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Current status of nanotechnology in insect pest management strategies: A review

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Abstract
Nanotechnology holds great promise for controlling insect pests by using controlled and targeted delivery of agrochemicals. As insecticides and insect repellents, nanoparticles, nano emulsions, nano suspensions, and nano capsules have a wide variety of uses. There have been studies on stored grain insects (*Tribolium castaneum*, *Callosobruchus maculatus*, *Martianus dermestoides*, *Rhyzopertha dominica*, *Sitophilus oryzae*, *Corcyra cephalonica*, etc.), crop pests (*Aphis nerii. Spodoptera litura*, *Bactrocera dorsalis* etc.) and other pests in this regard. Nanoencapsulation is the most promising technology for crop protection at the moment. Nanotechnology can revolutionize insect pest management in the future.

Keywords: crop protection, insect pest, sustainability, ecofriendly

Introduction

The field of nanotechnology has rapidly developed into a cutting-edge scientific field. The utilization of different techniques to create configurations and study physical fact between 1 and 100 nm in physical size is termed nanotechnology. Compared to with bulk molecules, nano scale materials possess unusual biological, chemical and physical characteristics (Li *et al*., 2001). Nanotechnology operates more through studies of new properties at nano scale, and through the ability to affect and synthesize structures at that scale. In practice, nanotechnology is primarily concerned with the exploration of novel properties that manifest themselves at that scale.

Kostoff *et al*. (2007) [26] traced nanotechnology's rich scientific heritage back to the 19th century. They presented a set of criteria for successful science and technology roadmaps in nanotechnology. In a follow-up to technology road mapping (Phaal *et al*., 2004) [37], a fast-start variant is described, along with more context for using the method.

Nanotechnology is a powerful technology with the potential to significantly alter the agricultural system. The development of nanomaterials could lead to more efficient, safe, and effective direct pesticides, herbicides, and fertilizers by controlling when and where they are released (Kuzma and VerHage, 2006). Nanotechnology in agriculture has the potential to revolutionize this section, with new tools for disease detection, targeted treatment, enhancing plants' ability to absorb nutrients, fight pests, and tolerate ecological pressures (Sharon *et al*., 2010) [44].

By developing nanotechnology systems to deliver pesticides appropriately, pest-management practices can be improved. The use of nanotechnology in pest management can take many forms. Nanoparticle-based insecticides exhibit remarkable properties during production, such as chemical reactivity, electrical conductivity, and extraordinary strength. As a result of their atomic strength, they have distinct physical, biological, and chemical properties. Agglomerated nanoparticles can be sized and shaped specifically and organized into layers (Roy 2009) [41]. New insecticides can be developed by exploiting the properties of nanoparticles. These particles are released slowly but effectively towards a specific host plant against an insect pest, as described by Scrinis and Lyons (2007) [43]. A growing number of pest control technology uses smart polymer nano capsules that contain insecticides, herbicides, fungicides, pheromones, repellents, and allomones to kill pests. Insect-pest control can be achieved by using nanoparticles, such as nano porous zeolites, nano capsules, and nano sensors. The application of carbon nanotubes (1 nm) to protect plants from pest insects has tremendous potential. These properties, along with self-assembly, stability, specificity, encapsulation, and biocompatibility, make nanomaterials highly desirable (Ehdaie 2007) [16].

In addition to increasing yields and nutritional values of crops, nanobiotechnology can also increase the plant's ability to resist insect pests (Bhattacharyya *et al*. 2010) [5]. Detecting plant pathogens, viral infections, and host plant diseases can be done with nanotechnological tools. Also, insect pest attacks can be prevented from causing huge losses in crops. Recently, DNA-tagged nanoparticles, insecticide-coated nanoparticles, and hormonally blended nanoparticles have been used to control insect pests (Chowdappa and Shivakumar Gowda 2013) [10].

In the future, nano scale systems can be used to control the release of agrochemicals, including fertilizers, pesticides, herbicides, plant growth regulators, and ionic attachments, which will reduce input and waste and allow for slow uptake of active ingredients. Its improved solubility and stability to degradation in the environment are the reasons for the importance of nano scale delivery systems in agriculture. Because nano scale delivery vehicles adhere firmly to plant surfaces, they provide increased effectiveness and reduce the environmental impact of agrochemical runoff. (Chen and Yada, 2011) [9]. Nanosensors are commonly used to detect and measure a range of factors, including crop nutrient status, insects, pathogens, weeds, soil fertility, temperature, and moisture. This provides vital information for precision farming practices that lead to a reduction in inputs, maximum output, and minimum waste during cultivation (Scott and Chen, 2003) [42]

Many communities, nations, and government have been concerned with food shortages for a long time. In the future, the issue appears to threaten even more. Despite reducing the amount of land that can be cultivated, the challenge is to feed a rising population with fewer costs of input, and with fewer risks to the environment. The ever-growing global population and increasing urbanization, along with environmental issues such as run-off and accumulation of agrochemicals, have led to an increase in the demand for food in the coming years (Chen and Yada, 2011) [9]. A limited supply of natural gas and petroleum has resulted in a drastic increase in the price of chemical fertilizers, pesticides, and other production inputs (Ditta, 2012) [15]. Nanotechnology and precision farming techniques can be used to overcome these constraints. Therefore, nanomaterials play a significant role in supporting sustainable agriculture and providing better products globally (GruËre, 2012).

The application of nanotechnology in developing countries is important for enhancing agriculture productivity, along with other emerging technologies including genetics, plant breeding, disease prevention, fertilizer, and other allied fields. (Jha *et al*., 2011). Despite there being no many signs that nanotechnology harms people or the environment, it is still an area of study where research and development are still at a bench-top level. This review examines the role of nanotechnology in insect pest management for the improvement of agriculture in a cost effective, and environmentally friendly greener way.

Nanopesticides

Definition of Nano Pesticides

As an alternative to conventional insecticides, nano-pesticides can fill in the gaps. A nano-pesticide is a plant protection chemical whose active ingredient or carrier molecule was developed using nanotechnology. In the European Union, regulation definitions of nanomaterials have not yet been universally accepted due to the conflicting definitions proposed by many national and international organizations (European Commission Joint Research Center, 2010). As nano pesticides are used in legal, scientific, public, and commercial contexts, it is important to distinguish how they are used and the criteria used in these contexts vary, for example, as a function of particle size, activity, and perceived novelty or risk. Kah *et al*. (2013) [30] previously discussed the definition of nanoparticles and how the criteria proposed to date can be applied to nano pesticides.

According to ISO 14644-6:2007, particles can also be liquids, such as droplets in emulsions or micelles. A Chemistry Council definition of engineered nanomaterials explicitly excludes micelles and single polymer molecules (European Commission Joint Research Center, 2010). It is becoming increasingly evident that nano pesticides require regulatory definitions. A pesticide formulation inventory (Crop Life International, 2008) does not use any specific terminology. Therefore, until a clear definition is agreed upon, it is impossible to answer the recurrent question of whether nano pesticides are already on the market. Depending on the definitions and products considered, nano pesticides may or may not qualify as nanomaterials.

Nanopesticide Formulations

Various nano formulations have been developed as a result of research in nanotechnology, including nano insecticides, nano herbicides, nano fungicides, and nano nematicides. Formulations for nano-pesticides are designed based on their intended purposes, such as improving solubility, slowing down active ingredient release, preventing degradation, etc. Most definitions of nanomaterials limit the size of nanoparticles to 100 nano meters (European Commission Joint Research Center, 2010). A possible explanation for this can be found in the use of the prefix nano- in association with novelty or higher performance. Polymers, Surfactants, and metal nanoparticles in the nm range are commonly used in nano formulations. It is still a subject of intensive research to develop economically viable methods of preparation and stabilization. Over the past decade, several reviews have been published on the preparation of organic nanoparticles (Gutierrez *et al*., 2008) [21].

A nano pesticide is defined as any pesticide formulation that includes entities with a nano meter size range (here we include entities with up to 1000 nm in size), carries the "nano" prefix (e.g., nano hybrid, nanocomposite), and/or is purported to have novel properties due to its small size.

The normal oil-in-water emulsion is known as a nano emulsion, where the active ingredient of the chemical is dispersed as nano sized droplets in water with the surfactant molecules confined at the interface between the pesticide and the water. Depending on the type and amount of surfactants, nano-emulsions can be classified as thermodynamically or kinetically stable. Nano-emulsions are thermodynamically stable if the pesticide is partially soluble in water and spontaneously forms an emulsion when surfactant, pesticide, and water are mixed. Pesticide droplets in the nano-emulsion will remain dispersed for an extended period of time due to the insolubility of the active ingredient. As a result, a continuous mix of the pesticide and surfactant will result in a kinetically stable nano-emulsion. Using Tween 20 as the surfactant, an oil-in-water nano emulsion of neem oil has been developed to control insects. The aim of nano emulsions is generally to increase the apparent solubility of poorly soluble active ingredients, while keeping the concentration of surfactants lower than that in micro emulsions. Nano emulsions of pesticidal active ingredients have often been suggested to increase the uptake of the active ingredients.

Polymer-Based Nanopesticides

It is most common to use polymer-based pesticide nano carriers to deliver active ingredients slowly and controlled to a specific target. Furthermore, they serve as a protective reservoir as well as improving dispersion in aqueous media. Beeswax, corn oil, lecithin, or cashew gum are a few examples of biodegradable materials of biological origin that have gained popularity during the last two years (Nguyen *et al*., 2012) [33]. Besides being environmentally friendly, it is also possible that those matrix materials, when used in conjunction with natural active ingredients, could be considered for organic farming.

In nature, there are many substances with pesticidal properties. However, these substances are unstable and need protection against premature degradation. New polymer-based nano formulations presented in recent papers all share the target of developing plant-protection products that are less harmful by using biodegradable polymers and/or artificial intelligence (AI). Recently, many polymer-based nano formulations have been proposed for this purpose in the form of nano spheres, nano gels, nano fibers, nano encapsulation, etc

A nanoparticle or nano capsule consists of an outer polymer coating or membrane surrounding a central cavity in which the active ingredient can be contained hydrophobic or hydrophilic. The bioactive ingredient is uniformly dispersed throughout the polymer matrix of nano spheres, which are homogeneous vesicular structures. Hydrogel nano partciles are also known as nanogels. In these formulations, polymeric particles with hydrophilic groups are cross-linked, enabling them to absorb a greater amount of water. Using electro spinning and thermal induced phase separation, nano-fibres are developed. In order to manage many lepidopteran insect pests, researchers have developed electospun nano fibers that contain the chemical (Z)-9-dodecenyl acetate, a component of pheromones.

Hybrid Nanoformulations

More complex nano formulations for the delivery of pesticides. examples using solid lipid nanoparticles and coated liposome. he preparation of coated liposomes for the slow-release of insecticide was first described by Bang *et al*. (2009) [2]. simultaneous application of nano formulated and conventional active ingredients ia a suggestion from many of the earlier worklers to reduce the active ingredient application frequency, and hence the costs of application

Inorganic Nanoparticles Associated with an Organic Active Ingredient

Nano formulations associated with an organic active ingredient involved either mesoporous silica as a carrier and TiO2 in a polymer matrix as a catalysing agent until recent years (Kah *et al*., 2013) [30]. Different formulations involving silica and calcium carbonate nanoparticles as carriers have been proposed recently (Mingming *et al*., 2013; Qian *et al*., 2011) [31, 38] for the slow release of an organic active ingredients. It was proved that the insecticidal activity of chlorfenapyr associated with silica nanoparticles was twice as high as that of chlorfenapyr associated with micro particles in both field and laboratory experiments (Mingming *et al*., 2013 [31]; (Qian *et al*., 2011) [38]

Inorganic Nanoparticles as Active Ingredients

Nano pesticides can also be made from inorganic solid nanoparticles. Most preferred as nanoparticles are silver, titanium oxide, aluminum, silica, and copper. Agricultural pest control has long been associated with silicon's ability to enhance plant tolerance to abiotic and biotic stresses, and silica nanoparticles have been suggested as potential candidates (Barik *et al*., 2008) [3].

Nanotechnology in Insect Pest Management

As nanotechnology advances, it will increasingly be used to formulate and deliver pesticide active ingredients, as well as enhance and offer new active ingredients. Insecticides, fungicides, and herbicides have all been used with nano pesticides. The use of polymer-based nanoparticles is being used to deliver active ingredients with improved penetration through leaves, as well as to control their release. Gene transfer using nanoparticles is a promising application of nanotechnology. In order to protect host plants against insect pests, DNA and other chemicals can be delivered into plant tissues. Insecticides, pesticides, and insect repelling chemicals can be prepared using these metal nanoparticles (Zahir *et al*., 2012) [50].

Silica nano-pesticide can be prepared from nano-silica. An insect's cuticle contains a variety of lipids for protection against water obstruction and death from dryness. The nano-silica that becomes absorbed into the lipids of the cuticle by physiosorption is used to provide this type of insect protection (Barik *et al*., 2008) [3]

Insect pest management will be made more efficient and effective with the use of nanomaterials. It appears there is an urgent need to apply nanotechnology and this warrants detailed investigation (De *et al*., 2014) [11]. Nanotubes filled with aluminosilicate can stick to plant surfaces, whereas ingredients within nanotubes can adhere to the surface of insects and ultimately get into the body, affecting certain physiological functions (Patil *et al*., 2009) [35]. Phytoplankton fossils have also been reported to contain high silica content, which makes Diatomaceous Earths (DEs) effective against insects.

Crop Pests

Several nanoparticles, including CdS, Ag, silica, Zinc and TiO2, have shown significant effects on Spodoptera litura (Ahmed *et al* 2021). A dose-response analysis of second instar S. litura larvae revealed that the LC50 of nanoparticles of CdS, TiO2 and Ag on S. litura was 508.84, 791.10 and 1403.14 ppm respectively (Chakravarthy *et al*., 2012) [6]. Spodoptera littoralis may be minimized by applying nano-silica to tomato plants. As a result of nano-silica sprays, Spodoptera littoralis are less likely to feed on tomato plants, increasing their resistance. Also it affects biological parameters of the insect such as longevity and nymph production, thus reducing the reproductive potential (El-Bendary & El-Helaly, 2013) [17] and would therefore can be a used in integrated pest management strategy. Silica nanoparticle was found effective in controlling S. littoralis in soyabean under laboratory conditions. (Chandra *et al*., 2013) reported that chitosan nanoparticle is effective in controlling in S. litura. Novaluron nanoparticle and thiamethoxam-ZnO nanoparticle also found very effective in controlling S. litura (Jameel *et al*., 2020).

Mohammad Rouhani *et al*., (2012) reported entomotoxic effects of Ag and Zn nanoparticles (synthesized through a solvothermal method) on *Aphis nerii*. For comparison purposes, imidacloprid was also used as a conventional insecticide. In the experiments, the LC50 value for imidacloprid, Ag and Ag-Zn nanoparticles were calculated to be 0.13 ìL m/L, 424.67 mg m/L, and 539.46 mg m/L, respectively. The result showed that Ag nanoparticles can be used as a valuable tool in pest management programs of *A. nerii*.

A nanogel has been prepared from apheromone, methyl eugenol (ME) using a low-molecular mass gelator. The nanogelled pheromone brought about an effective management of oriental fruit fly, *Bactrocera dorsalis*, a prevalent harmful pest for a number of fruits including guava (Bhagat *et al*., 2013) recorded a significant pest control activity of zinc oxide nanoparticle on the greenhouse whitefly, *Trialeurodes vaporarium.* Bioefficacy of amphiphilic nanopolymer of carbofuran was tested by (Pankaj *et al*., 2012). This nano formulation was effective in against the root-knot nematode *Meloidogyne incognita* infecting tomato

Stored Grain Pest

Agricultural products are severely damaged by stored-product insect pests. Nano formulations of essential oils have been tested as alternatives to synthetic pesticides. By using such formulations for pest control and treatment, it is possible to improve the solubility of active ingredients, bioavailability of agrochemicals, and stability and wettability properties during application in order to achieve better results (Martin *et al*., 2010). Therefore, these formulations are expected to be more productive than conventional botanicals and insecticides (C. Anjali *et al*., 2012) [1] Essential oil-based nano formulations have shown significant efficacy in the management of different storage pests over the past decade (Pavoni *et al*., 2019) [36].

Compared to the 95% IMI, nanoparticles loaded with garlic essential oil are more toxic to Martianusder mestoides Chevrolat (Coleoptera: Tenebrionidae) than the 50% nano-SDS/Ag/TiO2-IMI as indicated by the lower LC50 value (Guan *et al*., 2008) [20]. Callosobruchus maculatus larvae and adults may be protected from pesticides using SiO2 and Ag nanoparticles (M Rouhani *et al*., 201A LC50 value of 0.68 g/kg cowpeas for SiO2 and 2.06 g/kg cowpeas for Ag nanoparticles was calculated on adults, and 1.03 and 1.00 g/kg on larvae, Results showed that both nanoparticles (silica and silver) were highly effective on both adults and larvae, adults and larvae with 100% and 83% mortality, respectively

It is suggested by Debnath *et al*. (2011) that surface functionalized silica nanoparticles (SNPs) could potentially replace conventional pesticides. A comparison of the entomo-toxicity of SNP and bulk-size silica (individual particles larger than 1 micrometer) was conducted regarding its efficacy against rice weevil Sitophilus oryzae. The effectiveness of SNP for insect pest control is demonstrated by the high mortality rate caused by amorphous SNP against this pest. Using scanning electron microscopy, X-ray diffraction, and energy dispersive X-ray spectroscopy, Vani and Brindhaa (2013) tested Silica nano particles for their entomotoxic effects on stored grain pest Corcyra cephalonica. The use of amorphous silica nanoparticles caused 100% mortality against this insect pest. Amorphous lipophilic silica nanoparticles have also been reported to be effective against red flour beetles (Tribolium castaneum) (Debnath *et al*., 2012) [12]. Aqueous leaf extracts of Euphorbia prostrate were used to synthesize silver nanoparticles (Ag NPs) that were studied for their entomotoxic effects on Sitophilus oryzae. In 14-day pesticide bioassays, varying concentrations were used

The LD50 values of aqueous extract, AgNO3 solution and synthesized Ag NPs were 213.32, 247.90, 44.69 mg/kg; LD90=1648.08, 904 S. Routray *et al*., Fig.-1: Malformed larvae of S. litura due to treatment of CdS (2), Nano-Ag (3), Nano-TiO2 (4) and control (1) (Chakravarthy *et al*., 2012) [6] 2675.13, 168.28 mg/kg, respectively. These results suggest that the leaves aqueousextracts of E. prostrata, and synthesized Ag NPs have the potential to be used as an ideal eco-friendly approachfor the control of the S. oryzae. (Stadler *et al*., 2010) [45, 46] successfully applied nano alumina against two stored grainpests like S. oryzae and Rhyzopertha dominica.It has been known that the application of nanoparticles loaded with garlic essential oil controlled adult *Tribolium castaneum* in the store house (Yang *et al*., 2009) [49].

Medically Important Insects

Anopheles subpictus and Culex quinque fasciatus fourth instar larvae were killed most effectively using silver nanoparticles synthesized from aqueous leaf extracts of Tinospora cordifolia (Jayaseelan *et al*., 2011). Several novel drugs can be made from surface-modified hydrophobic or lipophilic nano silica to treat nuclear polyhedrosis virus (BmNPV) of silkworm (Bhattacharyya *et al*., 2008). Compared to commercial sulphur, nano sulphur showed significantly higher acaricidal activity against red spider mites, Tetranychus urticae (Gopal *et al*., 2012) [18]. For controlling grasserie disease in silkworms and rice weevils, various nanoparticles were used, including aluminium oxide nanoparticles, silver nanoparticles, titanium dioxide, and zinc oxide (Goswami *et al*., 2010) [19].

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