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Potential of Nanotechnology in Agriculture and Crop Protection: A Review

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Abstract

Nanotechnology is a new technology playing a vital role in different fields of science like medicine, engineering, electronic, pharmaceuticals, agriculture and food industry. Nanoparticles are used in this technology, which are of the size of 10^{-9} in diameter having several unique physical, biological and chemical characteristics. Nanoparticles are present naturally in insects especially on the wings. Precision farming, antimicrobial nano-materials for plant pathogens and development of nano-pesticides are modern approaches in agriculture. Nano-farming, nano-food and nano-packaging are the feature uses of nanotechnology in food industry. Smart gene delivery system, detection of pathogens by the use of nano-sensors and proper treatment at accurate time are possible due to nanotechnology. Insect pests, weeds and fungi affecting agricultural production can be managed by the use of nano-pesticides, herbicides and fungicides. The adoption of nanotechnology in the developing countries can revolutionize the agriculture and hence, converting it into green revolution for any nation.

Key Words: Nanotechnology, Insect Management, Nano-Pesticides, Nano-Herbicides, Nano-Fungicides

1. Introduction

Nanoparticles demonstrate unique targeted characteristics with elevated strength, high conductance of electricity and extra chemical reactivity (Nykypanchuk *et al*., 2008). The nanoparticles are of the size of 10^{-9} in diameter with distinctive chemical, physical and biological properties (Leiderer and Dekorsy, 2008; Bhattacharyyal *et al*., 2010; Sabbour, 2013). Scientists are engaged in synthesizing different kinds of organic, inorganic and hybrid nanoparticles possessing physical, optical and biological properties. These targeted characteristics have increased the importance of nanoparticles in several fields including engineering, electronic, agriculture, pharmaceuticals and medicine (Salata, 2004; Rai and Ingle, 2012; Dar and Soytong, 2013). From agricultural view point, nanotechnology has great potential to become a helping tool for pathologists in detection and treatment of plant diseases by the use of nano-based kits, detection of pests by the use of nano-sensors, enhanced capability of plants for nutrients absorption, maximized crop yield by nano-porous zeolites and insect pest management involving nanocapsules (Chaudhry *et al*., 2008; Rai and Ingle, 2012). The application of silicon in field on the vulnerable wheat cultivars enhanced crop resistance and decreased pest invasion (Basagli *et al*., 2003; Ecole and Sampaio, 2004; El-bendary and El-Helaly, 2013). It is also being supposed that efficiency of pesticides and insecticides will be increased due to the development of nanostructured catalysts in coming years with reduced doses. Insect pests are a major issue in agriculture as they destroy the crops and infest the stored food and food products. The loss is also caused by deterioration in quality of food and transmission of plant diseases (Neethirajan and Jayas, 2011; Ragaei and Sabry, 2014). Numerous chemicals have been used to combat the insect pests either by killing them or inhibiting their feeding or reproduction (Mogul *et al*., 1996). Several insects possess ferromagnetic materials in their body divisions i.e., head, thorax and abdomen. These materials act as geomagnetic sensors. The arrangement of nanoparticles in atom-by-atom pattern allows them by influencing their shape, size and orientation to react with the targeted tissues. In this review, our discussion is focused on the role of nanotechnology in agriculture and its approaches in insect pest management.

2. Natural Occurrence of Nano-Particles In Insects

The nano-structures that occur naturally are a big source of specific products but they are mostly neglected by the concerned people and the use of available free technology has been very little (Watson and Watson, 2004; Bhattacharyya and Debnath, 2008; Ehrlich *et al*., 2008). An array of structures in hexagonal ordered form is present in the wings of cicada *Psaltoda claripennis* Ashton and in the termites of the family Rhinotermitidae are investigated by atomic force microscopy (AFM) (Zhang and Liu, 2006). As the size of these structures vary from 200 to 1000 nm, they have a tendency to be round shape at the top and these structures come out of the flat surface to about 150-350 nm. The nanoparticles in the insect wings help to increase the aerodynamic effectiveness of the insect. Similarly, the insects have temperature dependent ferromagnetic resonance. In the head, thorax and abdomen of the insects like ants, the magnetic material is present. In social insects, geomagnetic sensors are these magnetic nanoparticles (Nowack and Bucheli, 2007). The behavior in higher animals is affected by the changes in the surrounding magnetic field. In the similar way, geomagnetic field information is used by the honey bees for homing, foraging and orientation (Binhi, 2004). The ant *Formica rufa* Linnaeus and *Solenopsis invicta* Buren also uses geomagnetic field for orientation and foraging (Slowik *et al*., 1997). Electron microscope technique observations demonstrate that many ant species use magnetite nanoparticles to recognize the magnetic signals. Ferric iron has also been observed in the abdomen of *S. invicta* workers (Abracado *et al*., 2005). Magnetic particles have also been observed in the in the stingless bee *Schwarziana quadripunctata* Lepeletier, *Pachycondyla marginata* Roger, *Apis mellifera* Linnaeus (Wajnberg *et al*., 2000; El-Jaick *et al*., 2007; Sahoo, 2014). Magnetic resonance imaging (MRI) technique was used to detect natural magnetism in fire ant (*S. invicta*) queens, workers and alates. Bright color components of butterflies and compound eyes of insects contain nanoparticles.

3. Nano Technology and Agriculture

Different sectors of agriculture and food industry can be revolutionized by the use of nanotechnology using modern tools for the detection and treatment of diseases, increased capability of plants to take up nutrients etc. Nano-based crystals are in developing process that will increase the effectiveness of herbicides and pesticides with decreased

doses. Smart delivery systems and sensors will increase the agricultural potential to fight with the pathogens and viruses (Rickman *et al*., 1999; Rai and Ingle, 2012). Nanotechnology is applied in different fields of food industry such as farming, food manufacturing and food packaging (Bhattacharyya *et al*., 2011).

3.1. Precision Farming

Increasing the yield output by decreasing the input (such as herbicides, fertilizer and pesticides) called precision or accurate farming has always remained a desired target of the agriculturists. Sensors and satellite systems are used to measure the best environmental conditions for the crops growth at maximum efficiency with the accurate identification of issues and problems. By the precision farming, pollution will be indirectly minimized by the decreased agricultural wastes. Monitory systems and small sensors prepared by the nanotechnology will greatly affect the near future precision farming practices (Cioffi *et al*., 2004; Rai and Ingle, 2012).

3.2. Antimicrobial Nano-Materials for Phytopathogens

Several metallic nanoparticles such as silver and copper have the property of antimicrobial activity. Polymer-based copper nano-compounds have been investigated with the antifungal activity against plant infecting fungi (Cioffi *et al*., 2004). Efficacy of silica-silver nanoparticles was studied by Park *et al***.,** (2006) against the plant infecting fungi *Rhizoctonia solani*, *Pythium ultimum*, *Botrytis cinerea*, *Magnaporthe grisea* and *Colletotrichum gloeosporioides* for their control. Similarly, nano-based products were used for the control of pumpkin disease, the powdery mildew and it was demonstrated that the infecting pathogens on the leaves causing the disease were vanished within three days after spraying the product. Antifungal action of several types of nanoparticles and their combinations has been demonstrated against different plant pathogenic fungi such as *Raffaelea sp.* (causing disease in oak trees), *B. sorokiniana*, *M. grisea*, *Fusarium*, *Phoma*, gram-negative and gram-positive bacteria (Kim *et al*., 2009; Gajbhiye *et al*., 2009; Esteban-Tejeda *et al*., 2010). It was concluded from different experiments that the growth of fungal hyphae and conidial germination are significantly inhibited by nano-based products especially of silver and copper nanoparticles. In recent times, nano-herbicides, nano-fungicides and nano-pesticides are in use in the agriculture. Some companies are preparing water soluble formulations while others are preparing nano-emulsions which contain different ranges of nano-particles such as 100-250 nm and 200-400 nm in size respectively. These formulations have numerous applications of prevention, treatment and preservation of harvested products (Rickman *et al*., 1999; Zahir *et al*., 2012).

4. Insect Pest Management by the Use of Nanotechnology

Like other fields of agriculture and food industry, nanotechnology is also being suggested for insect pest control. It is studied that nanoparticles show their efficacy against plant pathogens and insect pests. Therefore, these metal particles can be used for preparaing the formulations of insecticides, pesticides and insect repelling chemicals (Esteban-Tejeda *et al*., 2010; Zahir *et al*., 2012). A promising application of nanotechnology is the gene (DNA) transfer by the nanoparticles. Desired chemicals and DNA can be transferred into the plant tissues for host plant defense against the pest insects (Torney, 2009). A "porous hollow silica nanoparticles" full of validamycin is an effective transfer system for pesticides that are soluble in water for the release under controlled conditions. Nano-emulsions (oil in water) were considered as useful for pesticide formulations and efficient against several agricultural insect pests. In the same way, other useful formulation for nano-pesticides is essential oil filled lipid nanoparticles that are solid in nature (Gao *et al*., 2007). Nano-silica that is prepared from silica can also be used as nano-pesticide. Insects use a diversity of lipids on their cuticle for the protection of water obstruction on their bodies thus preventing the death from dryness. This mechanism of insect protection is used by the nano-silica that becomes absorbed into the lipids of cuticle by physiosorption thus causing insect death solely by physical ways when this pesticide is applied on the surfaces of leaves and stem (Barik et al. 2008). A wide range of agricultural insect pests can be controlled by the use of nano-silica (Ulrichs *et al*., 2005). Nanoparticles coated with Polyethylene glycol that were coated with natural oil of garlic were checked for their biocidal activity against adult stage of red flour beetle, *Tribolium castaneum*, a stored grain pest (Yang *et al*., 2009).

Different types of nanoparticles like aluminium oxide nanoparticles (ANP), silver nanoparticles (SNP), titanium dioxide and zinc oxide were experimented for the control of grasserie disease in silkworm and rice weevil (Goswami *et al*., 2010). El-bendary and El-Helaly (2013) reported that nano-silica application to the tomato plants can minimize the issues caused by *Spodoptera littoralis* providing resistance to the moderate level. Sprays of nano-silica on tomato plants influence the feeding preference of *S. littoralis* ultimately increasing the resistance in plants. It affects the reproductive potential of insect females causing a reduction in population density of insect, damages and crop yield. Nanostructured alumina was also studied for its insecticidal activity against *Rhyzopertha dominica* and *Sitophilus oryzae* which are the main insect pests of stored grain products throughout the world (Teodoro *et al*., 2010). It may provide a reliable and cheap alternative source for the management of pest insects. Nano-encapsulation, a good example of nanotechnology that is recently being applies as new technology for host plant's protection against pest insects. In the nano-encapsulation technology, different nanoparticles types are used with insecticide (Scrinis and Lyons, 2007; Bhattacharyya *et al*., 2010).

5. Conclusion

In most of the countries in the world, agriculture is the backbone of the country. The adoption of new technology in different fields of agriculture and food industry by the proper monitoring systems, pest and disease detection, smart systems of chemicals and gene delivery in the crops, nano-pesticides and encapsulation, nano-formulations and many other applications will revolutionize the agriculture. It will increase the productivity and reduction in agricultural wastes will occur that will indirectly reduce the pollution from the environment. It is the need of time to incorporate nanotechnology in the agriculture system with further research studies and practical application in the fields.

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