ISSN PRINT 2319-1775 Online 2320-7876, www.ijfans.org
Vol.11, Iss.12, Dec- 2022

A SYSTEMATIC REVIEW ON APPLICATION OF NANOTECHNOLOGY FOR THE INSECT PEST MANAGEMENT

A. Selvam[1], M. Sheik Muhideen Badhusha[1] , R. R. Muthuchudarodi[2]

[1] Research Scholar (Reg. No: 17212232032012) Department of Chemistry, Sadakathullah Appa College, Tirunelveli 627011, Tamil Nadu, India.Affiliated to ManonmaniamSundaranar University, Abishekapatti, Tirunelveli 627012, Tamil Nadu, India

[1*] Assistant Professor, Research Department of Chemistry, Sadakathullah Appa College, Tirunelveli 627011

[2]Associate Professor, Research Department of chemistry, V.O. Chidambaram College, Thoothukudi-628008, TamilNadu, India

Corresponding Author: drbadhunano@gmail.com

ABSTRACT:
Nanotechnology is a promising field of interdisciplinary research. It provides up prospects in the areas of medicine, electronics, agriculture, and insecticides. The uses of nanotechnology are quite diverse. Among these is the use of nanomaterials for the management of insect pests. The use of chemical pesticides, which are harmful to people, animals, and the fertility of the soil, renders integrated pest management ineffective. Without having a negative impact on the environment, nanotechnology can one day provide environmentally friendly and efficient methods for the management of insect pests in agriculture. This painting focuses on traditional means to managing insect pests as well as the potential of using nanomaterials in such management as a modern use of nanotechnology.

Pesticides increase the productivity of agriculture, but their misuse can contaminate both the environment and the food supply. Improvements to pesticide delivery systems can increase bioefficacy while minimizing negative effects on the environment and human health. In modern insect pest management, nanoparticles are used as an effective tool. The efficiency of nanopesticides at low concentrations is beneficial to farmers and helps decrease pollution. This article provides a systematic review of traditional approaches to the management of insect pests as well as the potential of nanomaterials in the context of contemporary nanotechnology-based insect pest control.

Keywords: Agriculture, Nanotechnology, Bioefficacy, formulation, Nanoparticles, Environmental, Pest and Management,

1. INTRODUCTION

Agriculture employs 19% of the global population [1]. Both biotic and abiotic stresses are factors that reduce agricultural yield. Pests, which include weeds, insects, illnesses, and nematodes, are responsible for 20–40% of lost crops (FAO) [2]. 18–20% of the world's crops are destroyed by insect pests. Insect larvae and adults harm agricultural plants. Since the beginning of human history, people have used cultural, mechanical, biological, and chemical pest management measures in order to keep insect pests under control. Chemical pest management that is based on synthetic pesticides is popular among farmers. It plays an important role in modern agriculture, helping to enhance crop productivity while also protecting crops. Insecticides make up 29.5% of the total 2 million tons of chemicals. Traditional formulations of pesticides have several flaws, including insufficient dispersion, harmful solvents, dust, drift, and so forth. After application, then, more than 90 percent of pesticides are carried over into agricultural products and remain there. The uncontrolled and excessive use of dangerous pesticides contributes to the development of pest resistance, the spread of disease, the destruction of natural habitats, the reduction of biodiversity, and the disruption of ecological balance, as well as to the risk to human health. The process of bioaccumulation takes place when active compounds or their metabolites build up in an environment or in organisms. This opens the door for toxins to enter the food chain, which puts animals and humans in risk. The majority of these pesticides' active components are water-insoluble chemical compounds, which means that the field spray distribution of these pesticides requires a carrier fluid. Because conventional pesticides lack selectivity, it is possible that they will also destroy the natural enemies that insects pests have [4]. As a result, a way of insect pest management that is more efficient has to take their place.

2. NANOTECHNOLOGY

Nano is derived from the Greek term meaning dwarf, according to Bhattacharyyal et al. [5]. In scientific parlance, the term nano refers to a scale of 10^{-9}, or one billionth. Viruses are 100 nm. From nanometer-sized particles, nanotechnology developed (size of 1 to 100 nm). There are several uses for nanotechnology. Agricultural production is increased by nanoporous zeolites for the delayed release and effective dosage of water and fertilizer, nanocapsules for the delivery of herbicides and vector and pest management, and nanosensors for the detection of pests. Atom by atom, it is possible to modify the size, shape, and orientation of nano particles for tissue response. Ferromagnetic materials are used in the heads, thoraces, and abdomens of many different species of insects to create geomagnetic sensors. The management of insect pests and insect nanoparticles are also topics covered in this work. According to Leiderer and Dekorsy, targeted nanoparticles exhibit exceptional mechanical robustness, chemical reactivity, and electrical conductivity. Therefore, nanotechnology has the potential to be a game-changing new technology. Nanoparticles exhibit properties that are connected to atomic strength in the physical, biological, and chemical realms.

2.1. Nanoscale Materials and Their Application

Bacteria and beetles use protein machinery on the nanoscale scale to whip their flagella and muscles. Nanometer-sized carbon, also referred to as carbon black, which enhances the mechanical properties of tires, nanometer silver particles, which pioneered the development of photographic films, and nanometer particles, which serve as the basis for catalysts crucial to the petrochemical industry, have all made significant contributions to commercial products over time. Nanotechnology has a lot of potential for environmental safety.

2.2. Natural Nanoparticles in Several Insects

Despite being overlooked, naturally occurring nanostructures provide a rich source of materials with desirable properties [6]. Nanotechnology-based companies have just recently begun to use the very few free technologies found in nature. Hexagonal markings on the wings are shared by the cicada Psaltodaclaripennis Ashton and the termite family Rhinotermitidae. The research indicates that the size of nanoparticles can range from 200 nm to 1000 nm. The structures feature rounded apexes that extend outward from the surface plane by 150-350 nm. An insect's wings can have more aerodynamic properties that help nano particles. Nanoparticles in the insect's head with the antennae are 11 nm in size, while those in the abdomen with the petiole are 12 nm. The insect's complex eyes can include nanostructure components. Nanoparticle paint is used to decorate butterfly wings. Recent studies have led to the creation of a photodegradable pesticide based on nanoparticles.

2.3. Nanopesticides

Nanopesticides, which can be described as any product that purposefully combines components in the nm size range and/or claims specific qualities associated with these teeny-tiny sizes, have been available for purchase on the market for some time now. Nanopesticides are a varied category. Inorganic (metal oxides) and organic (polymers) components can both be included in nano insecticides in varying amounts (e.g., particles and micelles). Nanoformulations have the same aims as conventional pesticide formulations:

- Improving active ingredient solubility
- Slow/targeted release of the active component and/or protection against early breakdown.

It is anticipated that

1. Nano formulations will have significant impacts on the fate of the active component

2- Introduce new compounds whose environmental fate is poorly understood. (e.g. nanosilver).

3- The advantages and cons of using some nanopesticides cannot be adequately evaluated at this time. To successfully combine analytical techniques that can detect, characterize (such as size, size range, shape or nature, surface properties), and quantify the active ingredient and adjuvants from nanoformulations and understand how their characteristics change over time under realistic conditions will require a significant amount of effort and work.

2.4. Polymers

Adak et al. [7] used encapsulation to create a CR formulation of imidacloprid [1-(6-chloro-3-pyridinyl methyl)-N-nitro imidazolidin-2-ylideneamine] using amphiphilic copolymers synthesized from poly (ethylene glycols) and various aliphatic diacids, which self-assemble into nano-micellar aggregates in aqueous media. These amphiphilic polymers have a low CMC and a high solubilization power, which might improve the effectiveness of formulations. Methods such as infrared spectroscopy, dynamic light scattering, and transmission electron microscopy were employed to define the compounds. The encapsulation efficiency, formulation loading capacity, and formulation stability under accelerated storage conditions were all assessed. Release kinetics of imidacloprid in water from a number of various formulations were studied. Commercial formulations have a substantially faster release rate than CR formulations. When tested with different formulations, the diffusion exponents (n values) for imidacloprid in water range from 0.22 to 0.37. Imidacloprid 50% CR formulations were manufactured in 2.32-9.31 days. The newly discovered CR formulations can be used for effective pest management on many different types of crops. Components of a commercial formulation for use in the real world must be nontoxic, biodegradable, and affordable in addition to being safe for the environment. Biopolymers, which are natural polymers with desirable physical and chemical qualities that biodegrade in a non-toxic way, are an attractive alternative to petrochemical derivatives, which have the potential to damage the surrounding environment.

3. THE NANOPARTICLES USED IN BIOPESTICIDES CONTROLLED RELEASE FORMULATIONS

- Nano spheres are an aggregate in which the active ingredient is evenly distributed throughout the polymeric matrix.
- Nanocapsules, which contain the active chemical in its center and are surrounded by a polymer matrix, are the second type of aggregate.
- Nanogels are hydrophilic polymers that are often cross-linked and have a high water absorption capacity.
- Micelles, defined as an aggregation of molecules with both hydrophilic and hydrophobic moieties, are formed in aqueous solutions.

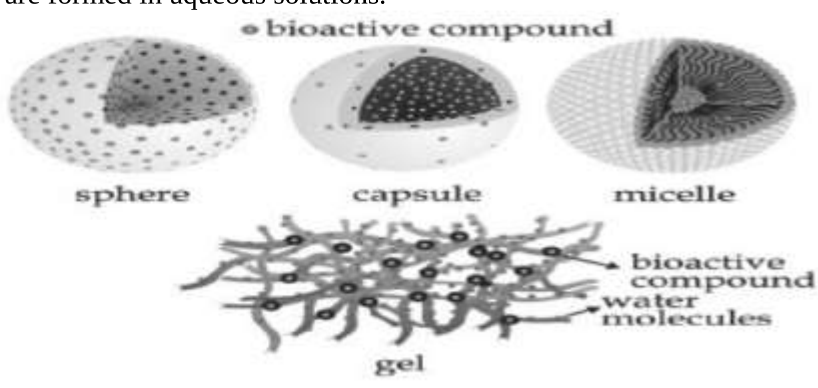

Fig. 1. A morphological depiction of each of the various nanoparticles.

ISSN PRINT 2319-1775 Online 2320-7876, www.ijfans.org
Vol.11, Iss.12, Dec- 2022

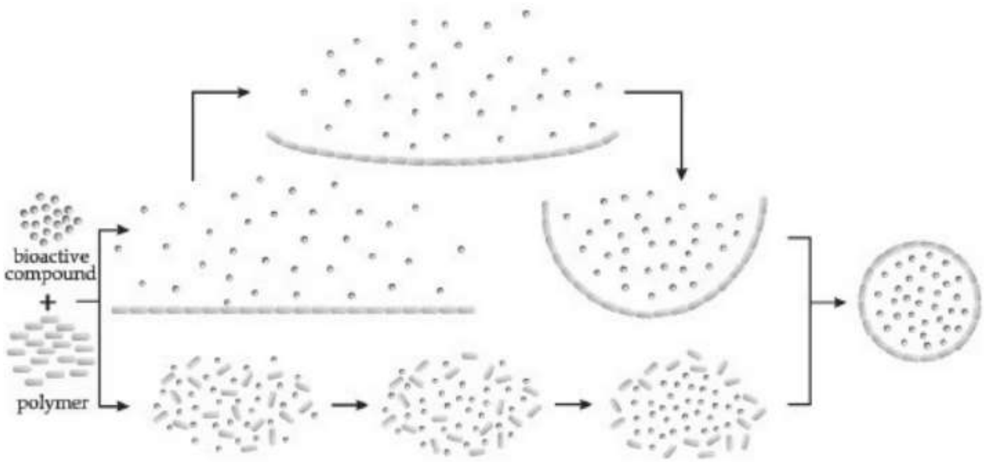

Fig. 2. Physical methods for CRF preparation

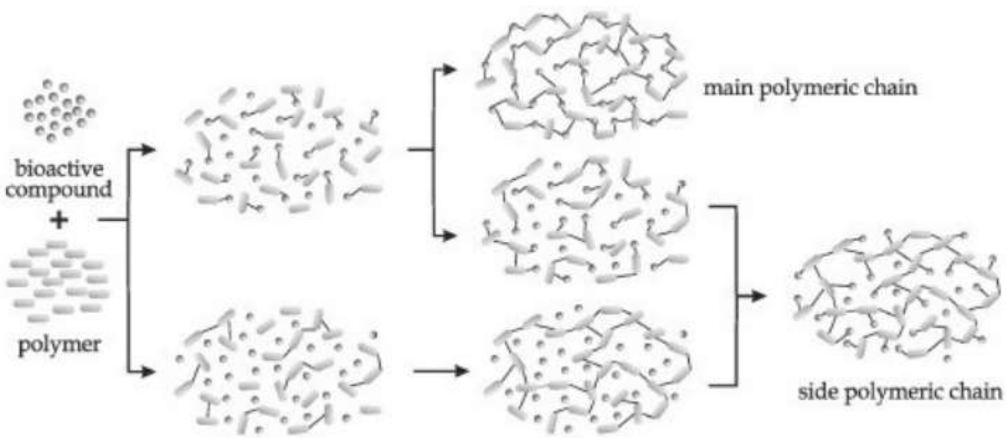

Fig. 3. Physical methods for CRF preparation

In order to isolate the bioactive component, the polymeric chain forms a membrane between the two substances. Nanocapsulescan be created using this technique. For the aim of biocide release, CR formulations often include either microcapsules or nanocapsules, two forms of nanomaterials.

4. EMERGING FIELD OF NANO-PESTICIDES FOR CONTROLLING INSECT PESTS

Pests like insects are controlled using nano-formulations. Organic polymers of a few nanometers in size or inorganic metal oxides can be used in nano-formulations [8]. Nano - Pesticide formulations work to improve the solubility of active ingredients (AI) that are poorly soluble, release them gradually or in a targeted way, and/or stop them from deteriorating too rapidly. Nanoformulations for pesticides are made using a variety of natural and synthesized particles, including metal, metal oxides, non-metal oxides, carbon, silicates, ceramics, clays, layered double hydroxides, polymers, lipids, dendrimers, proteins, quantum dots, and more. Nanostructured delivery methods use polymeric nano-particles for controlled-release formulations. They are used in the delivery of pesticides that have active components loaded onto polymers and fall within the nano range (between 1 and 1000 nm). There are many different types of nano-insecticides, but the most common include emulsions, particles, and capsules (Fig. 4). Nanogel, nanosphere, and nanosuspension are further important nanosystems for insect pest management.

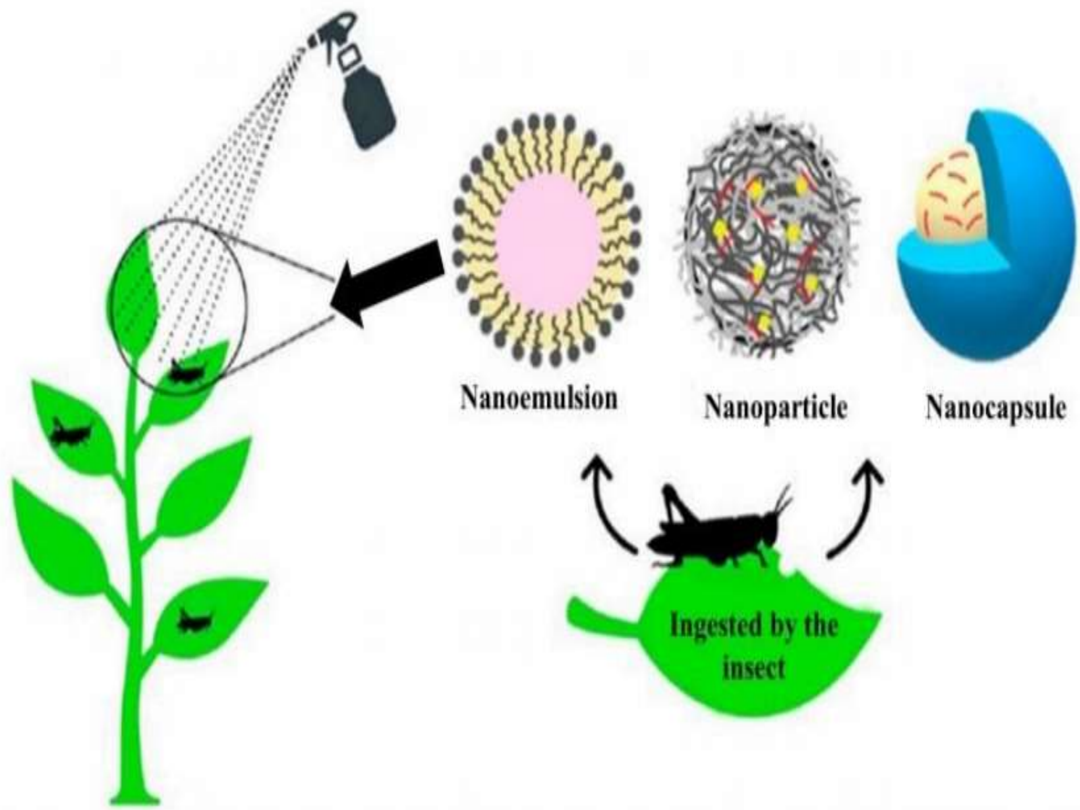

Fig. 4. Pest control using the most prevalent nanosystems for dealing with insects.

5. DEVELOPING NEW NANOPESTICIDES

Insects that spread the disease can be controlled biologically, but it will take a long time. Controlled release strategies are highly sought after on this battlefield. To create CRFs, active compounds are mixed with inert materials. Later ones provide defense and control over the compound release over time into the target area. The topical bioavailability of active substances can be controlled via controlled release methods [9]. Improvements in nanotechnology have enabled the majority of controlled release biopesticide applications. Nanomaterial formulations have been around for decades. The first microcapsule-based formulation appeared on store shelves in the 1970s. According to Kuntworbe et al. [10], nanocapsules have been utilized effectively to treat cancer as well as tropical disorders. Microencapsulation improves the dispersion of hydrophobic pesticides in aquatic situations and controls the release of the active ingredient. Because they do not interfere with pathogen targeting, smart delivery methods have the potential to improve the selectivity of bioactive substances. Nano particle insecticides can also be utilized to create formulations with substances that are normally insoluble but which dissolve more easily that helps the use of surfactants. The increased density improves insect interaction while decreasing the likelihood of drifting and leaching. These characteristics allow for a more efficient use of the active chemical by reducing the dose required to treat an area with the formulation that keeps the desired insecticide at an effective concentration for a longer length of time. Because they are not required to be applied repeatedly, they have a lower potential for producing irritation to people' mucosal membranes, phytotoxicity, and environmental harm. Nanotechnology has a number of opportunities for improving the effectiveness of pesticides used in agriculture.

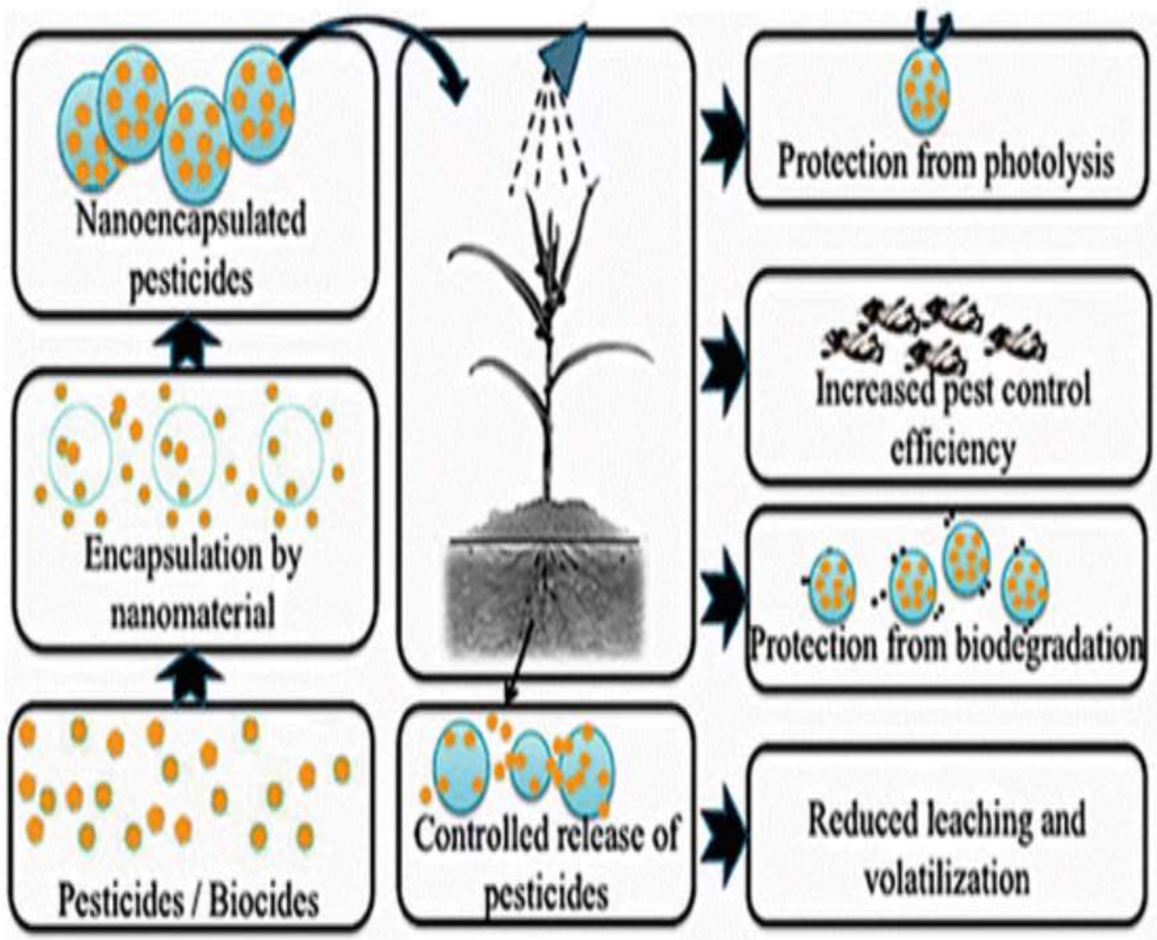

Fig. 5. Diagram of an insecticide including a nanocapsule.

5.1. Nanoencapsulation

Nano encapsulation delivers an effective chemical to the host slowly over time, allowing for the control of insect pests. Dissolution, biodegradation, diffusion, and osmotic pressure can all impact release, and pH has a role in all of them [11]. Persistent droplets capable of holding citronella oil nano-emulsion and gradually releasing it are formed when a 2.5% surfactant and 100% glycerol are homogenized under high pressure. When the release rate is slowed, people can go longer without being bit by mosquitoes. Agricultural production often makes use of nano insecticides, nanofungicides, and nanoherbicides. Pheromone-based fruit fly management reduces pest populations, which boosts agricultural output and quality, as stated by Bhagat et al. [12]. Methyl eugenol (ME), a pheromone, was combined with a low-molecular-mass gelator to create ananogel. Pheromones were kept in longer because of this since it was stable in the open air. Because it doesn't spoil easily, less pheromone renewal in the orchard will be required when it's handled and moved. Bactrocera dorsalis, often known as the oriental fruit fly, is a pest that enjoys munching on a wide range of fruits, guavas included. In terms of pest management, the nanogelled pheromone was successful.

5.2. Nanoparticles

Lice found on human scalps Using an aqueous leaf extract of Tinospora cordifolia, silver nanoparticles with pediculocidal and larvicidal properties against Pediculus humanus and fourth-instar Anopheles subpictus and Culex-quinque fasciatus larvae were synthesized. These were the organisms that the silver nanoparticles' pediculocidal and larvicidal properties were designed to kill. Triboliumcastaneum Herbst is efficient against nanoparticles containing garlic oil. Nano tubes filled with aluminosilicate can adhere to plant surfaces, whereas nanotube components can become caught on the hair of insect pests and travel within the body, disrupting internal physiological processes. Lacking knowledge of how nanoparticles function and how to manage them, authorities are hesitant to release them into the environment. Although authorities do not completely understand how nano particles function, they can be able to assist control pests more effectively and efficiently [13]. The environmental impact of pesticides can be reduced with nano insecticides.

5.3. Application of insecticides nanoformulations

Nanopesticides, which can be fungicides or insecticides, were tested against conventional options [14]. Infrared, FT-SEM, and FT-IR spectroscopy all confirmed that the nano-hexaconazole was smaller than 100 nm. Nano-hexaconazole has been submitted for patent. Nano hexaconazole and Nanosulfur are five and ten times more effective in controlling infections and mites, respectively, than their water dispersible powder (WDP) formulations. Before the launch, materials were put through their paces. Casanova et al. [15] created a nanoemulsion containing nicotine carboxylate using fatty acids varying in carbon number from C10 to C18 and a surfactant. The oil-in-water nanoemulsion had an average particle size of 100 nm. The half-life of different pesticide formulations was studied by using adult Drosophila melanogaster. Encapsulation becomes less efficient as fatty acids grow in size. As the chain length decreased, its bioactivity rose.

6. NANO-BASED PEST MANAGEMENT

It has been suggested that nanotechnology be implemented in the following sectors: biomass; food; nutrition; paint; sensing technology; paper; fertilizer; plant protection; and agrochemicals. Nano particle-based pesticides, such as those made of ZnO, Cu, Ag, and SiO2, are more effective than traditional insecticides, need less water, and have less negative effects on the environment. In addition to promoting plant growth, the presence of zinc also discourages insect pests from settling in. In medicine, animal care, pest control, and plant management, silver's potential as a microbiological, fungal, larvicidal, pesticidal, antibacterial, and antiviral agent is immense. Using environmentally friendly approaches can help this potential be achieved with more efficiency and activity. ZnO nanoparticles' antifungal properties were tested using Fusarium graminearum. Nanoparticles of metal are stable, considerably smaller than their bulkier relatives, and don't pose any health risks. Nanoformulated pesticides are the most effective alternative management strategy for controlling insect pests.

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

Nanoparticle engineering is a cutting-edge method that has been developed in recent years due to the technique's extremely concentrated and powerful properties. The word nanotechnology was coined in 1974 by Tokyo University of Science professor Norio Taniguichi [16]. The study and use of techniques for working with atoms and molecules on a scale of a few nanometers. Among the numerous sectors that have embraced nanotechnology in recent years is agriculture. In the formulations of nano-based insecticides, novel particles with sizes below 500 nm are used. Nanomaterials offer potential for pest management and control. These include the management of insect pests through the use of nanotechnology-based pesticides, the introduction of genes or DNA into plants to create cultivars that are resistant to insect pests, and the enhancement of agricultural production through the use of nanoparticles (encapsulation) for gradual release. Nanoscale calcium carbonate particles have been shown to improve plant resistance to insect pests.

Nano-based pesticides can be synthesized by converting oil in water emulsion (micro- and nano-emulsion) into organic nanoparticles. This procedure is performed so that the necessary particle size can be attained [17]. Nanotechnology-based insecticides can be synthesized into nanoparticles or loaded onto nanocarriers. Insecticides based on nanotechnology might already be on store shelves. In Table 1, we can see how nano particles can be used to combat insect pests.

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)

6.2. Mechanism of nanoformulation Release

Kratz et al. [18] explains that Nanoparticles only start working after they are placed in a desired location. For the CR formulation to work, the active ingredient must be kept dormant until it is needed. When it comes to controlling the release of chemicals, scientists have been interested in inert materials like nanopolymers since the late 1960s and early 1970s [19]. The chemical make-up determines the rate of release of bioactive substances. Controlling the release of their contents is possible with polymeric nanomaterials. Lignin-imidacloprid granules were created by Fernandez-Perez et al. [20]. They tracked the release of several different water components over time and in varying flows. Water has the potential to dismantle certain polymeric nanomatrixes, such as those formed by a carboxylic acid and a metallic cation, therefore releasing the bioactive chemical. The idea of release by chemical severance was proposed by Allan and coworkers in 1971. A chain reaction occurs at the interface between the polymer and the insecticide during hydrolysis. Size, structure, and chemical properties of the macromolecule establish the degree of release control.

6.3. Potential Human Health Concerns:

1-Absorption via the skin (so small they can pass through cell membranes)

2- Inhale (go to the deep lung and cantranslocateto the brain i.e, could cross the blood brain barrier)

3- The great durability or reactivity of certain nanoparticles makes the destiny of such nanomaterials in the environment more difficult to predict.

4- A lack of sufficient evidence about the effect that man-made nanomaterials have on the surrounding environment.

6.4. Special considerations for nanotechnology-based pesticides (NBPs) exposures

Exposure to pesticides via the skin can have both local and systemic effects, as shown by the research of Alvarez-Roman et al. [21]. Whether or whether the active component or carrier is lipid soluble is only one of several variables that might affect this. NBPs, when in touch with the skin, might potentially penetrate the outermost layer of the dermis and have an impact there. There is renewed utility in pursuing NP research. Studies of dermal exposure to titanium dioxide can be used to estimate dermal exposure to NBP. Studies using functional carriers, such sunblock, are also included. Smaller nanoparticles were better absorbed by the small intestine, as shown by Hillyer and Albrecht [22] in mice. Like other forms of NBP exposure, ingestion might cause problems at work and at home.

6.5. Recommendations to Assess Exposure to Nanotechnology- Based Pesticides

Mittal et al. [23] claim that since 2007, the EPA has received a large number of registration applications for nanosilver insecticides. Depending on the application, the regulatory body can be given information on the herbicide's nanoparticle content or can be able to infer it from the manufacturing methods. The EPA has been registering a pesticide containing nanoparticles since 2007 without doing the necessary research. According to the findings of Stone et al. [24], more research and assessments are needed to tackle exposure-related concerns. Fortunately, NBP exposure has been linked to a wide range of nanotechnology and pesticide research topics. Even while no one study can address all of the problems associated with exposure, scientists have found that many of the lessons learned from studying pesticides and nanomaterials can be applied to NBP. The identical writers noted:

1. Find out whether the completely unique active components produced as NBPs can be examined and assessed in the same way that more well-known drugs are.
2. The validity of potential NBP registration data derived from data on conventional active components undergoing reformulation.
3. We must consider whether or not NBPs need a brand-new regulatory framework.
4. The case-by-case consideration of whether a product or a procedure ought to be prioritized.

7. CONCLUSION

Although it has already begun, the application of nanotechnology in plant protection for the elimination of pests is still a novel idea. Nano-encapsulated insecticides are delivered exclusively on the target side, reducing insecticide loss. Nano-formulated insecticides can be more effective in controlling the targeted insects at lower concentrations because of their enhanced surface area. Possible entomotoxicity of nanoparticles against major insect pests.

The scientific community as a whole has found several applications for nanotechnology. Nanotechnology is on the cusp of being used in eco-friendly pest management. Biomaterials provide a promising route toward inexpensive nanoparticle production. When compared to chemical insecticides, this synthetic molecule has a lower environmental impact. The ability of nano particles to control pests and their potential for future uses are covered in this review study. One possible method for ecologically sound insect pest control is the generation of nanoparticles by biological agents like plants and microorganisms. Insecticides based on nanotechnology have the potential to lessen the environmental impact of pesticide usage while enhancing the effectiveness of traditional pesticides.

REFERENCES

[1]. Ingle, Pramod U., et al. "Emerging role of nanotechnology in precision farming." *Nanotechnology in Agriculture and Agroecosystems*. Elsevier, 2023. 71-91.

[2]. Naaz, Haleema, et al. "Silica nanoparticles synthesis and applications in agriculture for plant fertilization and protection: A review." *Environmental Chemistry Letters* 21.1 (2023): 539-559.

[3]. Yan, Shuo, and Jie Shen. "Prospects for the application of nanotechnology in green pest control." *Chinese Journal of Applied Entomology* 56.4 (2019): 617-624.
[4]. Bayat, Maryam, et al. "Review on agro-nanotechnology for ameliorating strawberry cultivation." *Research on Crops* 20.4 (2019): 731-736.
[5]. Kong, Xiang-Ping, Bao-Hua Zhang, and Juan Wang. "Multiple roles of mesoporous silica in safe pesticide application by nanotechnology: A review." *Journal of Agricultural and Food Chemistry* 69.24 (2021): 6735-6754.
[6]. Adisa, Ishaq O., et al. "Recent advances in nano-enabled fertilizers and pesticides: a critical review of mechanisms of action." *Environmental Science: Nano* 6.7 (2019): 2002-2030
[7]. Katel, Shambhu, et al. "Nanotechnology for agricultural transformation: A review." *Fundamental and Applied Agriculture* 6.4 (2021): 403-414.
[8]. Chauhan, Poonam, and Ashwani Tapwal. "Green synthesis of nanoparticles using botanicals and their application in management of fungal phytopathogens: a review." *Archives of Microbiology* 205.3 (2023): 1-21.
[9]. Ghouri, Muhammad Zubair, et al. "Nanotechnology: Transformation of agriculture and food security." *Bioscience* 3 (2020): 19.
[10]. Mughal, Shahzad Sharif. "DIAGNOSIS AND TREATMENT OF DISEASES BY USING METALLIC NANOPARTICLES-A REVIEW." *Authorea Preprints* (2022).
[11]. Jasrotia, Poonam, et al. "Nanomaterials for postharvest management of insect pests: Current state and future perspectives." *Frontiers in Nanotechnology* 3 (2022): 100.
[12]. Kumar, Pradeep, et al. "Bacillus-based nano-bioformulations for phytopathogens and insect–pest management." *Egyptian Journal of Biological Pest Control* 31 (2021): 1-11.
[13]. Cáceres, Mariano, et al. "Silica nanoparticles for insect pest control." *Current Pharmaceutical Design* 25.37 (2019): 4030-4038.
[14]. Kaur, Harmanjot, Nalini Singh Chauhan, and Abhay Punia. "Role of Nanotechnology in Agriculture: A review."
[15]. Singh, Manoj, et al. "Effective Management of Aedes aegypti Linn.(Diptera: Culicidae) Population through Conventional to Genetic Control and Nanotechnology Approaches: A Short Review." *International Journal of Mosquito Research* 9.2 (2022): 95-99.
[16]. Raj, S. Nisha, et al. "A comprehensive review on regulatory invention of nano pesticides in Agricultural nano formulation and food system." *Journal of Molecular Structure* 1239 (2021): 130517.
[17]. Vaghasiya, T. P., A. Kumar, and K. Nakum. "A Review on Wide Range Application of Nanoparticles in Agriculture and its Implications in Plant Disease Management." *J Nanoworld* 8.2 (2022): 55-65.
[18]. Nimisha, T., and K. B. Deepthy. "Nanotechnology applications in insect pest management-A review." *Journal of Eco-friendly Agriculture* 15.1 (2020): 1-6.
[19]. Javaid, M., et al. "Role of nanotechnology in crop protection and production: A review." *Journal of Innovative Sciences* 6.2 (2020): 221-227.
[20]. Javaid, M., et al. "Role of nanotechnology in crop protection and production: A review." *Journal of Innovative Sciences* 6.2 (2020): 221-227.
[21]. Manjunatha, R. L., Dhananjay Naik, and K. V. Usharani. "Nanotechnology application in agriculture: A review." *Journal of Pharmacognosy and Phytochemistry* 8.3 (2019): 1073-1083.
[22]. Kannan, M., et al. "Nanopesticides in agricultural pest management and their environmental risks: A review." *International Journal of Environmental Science and Technology* (2023): 1-26.
[23]. Deka, Bhabesh, et al. "Nanopesticides: A systematic review of their prospects with special reference to tea pest management." *Frontiers in Nutrition* 8 (2021): 686131.
[24]. Shang, Yifen, et al. "Applications of nanotechnology in plant growth and crop protection: a review." *Molecules* 24.14 (2019): 2558.