	Ganesh *et al.* (2015)
Bio-nanomaterials			
Polyethylene glycol	Garlic essential oil	*Tribolium castaneum*	Yang *et al.* (2009)
Diatomaceous earth		*Tribolium confusum* and *Tribolium castaneum*	Sabbour and El-Aziz (2015)
Polyethylene glycol	Garlic oil	*Tribolium castaneum*	Yang *et al.* (2009)
Ag	*Euphorbia prostrata*	*Sitophilus oryzae*	Zahir *et al.* (2012)
Silver and lead	*Avivennia marina*	*Sitophilus oryzae*	Sankar and Abideen (2015)
Ag	*Euphorbia prostrate*	*Sitophilus oryzae*	Zahir *et al.* (2012)
Chitosan nanoparticles		*Callosobruchus maculatus*	Sahab *et al.* (2015)

to treated wheat was observed, whereas, nine days after treatment, the median Lethal Doses (LD_{50}) ranged from 127-235 mg kg^{-1} (Stadler *et al.*, 2010). Furthermore, the nanoparticles of SiO_2 show nearly 100% mortality against *S. oryzae* (Goswami *et al.*, 2010). Entomotoxicity of Surface-functionalized silica nanoparticles (SNP) was tested against rice weevil *S. oryzae* and its efficacy was compared with bulk-sized silica (individual particles larger than 1 µm). Amorphous SNP was found to be highly effective against this insect pest causing more than 90% mortality, indicating the effectiveness of SNP to control insect pests (Debnath *et al.*, 2011). Nanoparticles (Al_2O_3 and TiO_2) proved their insecticidal activity against *S. oryzae* under laboratory conditions (Sabbour, 2012).

***Callosobruchus* spp.:** Magnetite octadecylsilane nanoparticles were synthesized and used for pest control (Maddah and Shamsi, 2012); the bioefficacy of β-cyfluthrin formulations synthesized poly (ethylene glycols) based amphiphilic copolymers were evaluated against *Callosobruchus maculatus* (Loha *et al.*, 2012). Results reveal that the formulations showed greater efficacy after 14 days as evident from EC_{50} value (1.58 mg L^{-1}) as compared to the control (EC_{50} value on the first day (0.51 mg L^{-1}). Silica nanoparticles (SNPs) with the pulse seeds of *Cajanus cajan*, *Macrotyloma uniflorum*, *Vigna mungo*, *Vigna radiata*, *Cicer arietinum* and *Vigna unguiculata* against the infestation of stored pulse beetle, *Callosobruchus maculatus* revealed a significant reduction in oviposition, adult emergence and seed damage potential (Arumugam *et al.*, 2015) (Table 2).

BIONANOMATERIALS

***Tribolium* spp.:** Polyethylene glycol-coated nanoparticles loaded with garlic essential oil, against adult *Tribolium castaneum* (Herbst) demonstrated the insecticidal activity of the bionano polyethylene glycol-coated nanoparticles (Yang *et al.*, 2009). Similarly, Nano-Diatomaceous Earth (Nano-DE) in comparison with natural Diatomaceous Earth (DE) against *Tribolium confusum* (Jacquelin) and *T. castaneum* under laboratory and stored conditions caused increased larval mortality with increase of Nano-DE and DE. Larvae of *T. confusum* was more susceptible to the treatments than *T. castaneum* larvae. Nano-DE was more effective than natural-DE. The fecundity of tested insects was highly affected with both DE and nano-DE. Further, nano-DE strongly suppressed the number of deposited eggs by *T. confusum* more than *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 several different modes of action by reducing oviposition, adult emergence and infestation. The results showed that DE-nanoparticles can be used as a valuable tool in pest management programs of *T. confusum* and *T. castaneum* (Sabbour and Abd El-Aziz, 2015). Yang *et al.* (2009) nanoparticles coated with garlic oil then combined with polyethylene glycol (PEG) using melt-dispersion method. This nanomaterial caused 100% mortality to *T. castaneum* after five months. It was mainly due to the slow and continuous release of the active components from nanoparticles. Dueing the same period control test materials caused only 11% mortality.

***Sitophilus* spp.:** Green synthesis of AgNPs have been reported using *Euphorbia prostrata* and used to control the adult of *S. oryzae* (Zahir *et al*., 2012). Silver and lead nanoparticles synthesized utilizing mangrove plants extract of *Avivennia marina* showed pesticidal activity against *S. oryzae* and the results revealed that treatment caused 100% mortality within 4 days of treatment (Sankar and Abideen, 2015). Nanomaterials can be beneficial in agricultural research and applications due to their size which is similar to that of most biological molecules so that, they can diffuse through cell membranes to act on the target. Silver nanoparticles (Ag NPs) were synthesized by using aqueous leaves extracts of *Euphorbia prostrate* showed insecticidal activity against adult of *S. oryzae* (Zahir *et al*., 2012). The LD_{50} values of aqueous extract, $AgNO_3$ solution and synthesized Ag NPs were 213.32, 247.90 and 44.69 mg kg^{-1}; $LD_{90} = 1648.08$, 2675.13 and 168.28 mg kg^{-1}, respectively.

***Callosobruchus* spp.:** Chitosan nanoparticles reduced egg laying of *C. maculatus* (10.9$\pm$9.9 and 19.9$\pm$9.9 eggs/female laboratory and under semi-storage conditions, respectively) than control (95.3$\pm$4.9 and 94.3$\pm$4.9 eggs/female laboratory and under semi-storage conditions, respectively) (Sahab *et al*., 2015). Similar kind of results was also recorded in *C. chinensis* (Table 2).

MERITS AND CONSEQUENCES OF CHEMCIAL AND BIONANOMATERIALS

Before introducing the ENPs in agriculture application particularly insect pest and phytopathogens management, there impacts on biological organisms dwelled water, or soil and also their possible harmful effects on living beings including human beings. Literature survey mainly emphasized the potential benefits of ENPs, although meager is known about the safety of nanomaterials or nanoparticles in agriculture sector. Considering the soil pollution, very recently it was reported (Stolte *et al*., 2016) that nanoparticles pollution in soil is still in the process of development.

Nanoparticles (multi-walled carbon nanotube, aluminum, alumina, zinc and zinc oxide) showed anti-germicidal activity except by nanoscale zinc (nano-Zn) on ryegrass and zinc oxide (nano-ZnO) on corn at 2000 mg L^{-1} (Lin and Xing, 2007). They further reported that the suspensions of 2000 mg L^{-1} nano-Zn or nano-ZnO practically terminated root elongation of the radish, rape, ryegrass, lettuce, corn and cucumber. Fifty percent Inhibitory Concentrations (IC_{50}) of nano-Zn and nano-ZnO were estimated to be near 50 mg L^{-1} for radish and about 20 mg L^{-1} for rape and ryegrass.

The CuO nanoparticles significantly inhibited the growth and development, reduced the uptake of nutrients, such as B, Mo, Mn, Mg, Zn and Fe of both transgenic and conventional cottons. However, at low concentration of CuO NPs enhanced the expression of the Bt toxin protein of Bt-transgenic cotton (Le Van *et al*., 2016) is a desirable character of this chemical nanoparticles. Similarly, ZnO NPs particles adhere onto the root surface indicates the absorption, however, not transported from root to shoot (Lin and Xing, 2008). Another study reveals that plants are being developing one or other mechanisms to resist or neutralize the accumulation of nanomaterials. For instance, the radial penetration of the metals such as Zn^{2+}, Cu^{2+} or Ce^{4+} into the taproot and subsequent translocation to shoots of carrot (*Daucus carota*) were also generally greater for plants receiving the ionic treatment than those receiving the ENP like ZnO, CuO, or CeO_2 NPs treatment resulted accumulation of Zn, Cu, or Ce in the taproot was restricted to the taproot periderm (Ebbs *et al*., 2016) reveals no marked impact against the root crops. Armstrong *et al*. (2013) reported that silver nanoparticles (AgNPs), like almost all nanoparticles, are potentially toxic beyond a certain concentration because the survival of the organism is compromised due to scores of pathophysiological abnormalities past that concentration.

Considering the nominal impact as well as little benefits of chemical nanomaterials, it is essential to utilize biogenic nanomaterials for pest management. It was reported by Joy (2000) that in green synthesis we are using safer solvents and biomareial, hence it is safer than chemical synthesis. In addition, selection of more biocompatible metal is more important rather than synthesis or utilization. Freitas (2003) suggested utilizing very biocompatible gold, platinum and palladium than moderately biocompatible silver and not biocompatible single crystal silicon. Furthermore, many soil doweled microbes were utilized for the biomimitics of nanoparticles. For instance, 37 different bacterial soil isolates of *Bacillus cereus* and *Escherichia fergusonii* were used for biosynthesis of AgNPs (Patil *et al*., 2016). Hence it is expected that biogenic nanoparticles does not harm against many soil-microorganism. Biogeneic nanoparticles were also safer to vertebrates. However, AgNPs synthesized using *Malva crispa* Linn. leaves extract showed oxidative stress and immunotoxicity in adult zebrafish (*Danio rerio*) (Krishnaraj *et al*., 2016).

Functionality and charge (nature of the surface), size and portal of entry (lungs, intestinal or skin) of NPs place crucial role for entry of nanoparticles into the human body accordingly we select the particles. However, the mechanism of AgNPs toxicity remains undetermined. It is suggested to study the physical, chemical and biological properties, bio-encapuslation process, suitability of carriers and behaviors and also mechanism of single or multiple NPs or NPs with chemical or biological or natural materials with its surrounding environment like soil, water and organism inhabiting on them before recommending for agriculture purposes. Furthermore, formulation methods, handling and application technologies can also be devised for the better utilization of ENPs in agriculture sector. Moreover, compared to commercially available insecticides, chemical and biogenic nano-structured selected metals can provide a cheap and reliable alternative for control of insect pests and such studies may expand the frontiers for nanoparticle-based technologies in pest management.

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REFERENCES

Armstrong, N., M. Ramamoorthy, D. Lyon, K. Jones and A. Duttaroy, 2013. Mechanism of silver nanoparticles action on insect pigmentation reveals intervention of copper homeostasis. PLoS ONE, Vol. 8. 10.1371/journal.pone.0053186.

Arumugam, G., V. Velayutham, S. Shanmugavel and J. Sundaram, 2015. Efficacy of nanostructured silica as a stored pulse protector against the infestation of bruchid beetle, *Callosobruchus maculatus* (Coleoptera: Bruchidae). Applied Nanosci. 10.1007/s13204-015-0446-2

Barik, T.K., B. Sahu and V. Swain, 2008. Nanosilica-From medicine to pest control. Parasitol. Res., 103: 253-258.

Bhattacharyya, A., A. Bhaumik, P.U. Rani, S. Mandals and T.T. Epidi, 2010. Nano-particles-A recent approach to insect pest control. Afr. J. Biotechnol., 9: 3489-3493.

Chakravarthy, A.K., A. Bhattacharyya, P.R. Shashank, T.T. Epidi, B. Doddabasappa and S.K. Mandal, 2012a. DNA-tagged nano gold: A new tool for the control of the armyworm, *Spodoptera litura* Fab. (Lepidoptera: Noctuidae). Afr. J. Biotechnol., 11: 9295-9301.

Chakravarthy, A.K., Chandrashekharaiah, S.B. Kandakoor, A. Bhattacharya, K. Dhanabala, K. Gurunatha and P. Ramesh, 2012b. Bio efficacy of inorganic nanoparticles CdS, Nano-Ag and Nano-TiO_2 against *Spodoptera litura* (Fabricius) (Lepidoptera: Noctuidae). Curr. Biotica, 6: 271-281.

Chandra, J.H., L.F.A.A. Raj, S.K.R. Namasivayam and R.S.A. Bharani, 2013. Improved pesticidal activity of fungal metabolite from nomureae rileyi with chitosan nanoparticles. Proceedings of the International Conference on Advanced Nanomaterials and Emerging Engineering Technologies, July 24-26, 2013, Chennai, pp: 387-390.

Chandrashekharaiah, M., S.B. Kandakoor, G.B. Gowda, V. Kammar and A.K. Chakravarthy, 2015. Nanomaterials: A Review of their Action and Application in Pest Management and Evaluation of DNA-Tagged Particles. In: New Horizons in Insect Science: Towards Sustainable Pest Management, Chakravarthy, A.K. (Ed.). Springer, India, ISBN-13: 978-81-322-2089-3, pp: 113-126.

Christenson, L.D. and R.H. Foote, 1960. Biology of fruit flies. Annu. Rev. Entomol., 5: 171-192.

Christofoli, M., E.C.C. Costa, K.U. Bicalho, V. de Cassia Domingues, M.F. Peixoto, C.C.F. Alves and C. de Melo Cazal, 2015. Insecticidal effect of nanoencapsulated essential oils from *Zanthoxylum rhoifolium* (Rutaceae) in *Bemisia tabaci* populations. Ind. Crops Prod., 70: 301-308.

De, A., R. Bose, A. Kumar and S. Mozumdar, 2014. Management of Insect Pests Using Nanotechnology: As Modern Approaches. In: Targeted Delivery of Pesticides Using Biodegradable Polymeric Nanoparticles, De, A., R. Bose, A. Kumar and S. Mozumdar (Eds.). Springer, India, ISBN-13: 978-81-322-1689-6, pp: 29-33.

Debnath, N., S. Das, D. Seth, R. Chandra, S.C. Bhattacharya and A. Goswami, 2011. Entomotoxic effect of silica nanoparticles against *Sitophilus oryzae* (L.). J. Pest Sci., 84: 99-105.

Debnath, N., S. Mitra, S. Das and A. Goswami, 2012. Synthesis of surface functionalized silica nanoparticles and their use as entomotoxic nanocides. Powder Technol., 221: 252-256.

Ebbs, S.D., S.J. Bradfield, P. Kumar, J.C. White, C. Musante and X. Ma, 2016. Accumulation of zinc, copper, or cerium in carrot (*Daucus carota*) exposed to metal oxide nanoparticles and metal ions. Environ. Sci. Nano, (In Press). 10.1039/C5EN00161G

Elek, N., R. Hoffman, U. Raviv, R. Resh, I. Ishaaya and S. Magdassi, 2010. Novaluron nanoparticles: Formation and potential use in controlling agricultural insect pests. Colloids Surf. A: Physicochem. Eng. Aspects, 372: 66-72.

Freitas, R.A., 2003. Nanomedicine: Biocompatibility. Volume IIA. Landes Bioscience, Georgetown, TX.,ISBN-13: 9781570597411, Pages: 348.

Friedrich, T., 2015. A new paradigm for feeding the world in 2050 the sustainable intensification of crop production. Resour. Mag., 22: 18-18.

Gogos, A., K. Knauer and T.D. Bucheli, 2012. Nanomaterials in plant protection and fertilization: Current state, foreseen applications and research priorities. J. Agric. Food Chem., 60: 9781-9792.

Goswami, A., I. Roy, S. Sengupta and N. Debnath, 2010. Novel applications of solid and liquid formulations of nanoparticles against insect pests and pathogens. Thin Solid Films, 519: 1252-1257.

He, Y., Z. Du, H. Lv, Q. Jia and Z. Tang *et al*., 2013. Green synthesis of silver nanoparticles by *Chrysanthemum morifolium* Ramat. extract and their application in clinical ultrasound gel. Int. J. Nanomed., 8: 1809-1815.

Hua, K.H., H.C. Wang, R.S. Chung and J.C. Hsu, 2015. Calcium carbonate nanoparticles can enhance plant nutrition and insect pest tolerance. J. Pestic. Sci., 40: 208-213.

Jordan, W., 2010. Nanotechnology and pesticides. Pesticide Program Dialogue Committee, April 29, 2010. https://www.nanotechproject.org/process/assets/files/8309/epa_newpolicy_nanomaterials.pdf

Joy, B., 2000. Why the future doesn't need us. http://reasonandmeaning.com/joys-why-the-future-doesnt-need-us/

Khan, Z., J.I. Hussain and A.A. Hashmi, 2012. Shape-directing role of cetyltrimethylammonium bromide in the green synthesis of Ag-nanoparticles using Neem (*Azadirachta indica*) leaf extract. Colloids Surf. B: Biointerfaces, 95: 229-234.

Khot, L.R., S. Sankaran, J.M. Maja, R. Ehsani and E.W. Schuster, 2012. Applications of nanomaterials in agricultural production and crop protection: A review. Crop Prot., 35: 64-70.

Krishnaraj, C., S.L. Harper and S.I. Yun, 2016. *In vivo* toxicological assessment of biologically synthesized silver nanoparticles in adult Zebrafish (*Danio rerio*). J. Hazard. Mater., 301: 480-491.

Le Van, N., C. Ma, J. Shang, Y. Rui, S. Liu and B. Xing, 2016. Effects of CuO nanoparticles on insecticidal activity and phytotoxicity in conventional and transgenic cotton. Chemosphere, 144: 661-670.

Lin, D. and B. Xing, 2007. Phytotoxicity of nanoparticles: Inhibition of seed germination and root growth. Environ. Pollut., 150: 243-250.

Lin, D. and B. Xing, 2008. Root uptake and phytotoxicity of ZnO nanoparticles. Environ. Sci. Technol., 42: 5580-5585.

Loha, K.M., N.A. Shakil, J. Kumar, M.K. Singh and C. Srivastava, 2012. Bio-efficacy evaluation of nanoformulations of β-cyfluthrin against *Callosobruchus maculatus* (Coleoptera: Bruchidae). J. Environ. Sci. Health, Part B: Pestic. Food Contam. Agric. Wastes, 47: 687-691.

Louder, J.K., 2015. Nanotechnology in Agriculture: Interactions between nanomaterials and cotton agrochemicals. Ph.D. Thesis, Texas Tech University, Texas, USA.

Maddah, B. and J. Shamsi, 2012. Extraction and preconcentration of trace amounts of diazinon and fenitrothion from environmental water by magnetite octadecylsilane nanoparticles. J. Chromatogr. A, 1256: 40-45.

Naik, B.R., G.S. Gowreeswari, Y. Singh, R. Satyavathi, S.S. Daravath and P.R. Reddy, 2014. Bio-synthesis of silver nanoparticles from leaf extract of *Pongamia pinnata* as an effective larvicide on dengue vector *Aedes albopictus* (Skuse) (Diptera: Culicidae). Adv. Entomol., 2: 93-101.

Patil, S.S., U.U. Shedbalkar, A. Truskewycz, B.A. Chopade and A.S. Ball, 2016. Nanoparticles for environmental clean-up: A review of potential risks and emerging solutions. Environ. Technol. Innov., 5: 10-21.

Prasad, R., V. Kumar and K.S. Prasad, 2014. Nanotechnology in sustainable agriculture: Present concerns and future aspects. Afr. J. Biotechnol., 13: 705-713.

Rabea, E.I., M.E.I. Badawy, T.M. Rogge, C.V. Stevens, M. Hofte, W. Steurbaut and G. Smagghe, 2005. Insecticidal and fungicidal activity of new synthesized chitosan derivatives. Pest Manage. Sci., 61: 951-960.

Raut, R.W., N.S. Kolekar, J.R. Lakkakula, V.D. Mendhulkar and S.B. Kashid, 2010. Extracellular synthesis of silver nanoparticles using dried leaves of *Pongamia pinnata* (L.) Pierre. Nano-Micro Lett., 2: 106-113.

Resham, S., M. Khalid and A.G. Kazi, 2015. Nanobiotechnology in Agricultural Development. In: PlantOmics: The Omics of Plant Science, Barh, D., M.S. Khan and E. Davies (Eds.). Springer, India, ISBN-13: 978-81-322-2172-2, pp: 683-698.

Rouhani, M., M.A. Samih and S. Kalantari, 2012. Insecticide effect of silver and zinc nanoparticles against *Aphis nerii* Boyer De Fonscolombe (Hemiptera: Aphididae). Chilean J. Agric. Res., 72: 590-594.

Sabbour, M.M., 2012. Entomotoxicity assay of two nanoparticle materials 1-(Al_2O_3 and TiO_2) against *Sitophilus oryzae* under laboratory and store conditions in Egypt. J. Novel Applied Sci., 1: 103-108.

Sabbour, M.M and S.E. Abd El-Aziz, 2015. Efficacy of nano-diatomaceous earth against red flour beetle, *Tribolium castaneum* and confused flour beetle, *Tribolium confusum* (Coleoptera: Tenebrionidae) under laboratory and storage conditions. Bull. Environ. Pharmacol. Life Sci., 4: 54-59.

Sahab, A.F., A.I. Waly, M.M. Sabbour and S.N. Lubna, 2015. Synthesis, antifungal and insecticidal potential of chitosan (CS)-g-poly (acrylic acid) (PAA) nanoparticles against some seed borne fungi and insects of soybean. Int. J. ChemTech Res., 8: 589-598.

Sahayaraj, K., M. Roobadevi, S. Rajesh and S. Azizi, 2014. *Vernonia cinerea* (L.) Less. silver nanocomposite and its antibacterial activity against a cotton pathogen. Res. Chem. Intermediates, 41: 5495-5507.

Sahayaraj, K., 2014a. Nanotechnology and Plant Biopesticides: An Overview. In: Advances in Plant Biopesticides. D. Singh (Ed.). Springer India, New Delhi, India, ISBN: 978-81-322-2006-0, pp: 279-293.

Sahayaraj, K., 2014b. Novel biosilver nanoparticles and their biological utility and overview. Int. J. Pharm., 4: 26-39.

Sankar, M.V. and S. Abideen, 2015. Pesticidal effect of green synthesized silver and lead nanoparticles using *Avicennia marina* against grain storage pest *Sitophilus oryzae*. Int. J. Nanomater. Biostruct., 5: 32-39.

Siva, C. and M.S. Kumar, 2015. Pesticidal activity of eco-friendly synthesized silver nanoparticles using *Aristolochia indica* extract against *Helicoverpa armigera* Hubner (Lepidoptera: Noctuidae). Int. J. Adv. Scient. Tech. Res., 2: 197-226.

Stadler, T., M. Buteler and D.K. Weaver, 2010. Novel use of nanostructured alumina as an insecticide. Pest Manage. Sci., 66: 577-579.

Stolte, J., M. Tesfai, L. Oygarden, S. Kvaerno and J. Keizer *et al*., 2016. Soil threats in Europe: Status, methods, drivers and effects on ecosystem services. JRC Technical Report, EUR 27607 EN, Europe, USA. http://esdac.jrc.ec.europa.eu/public_path/shared_folder/doc_pub/EUR27607.pdf.

Velusamy, P., J. Das, R. Pachaiappan, B. Vaseeharan and K. Pandian, 2015. Greener approach for synthesis of antibacterial silver nanoparticles using aqueous solution of neem gum (*Azadirachta indica* L.). Ind. Crops Prod., 66: 103-109.

Vinutha, J.S., D. Bhagat and N. Bakthavatsalam, 2013. Nanotechnology in the management of polyphagous pest *Helicoverpa armigera*. J. Acad. Indus. Res., 1: 606-608.

Vivek, R., R. Thangam, K. Muthuchelian, P. Gunasekaran, K. Kaveri and S. Kannan, 2012. Green biosynthesis of silver nanoparticles from *Annona squamosa* leaf extract and its *in vitro* cytotoxic effect on MCF-7 cells. Process Biochem., 47: 2405-2410.

Watson, S.B., A. Gergely and E.R. Janus, 2011. Where is agronanotechnology heading in the United States and European Union. Nat. Resour. Environ., 26: 8-12.

Wieczorek, A., 2003. Use of biotechnology in agriculture-benefits and risks. Biotechnology; BIO-3, University of Hawaii, Honolulu HI., pp: 1-6. http://www.ctahr.hawaii.edu/oc/freepubs/pdf/BIO-3.pdf.

Yang, F.L., X.G. Li, F. Zhu and C.L. Lei, 2009. Structural characterization of nanoparticles loaded with garlic essential oil and their insecticidal activity against *Tribolium castaneum* (Herbst) (Coleoptera: Tenebrionidae). J. Agric. Food Chem., 57: 10156-10162.

Yasur, J. and P.U. Rani, 2015. Lepidopteran insect susceptibility to silver nanoparticles and measurement of changes in their growth, development and physiology. Chemosphere, 124: 92-102.

Zahir, A.A., A. Bagavan, C. Kamaraj, G. Elango and A.A. Rahuman, 2012. Efficacy of plant-mediated synthesized silver nanoparticles against *Sitophilus oryzae*. J. Biopest., 5: 95-102.

Zheng, L., F. Hong, S. Lu and C. Liu, 2005. Effect of nano-TiO_2 on strength of naturally aged seeds and growth of spinach. Biol. Trace Elem. Res., 104: 83-91.