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Review Article

APPLICATION OF NANOTECHNOLOGY IN INSECT PEST MANAGEMENT: A REVIEW

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ABSTRACT

Insect pests are one of the most concerned biotic obstacles in agriculture and humans are constantly in search of new strategies to control them. Chemical pesticides are extensively used for controlling insect pests which cause a lot of problem, such as pest resistance, elimination of natural enemies, environmental pollution, loss of biodiversity and human health hazards. As an alternative pest control strategy, the application of nanotechnology in insect pest management can be one of the most promising ways to overcome the problems related to the application of conventional chemical pesticide. According to various research findings, the nano based materials are described as very effective in insect pest management because they have larger surface area which ensures the contact of more volume of pesticides with the insect pests. They also provide selective, targeted and long term-controlled release of formulation of nanomaterial which is ecologically more viable. Moreover, the required amount of nano-insecticide is also very small for controlling insect and thus the pesticide load in the environment gets reduced. So, use of nanotechnology for insect pest management is considered as environmentally sustainable and a brilliant insect control strategy in green agriculture.

Keywords: Nanotechnology, Nano-formulation, Nanoparticles, Insect Pest Management

INTRODUCTION

Agriculture is one of the primary sectors of livelihood and around 19% people of the world are directly involved in agriculture. But the production of crop is hindered by various abiotic and biotic stresses. Pests are biotic factors including weeds, insects, pathogens, nematodes which cause about 20-40% crop loss (FAO, 2021). It is

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estimated that 18-20% of the produced crop is destroyed by the insect pests worldwide (Arora and Sandhu, 2017). Larvae and adult insects have been most lethal for the crop plants. To control insect pest humans have been taking various management techniques from the very beginning to present such as cultural method, mechanical method, biological method, chemical method, etc. The chemical control method in which synthetic pesticide is used, has become popular to farmers. It is now considered as an important input for increasing crop productivity and crop protection in modern agriculture. Approximately, 2 million tons of pesticides are used annually, which consists 29.5% of insecticides (Zhang, 2018). The inconvenience related to traditional pesticide formulation includes the use of poor dispersion, harmful solvent, dust, drift etc. As a result, more than 90% pesticides are run off into the environment and remain in agricultural products during the process of application (Zhao et al., 2017). Disorganized and excess use of this toxic chemicals result in so many problems, such as pest resistance, outbreak, environmental pollution, loss of biodiversity leading to ecological imbalance and human health hazards (Raju, 2019). Additionally, bioaccumulation can occur by the accumulation of active ingredients or their metabolites in the environment or in the organisms and by these process pollutants entering in the food chain cause a serious threat to both wildlife and humans (Stadler et al., 2018). Majority of the active ingredients of these pesticides are water insoluble organic compounds and need to add carrier material in order to make a suitable formulation which is conducive to spray application at the field level (Ghormade et al., 2011). The indiscriminate use of conventional pesticide can also lead to the elimination of the natural enemies of insect pests, as there is lack of selectivity in formulation (Khan et al., 2015). So, they need to be replaced by an alternative insect pest control strategy that can overcome the above mentioned problem.

Nanotechnology is considered as the fifth revolutionary technology of the last hundred years (Chhipa, 2017). In the recent two decades, the knowledge accumulated in these areas is being transferred and adapted in the agricultural sector to utilize it for the development of plant protecting agrochemicals (Mattos et al., 2017). Nanotechnology is the control of object at dimensions between 1 to 100 nanometers (nm) where unique phenomena involved novel applications (Chowdappa and Gowda, 2013). The properties of nanoscale materials namely physical, chemical and biological are completely distinct from their bulk materials and individual molecules (Li et al., 2001).

Using of nanotechnology for the insect pest management is one of the alternatives to overcome the problems related to the use of conventional pesticide and it is an emerging tool in agriculture for controlling insect pests. Nano-insecticides are plant protection chemicals, in which either the active ingredient or the carrier molecule is developed through nanotechnology. The absolute small size of nanomaterials is the blessings. Having smaller size, nanoparticles have larger surface area and thus more volume of pesticides gets contact with the insect pests (Rajna et al., 2019). The amount required from nano-pesticides is very small for effective pest management and it can reduce the pesticide load on the environment (Kumar et al., 2015). Moreover, nano-formulation provides selective, targeted and long term controlled release of pesticides, which is ecologically more viable. The desired material can be transferred into the plant or insect effectively in the form of nanoparticles, nano-capsule, nanogel and nano-emulsion (Raju, 2019). There are a lot of beneficial effects of nano-insecticides over traditional synthetic chemical insecticides for controlling insect pest. Therefore, the current endeavor is aimed to review current knowledge and application of nano-insecticides for insect pest management, and to explore the potentials of this emerging technology in Entomology.

The scope and approach of implying nanomaterials in modern insect pest management

Nanoparticle engineering is one of the latest technological innovations which demonstrate unique targeted characteristics with elevated strength. Norio Taniguichi, a professor at Tokyo University of Science first coined the term "nanotechnology" in 1974 (Khan and Rizvi, 2014). The nanotechnology is the branch of engineering which deals with the manipulation dimensions of individual atoms and molecules less than 100 nanometers (Raju, 2019). Nanotechnology has long been introduced in multiple disciplines and is a recent technological innovation in agriculture (Gogos et al., 2012). Any particles with dimension less than 500 nm that exhibit novel properties is accepted as nano-based pesticide formulations (Kah and Hofmann, 2014). Nanomaterials have a great promise for the management and control of insect pest. These include insect pests management through the formulations of nano based insecticides, transfer of nano-particle-mediated gene or DNA in plants for the development of insect pest resistant varieties, agricultural productivity enhancement using nanoparticles (encapsulation) for slow release (Bhan et al., 2018). It is also reported that calcium carbonate nanoparticles can enhance plant insect pest tolerance (Hua et al., 2015).

Some nano-based insecticides are synthesized by using oil in water emulsion system (micro-emulsion and nano-emulsion) and the conversion of emulsion to organic nanoparticles (Elek et al., 2010). Nano-insecticides can also be prepared by directly processing into nanoparticles or by loading insecticides with nanocarriers in delivery systems (Urkude, 2019). It would appear that some nano-based insecticides have already been on the market for several years. Some nano particles work against insect pests are given in Table1.

Table 1. Some nanoparticles and their active ingredients used against insect pests.

Nanoparticle	Active Ingredient	Target Organism	Reference
Nanoencapsulation	Essential oil (EO) of *Carum copticum*	Diamondback moth (*Plutella xylostella*)	Jamal et al. (2013)
Myristic acid-chitosan nanogels	Essential oil (EO) of *Carum copticum*	Wheat weevil (*Sitophilus granarius*)	Ziaee et al. (2014)
Polyethylene glycol coated nanoparticles	Essential oil of garlic	Red flour beetle (*Tribolium castaneum*)	Yang et al. (2009)
Nanogel	Methyl eugenol	Oriental fruit fly (*Bactrocera dorsalis*)	Baghat et al. (2013)
Nanocapsules	Pyridalyl	Cotton bollworm (*Helicoverpa armigera*)	Saini et al. (2014)
Nanocapsules with azidobenzaldehyde	Methomyl	Armyworm (*Spodoptera frugiperda*)	Sun et al. (2014)
Chitosan-coated nanoformulations	Pyrifluquinazon	Green peach aphid (*Myzus persicae*)	Kang et al. (2012)
Chitosan nanocarrier	Nomuraearileyi	Tobacco cutworm (*Spodoptera litura*)	Chandra et al. (2013)
Nano dust	Nano-Al_2O_3 dust	Rice weevil (*Sitophilus oryzae*)	Stadler et al. (2010)
Nano-DEPA (diethylphenylacetamide)	DEPA	Mosquito (*Culex quinquefasciatus*)	Balaji et al. (2017)

Emerging field of nano-pesticides for controlling insect pests

Various types of nano-formulations are mostly used to control insect pest. Any formulation with nanometer size ingredients and consist organic polymers or inorganic metal oxides are regarded as nano-formulation (Raju, 2019). The principal objectives of nano-pesticide formulations are: (a) to increase the solubility of poorly soluble active ingredients (a.i.) or (b) to release the a.i. in a slow/targeted manner and/or protect the a.i. against premature degradation (Shah et al., 2016). A wide variety of natural or synthesized particles such as metal, metal oxides, non-metal oxides, carbon, silicates, ceramics, clays, layered double hydroxides, polymers, lipids, dendrimers, proteins, quantum dots etc. used for production of pesticide nano-formulations (Niemeyer et al., 2001). Among the nano structured system, polymeric nano-particles are used for controlled release formulation (Sun et al., 2014). Recently they are used for the delivery of pesticide where the active ingredients are loaded with polymer, which are within the nano range of 1-1000 nm (Nuruzzaman et al., 2016). The most used nano-based insecticides are nano-emulsions, nano-particles and nano-capsules (Fig. 1). Besides this, nanogel, nanosphere, nanosuspension are also popular nano-system in insect pest management.

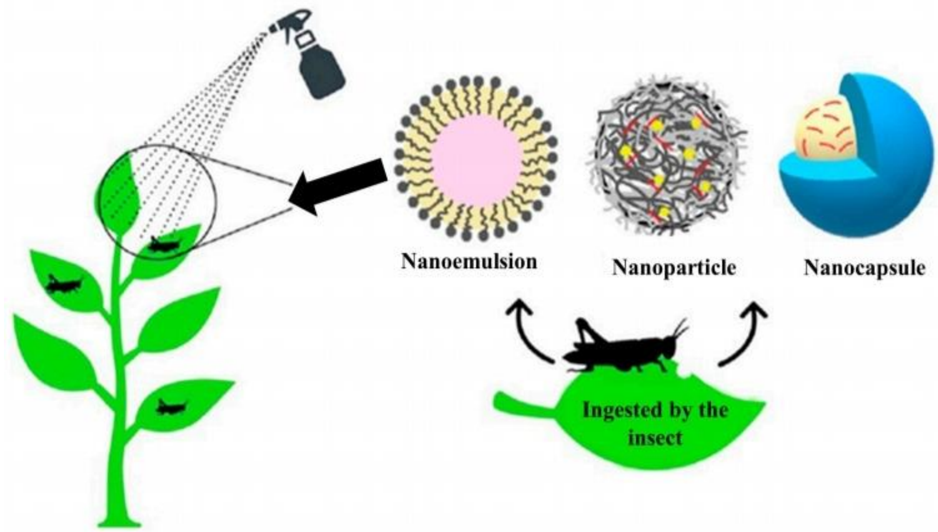

Figure 1. The most used nanosystems in insect pest control (Medina-Pérez et al., 2019).

Nano-formulations used in insect pest management

Nano encapsulation

The coating of various substances within another material at various sizes in the nano-range and through which a chemical is slowly but efficiently released is called nano-encapsulation (Ragaei and Sabry, 2014). In the process of nanoencapsulation, individual particles or droplets of solid or liquid core material are surrounded or covered with a continuous film of polymeric material. This ensures the release of the pesticide only in the targeted environment like in specific pH (e.g., in the stomach or inside a cell), specific temperature, moisture, external ultrasound frequency or in the occurrence of explicit compounds (Urkude, 2019). Li et al. (2016) stated that nano-capsules exhibited a higher release rate than the microcapsules because materials with smaller size have larger surface areas being exposed to the surroundings. It is the most vital technique for the protection of plants against insect pest. It has a lot of application in insect pest management. Schematic diagram of nanoencapsulation in pesticide applications is shown in Fig. 2.

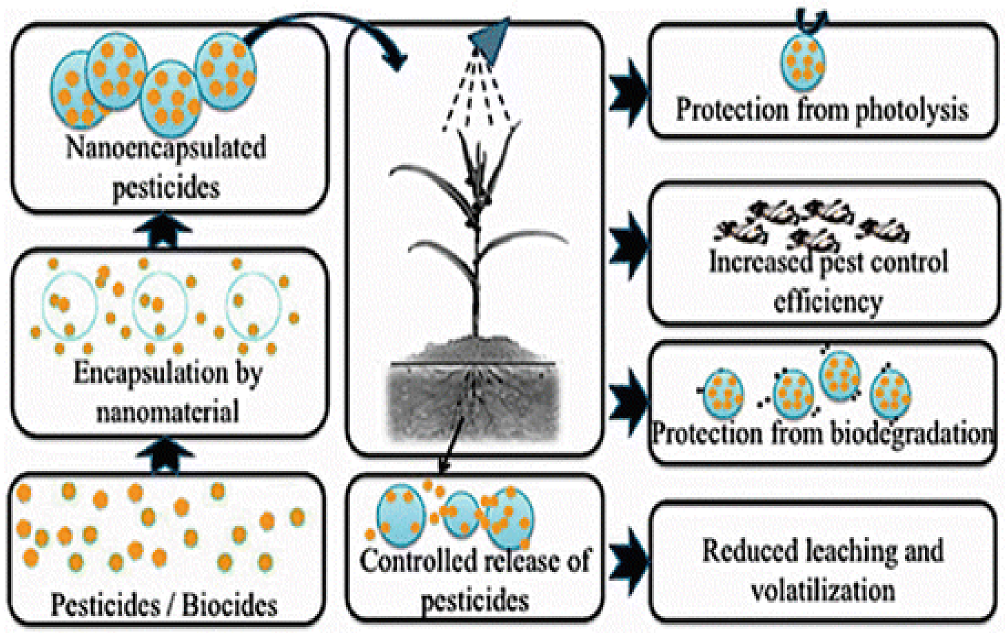

Figure 2. Schematic diagram of nanoencapsulation in insecticide applications (Nuruzzaman et al., 2016)

Nano-emulsion

Nano-emulsions are also most important formulations to enhance solubility and dissolution properties of poorly water-soluble substances (Wang et al., 2009). They have small droplet size (20-200 nm) and are also referred as mini-emulsions or ultrafine emulsions (Fernandes et al., 2014). In a nano-emulsion, one liquid is dispersed as small spherical droplets into another liquid but required a lesser amount of surfactants about 5-10% (Raju et al., 2019). The smaller droplet size of nano-emulsion confers them stability against sedimentation or creaming and a transparent or translucent optical aspect (Shah et al., 2016). Nenaah (2014) observed that nano-emulsion of Achillea plant's (a flowering plant of Asteraceae family) oil showed higher fumigant toxicity against the larvae and adult of red flour beetle.

Nanogel

Nanogels are aqueous dispersions of hydrogel particles formed by physically or chemically crosslinked polymer networks in the nanoscale size. This nanogel is chemically, thermally and mechanically more stable than natural pheromone and it lowers down the evaporation of the highly volatile pheromone methyl eugenol (ME) and protects it from the degrading by environmental factors like exposure to air, water and sunlight (Raju, 2019.). Bhagat et al. (2013) studied with nano-gelled pheromone for the management of *Bactrocera dorsalis*, a prevalent harmful pest for a number of fruits including guava. They found effective results using nano-gel based pheromone over natural pheromone, methyl eugenol. They also described nanogel as a potential particle for crop protection, long lasting residual activity, excellent efficacy and favorable safety profiles and effective in rainy season.

Metalic nano-particles

Some of the metal and metal oxide nanoparticles have insecticidal efficacy. Nanostructured alumina, nano-structured gold, nano-silver (Ag), nano-cadmium sulfide (CdS) etc. are very effective against insect pest (Ziaee and Hamzavi, 2013). Debnath et al. (2012) found that amorphous lipophilic silica nanoparticles had toxicity on *Tribolium castaneum*, a stored grain insect pest. Goswami et al. (2010) reported that nano-silica had insecticidal toxicity against some mosquito species that transmit human diseases. According to Chakravarthy et al. (2012), DNA tagged gold nanoparticles are effective against *Spodoptera litura,* fall army warm. Zahir et al. (2012) found in their experiment that silver nanoparticles (Ag NPs) were more effective to control *Sitophilus oryzae,* rice weevil than silver nitrate as well as aqueous extract of *Euphorbia prostrata* (a medicinal plant). Moreover, the required amount of Ag NPs was also less to kill the adult insect (Fig. 3).

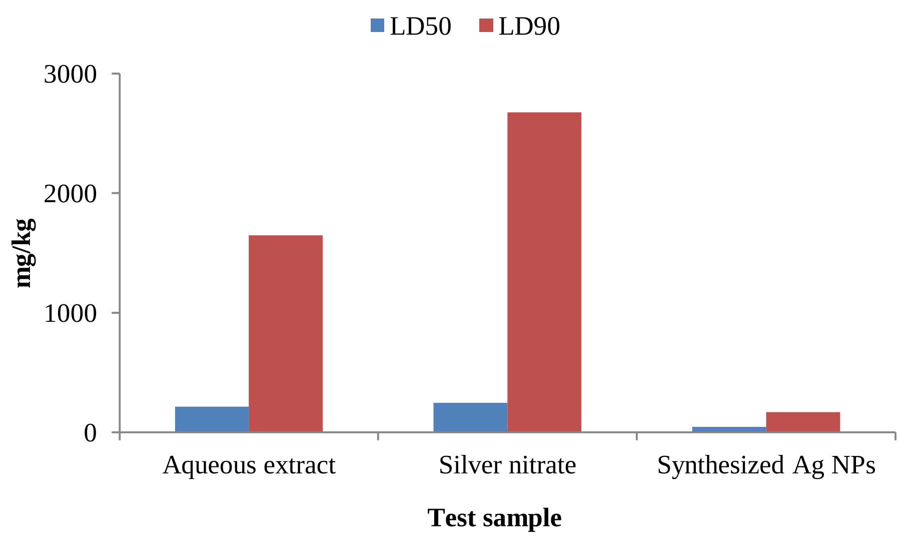

Figure 3. LD50 and LD90 of aqueous extract of *Euphorbia prostrata*, silver nitrate solution and synthesized Ag NPs against the adults of *Sitophilus oryzae* (LD: Lethal Dose) (Zahir et al., 2012).

Botanical nano-pesticide

As consumers demand for safe products widen, interest on developing plant-based insecticides has gained more attention (Omar et al., 2016). Botanicals offer an environmentally benign solution for the management of insect pests; however, their application is limited due to their low stability in environment (Forim et al., 2013). Nanotechnology offers great promise in this direction and nano-formulations can be used to improve both the stability and effectiveness of these natural products (Ghormade et al., 2011). Nanostructured botanicals such as azadirachtin, rotenone, carvacrol, thymol, curcumin etc are very effective against insect pest (Shah et al., 2016). Forim et al. (2013) observed that nanoparticles loaded with neem (*Azadirachta indica*) spray-dried powder can cause 100% larval mortality of diamondback moth with greater stability against UV.

CONCLUSION

Although nanotechnology is a recent trend in plant protection sector, the uses of nanotechnology for controlling insect has already been started. Nano-encapsulated insecticides can reduce the loss of insecticide in the environment as they release only in the specific target side. As nano-formulated insecticides have relatively larger surface area, they can efficiently control target insect pest with the lower concentration. A number of nano-particles may have entomotoxic effects on the existing key insect pests, which is yet to be exploited. Furthermore, the synthesis of nanoparticles from biological agents such as plants and microbes is a promising way of ecofriendly management of insect pests. Overall, nano-based insecticides can become a better alternative of conventional insecticide and can reduce the pesticide load in the environment.

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