Section A-Research paper
ISSN 2063-5346

ADVANCED APPLICATIONS OF NANOPARTICLES IN INTEGRATED PEST MANAGEMENT - A COMPREHENSIVE REVIEW

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ABSTRACT

Plants, algae, fungus, yeast, and other creatures all contain a wide variety of biomolecules, making nature a giant "bio-laboratory." Unsurprisingly, a wide range of biomolecules and synthetic techniques may be used to create nanoparticles of different sizes and forms. The production of variously sized and shaped molecules with a variety of qualities, including safety for the environment, plants, animals, and all useful species, is sped up by naturally existing biomolecules. There are several, ecologically friendly techniques for creating nanoparticles that use a variety of substances and compounds. Vegetables, fruits, ornamental plants, field crops, insect pests, and other factors that are density-dependent reduce crop quality and productivity in nature. During the previous decade, synthetic pesticides were employed to control insect pests, but their destructive usage causes resistance, environmental pollution, pest rebound, and negative effects on people, animals, and beneficial fauna. Pesticide residues are detrimental to human health, having both lethal and many chronic effects. Worldwide, a number of countries have shifted from chemical-based agriculture to organic agriculture, which is more cost-effective, socially beneficial, and environmentally sustainable. At the moment, nanotechnology has changed agriculture, with nanotechnology-based insecticides showing the most potential for the long-term management of insect pests. The most common techniques for creating nanoparticles are physical, chemical, and many others; however, chemical techniques are once more thought to be bad for the environment and people's health. In this review article, we'll concentrate on the benefits, recent advancements, difficulties, and prospects for using nanotechnology to manage insect infestations. A number of metals, including zinc (Zn), titanium (Ti), silver (Ag), and zirconium (Zr), with varying features and attributes for the environmentally responsible control of insect pests, are used in the manufacture of nanoparticles.

Keywords: *Nanotechnology, Insect Pest Control, IPM, Silver, zinc, iron, Termites, Mosquitos, Locusts*

INTRODUCTION

Using sustainable, abundant, safe, and cutting-edge technology tactics, we can grow a wide range of crops of exceptional quality. For producing crops in regions where they would normally be unable to do so, the various cultivation techniques are very advantageous. In addition to adapting IPM tactics on a larger scale, bio-intensive integrated disease and pest control requires numerous plant-specific protection measures, such as cultivars that are herbicide- and pesticide-resistant and have nutritionally enhanced traits. The name "Nano" simply means "small science" and is taken from a Greek word that meaning "small." Additionally, "nano" also denotes a billionth of something, or a value of 10-9. Nanotechnology undoubtedly refers to the use of particles of a size between 1 and 100 nm. Over the past ten years, nanotechnology has created a wide range of innovative materials for upcoming uses. The largest challenge in the modern agricultural civilization is environmental remediation, which is a major problem that may be addressed by the employment of nanoparticles. The main density-dependent factors that affect crop quality are creatures like insect pests, which are controlled by the use of synthetic pesticides, motivating the investigation of potential bio-rational and environmentally acceptable substitutes. Numerous scientific fields have seen new and significant advancements because to nanotechnology.

However, its use in protecting a variety of crops from insect pests is still in its early phases. Thus, these tiny nanomaterials have the potential to lessen the damaging effects that insect pests have on crops. These materials have all been used to create significant devices, including sensors, medical devices, chemical agents such as catalytic agents, pesticide coatings, and electronic components such as conductors and semi-conductors. The world has been transitioning to organic agriculture from synthetic chemical-based agriculture by employing biopesticides imbedded with nanoparticles. The populations of insects can be successfully reduced by the biopesticides. These plants have the capacity to produce a huge variety of nanoparticles.

DAMAGE TO FILED CROPS AND EFFECT ON PLANT PHYSIOLOGY

Crop output is decreasing as a result of extensive pest damage, which includes weeds that interfere with the main crop, insect pests that cause damage in various ways, mites that attack during times of stress, rodents that cause damage year-round, birds that damage seeds and fruits, mollusks that attack nurseries, and phytopathogens like fungi, viruses, and bacteria. These organisms are all considered to slow down photosynthetic rate, devour tissue, and hasten leaf senescence. Pest insects with sucking and chewing mouthparts severely reduce crop output. By propagating viruses and reducing chlorophyll levels, necrotrophic diseases degrade the quality of plants. Crop rotation, breeding resistant cultivars, plant rouging, use of chemical and biological control, and other management techniques are only a few of the efficient integrated pest management techniques that may help reduce the pest population. Due to the endotoxic potential of biosynthesized nanoparticles, immediate action is required to protect the environment from harmful substances and to manage pests.

INSECT PESTS THREAT TO CROPS

Numerous habitats have different species of insect pests. Numerous insect pests serve as vectors, spreading various illnesses among various plant types. Each year, billions of rupees are lost as a result of insect attacks on the economy and agricultural production. The use of synthetic pesticides is the main method used to control insect infestations. However, billions of rupees are lost every year as a result of problems with resistance development. Pea pod borer *Helicoverpa armigera* attacks cotton, pea, bean, peanut, corn, wild and farmed chickpea, solanum spp. (tomato), and sorghum crops globally on a number of occasions in field settings. In Africa, Asia, Oceania, and South America, *H. armigera* is one of the most pervasive insect pests.

Approximately 150 insect pest species prey on crops and reduce their quality and productivity at different stages of growth. This has given a researcher the chance to apply cutting-edge technologies to overcome these challenges. Why is nanotechnology-based agriculture important? The safest and greenest method for enhancing the production of food, raising agricultural output, enhancing food quality, taste, and crop protection is biotechnology. Various poisonous compounds, genetically engineered foods, microbes, viruses, and insecticidal resistance have spread across the environment's food chain systems. In order to address these issues, nanotechnology has transformed the fields of food, textiles, energy, and communications technology. The demand for and consumption of food has grown as a result of the alarming rate at which the world's population is expanding. In order to control bug infestations and increase agricultural product production, researchers are striving to solve these problems. The creation of nanoparticles from biological materials is crucial for the development of pesticides, water filtration, and crop protection.

The modern scientific era has given careful consideration to biotechnology as a safe agricultural technique intended to strengthen crop protection, food processing and packaging, provide more agricultural products, improve flavor, and raise nutritional value. This strategy is very helpful since it introduces changed genes into natural plants to increase toxic lethality by modifying the internal systems of pests. Therefore, it is crucial that scientists apply cutting-edge technology to address these problems. Numerous industries, including material science, computer technology, health care, the energy sector, communication, and agriculture, have been transformed by nanotechnology. Given the critical problem of the growing global population, it is necessary to increase crop quality and yield while decreasing harmful pests through the use of nanoparticles. The main purpose of biological and chemical nanomaterials is to support plant protection, pesticide formulation synthesis, and pesticide cleanup. The development of organic farming, the control of diseases, and the effective application of fertilizers, pesticides, and other agrochemicals all depend on nanotechnology.

GLOBAL VALUE AND SCOPE OF ORGANIC BIO PESTICIDES

The sum of money required to create pesticide formulations for farmers that are both ecologically sound and socially acceptable has progressively increased in the modern biosphere. Between 2013 and 2014, the usage of synthetic pesticides and biopesticides increased globally, from $54.8 to $61.8 billion to $83.7 billion in 2019. The global market for biopesticides hit USD 6.9 billion in 2019. The demand for biopesticides was 40% higher in North America than it was in Asia-Pacific (20%). Many countries throughout the globe rely on biopesticides to control dangerous insect pests in an environmentally responsible manner and ensure food security (Patent mall SDN BHD, Kuala Lumpur, Malaysia).

ROLE OF SYNTHETIC CHEMICALS IN PEST MANAGEMENT

Over the past ten years, the majority of synthetic pesticides have been sold in local and online pest control retailers like Amazon, and there are a lot of importers, distributors, and producers. Early items that contained Sulphur included phosphate fertilizers, fungicides, sulfuric acid, and insecticides. In addition to Sulphur, general pest control agents including fipronil, permethrin, bifenthrin, pyrethrum, boric acid, and abamectin were also utilized. Organochlorines, neonicotinoids, pyrethroids, organophosphates, and carbamates are some examples of chemicals that are categorized depending on the origin of their structures.

CLASSICAL BIOLOGICAL CONTROL OF INSECT PESTS

Terpenoids, alkaloids, phenolic compounds, glycosides, flavonoids, polyphenols, and tannins are a few examples of plant-based insecticides that have historically provided useful examples of metabolites that have been used as biopesticides against a variety of insect pests. Although it took a long time and was discovered that these pesticides were only partially successful, their effects on the environment were always positive and harmonious with other creatures. Effective insect pest control requires taking into account environmental factors, particularly the effects on people and animals. A number of medicinal plant preparations are helpful against the mosquito and the pea pod borer H. armigera. The majority of plant-based insecticides, including Gnidia glauca, Toddalia asiatica, Acorus calamus, Annona squamosa, Vitex negundo, neem extract, Calotropis procera, and Argimone maxicana, have harmful larvicidal effects. Researchers from Serval conducted an experiment to determine the negative effects of neem seed kernel extract, and they discovered that it caused the greatest proportion of infection—30.08%—in comparison to tobacco leaf extract, which caused just 26.68%. The ovicidal, hatching performance, nymphal duration, and antifeedant qualities of neem seed extract were assessed in a lab setting. Fruit, leaf, stem, and root extracts are just a few of the plant components that are utilised to assess the efficiency against insect pests.

INNOVATIVE APPROACH OF INSECT PEST CONTROL USING NANOPARTICLES

As a novel idea, nanotechnology is used in a variety of fields and disciplines to produce different formulations and applications, such as those in the biofuels, food, paint, coating, artificial intelligence, sensing, paper, fertilizer, plant protection, and agrochemical industries. Nano-based pesticide formulations including ZnO, Cu, Ag, and SiO_2 nanoparticles demonstrate a broad range, decrease water, and repair environmental damage when compared

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to traditional pesticides. Because of their stability, smaller particle size, and ecologically friendly byproducts, metal nanoparticles stand out. The best alternative management techniques for reducing insect pests are nano-formulations.

Natural occurrence of nanoparticles in insects

Even though they provide a significant source of precision manufacturing, some scientists have given up on the naturally occurring nanostructures. Psaltoda claripennis, a cicada, and the termite family Rhinotermitidae are two pests that are both examined using AFM (atomic force microscopy). The tops of these nanoparticles generally feature circular shapes between 200 and 1000 nm in size and flat surfaces between 150 and 350 nm in size. The aerodynamic effectiveness of insect wings depends on nanoparticles. According to Nowack and Bucheli (2007), social insects and ants have magnetic material and temperature-dependent ferromagnetic resonance in numerous body parts. Changes in the surroundings of the magnetic field also affect higher animal behavior. Formica rufa and Solenopsis invicta, two ant species that live among honey bees, utilised information from the geomagnetic field to aid in foraging, nesting, and direction.

Biosynthesis of nanoparticles

The most significant techniques for creating nanoparticles are those that combine physical, biological, and chemical processes. Both individuals and the ecosystem are harmed by the toxins that have absorbed on the surface. The most economical, morally upright, and environmentally good alternatives to physical and chemical methods are biological ones. There are several enzymes, green plant materials, different microbes, and fungi employed in the manufacture of nanoparticles, which have numerous uses in daily life. The various chemicals are also used in the production of nanoparticles. There is a chemical connection between the active ingredients and the coating matrix, such as a polymer. If the polymerization process occurs first and the insecticide molecule binds to the side chain only afterwards, the insecticide molecule may first link to the side chain of the monomer before the polymerization reaction occurs. The creation of the nanoparticles utilised metal oxides such as gold, copper, silver, and others that have been demonstrated to be effective against a range of insect pests.

Synthesis of nanoparticles by bacteria

A variety of bacteria, in particular E. coli, have been utilised to research the extracellular and intracellular synthesis of silver nanoparticles (Ag NPs). Many scientists have employed bacteria including Vibrio cholera, Salmonella typhus, Pseudomonas aeruginosa, Pseudomonas stulzeri, and Staphylococcus currens to create many nanoparticles with pesticidal capabilities. The metal ions are converted to metals with the help of microorganisms. A photoautotrophic cyanobacterium named Plectonema boryanum was used in the extracellular manufacture of silver-based nanoparticles. Few other silver-based products are even smaller in size than the 50 nm silver nanoparticles produced by Bacillus licheniformis. Recent studies have shown that cultivating silver nitrate nanoparticle solution with culture supernatants of Enterobacteria bacterial strains, such as Klebsiella pneumonia, produces silver nanoparticles faster than any other method.

Zinc oxide nanoparticles

Despite the fact that bacteria are used to make nanoparticles, doing so has a number of drawbacks. The selection of the microbes takes time, and the culture and development must be constantly monitored during the entire operation. In contrast to B. licheniformis, bacterial mounted ZnO nanoflowers may be produced quickly. The diameter and height of these nanoflowers are 40 nm and 400 nm, respectively. Another technique for effective bioremediation of organic waste material is the use of nanoparticles. A novel nanomaterial made from culture medium degrades hydrophobic materials utilizing Rhodococcus bacteria.

Preparation of nanoparticles

Silver Nanoparticles: The distinctive technique for producing Ag NPs uses plant extracts that are fairly priced, ecologically safe, and economically rational. These extracts regulate and reduce the body's concentration of silver ions. The process was altered to produce nanoparticles using green plant resources. Plant leaves are cleansed with distilled water and tap water before being turned into aqueous solutions containing nanoparticles based on plant extracts. Then, to create the plant extracts, boil 10g of leaves in 100 ml of filtered water. $AgNO_3$ is combined with the distilled water to produce an aqueous solution. The plant extracts were added to the silver nitrate aqueous solution in the correct order.

Zinc oxide (ZnO) nanoparticles

ZnO has a key role in semiconducting metal oxide, biological systems, optics, and electronics. ZnO is essential to biomedical sciences because of its anti-diabetic, anti-cancer, antifungal, anti-cancer, drug delivery, and agricultural properties. ZnO nanoparticles offer the advantages of being reliable, inexpensive, and easy to produce. Zinc oxides have been deemed generally safe metal oxides in a US FDA assessment. Several plant parts that contain dangerous compounds are used to create nanoparticles. Studies show that the plants also act as reducing and stabilising agents. ZnO nanoparticles were created utilizing an extract from the Trifolium pratense flower, Rosa canina extract, and Aloe vera extract as capping in order to show the various peaks and the manufacture of stable nanoparticles.

Synthesis of nanoparticles using fungus

NPS was produced extracellularly using fungi. Fungal strains are more resistant and have better bioaccumulation abilities than bacteria. Dynamic light scattering (DLS) characteristics were used to analyse the average height of nanoparticles, which is almost 8.56 nm in size. Atomic force microscopy (AFM) was used to examine the average size of nanoparticles, which was 3.8 nm. The most common fungus species used in the production of nanoparticles is Aspergillus, which is predominantly spherical.

Ecofriendly way of nanoparticle application and their composition

Nanoparticles have been produced using readily available, inexpensive, and accessible plant extracts. Different parts of plants contain a vast range of phytochemicals. Nanoporous zeolites were used to delay the discharge of insecticides, fertilizers, irrigation fluid, and herbicides. Nanosensors are used in the field to detect pests. Insecticides, pesticides, and insect repellents have all been made using nanoparticles. In order to handle all entomological problems, nanotechnology offers biopesticides that are socially and environmentally acceptable. Garlic essential oils combined with nanoparticles efficiently inhibited Tribolium castaneum Fig (1 & 2).

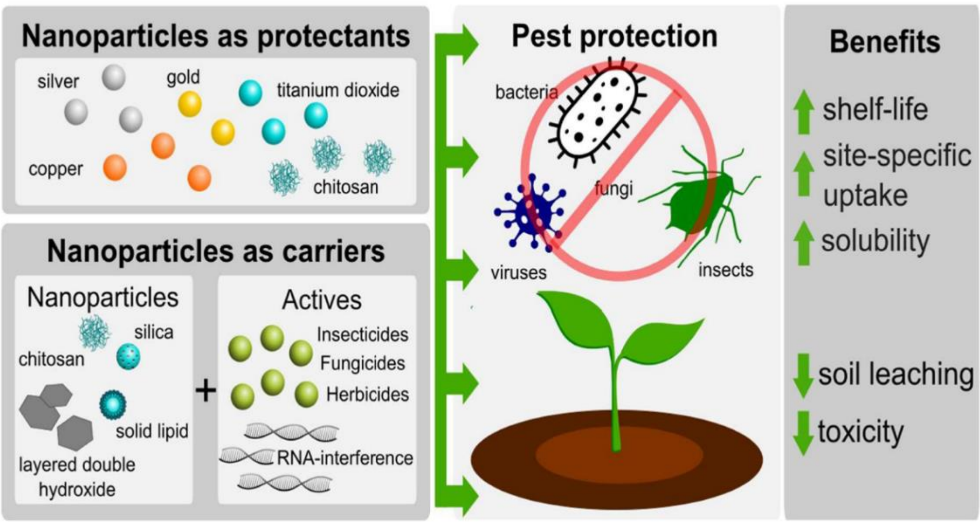

Figure 1: Applications and compositions of various nanoparticles in integrated pest management (agronomy-08-00285-g001.png (3484×1695) (mdpi.com).

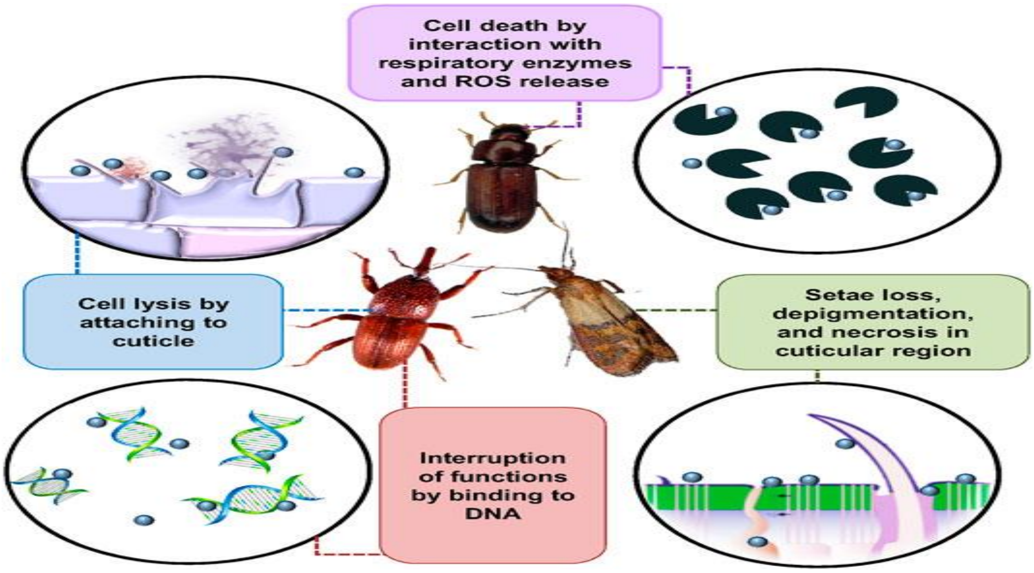

Figure 2: At Global level nearly 1/4 -3/4 of total food grains are lost due to pest infestation. To control losses the nanotechnology has opened a wide range of methods and techniques as an effective alternative control option.

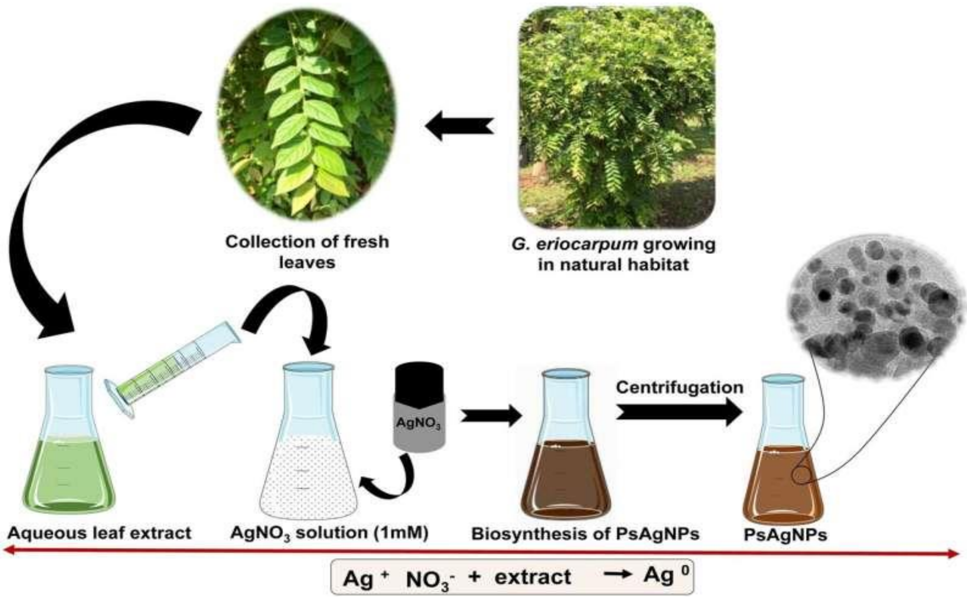

Figure 3: In the 21st century the synthesis approach involving plants has gained great attention with the aim of generating environment-friendly nanoparticles encompassing a vast range of applications using various silver nanoparticles (AgNPs, but more specifically, biosynthesized AgNPs) against termites (Source: Sandhya Mishra 2020)

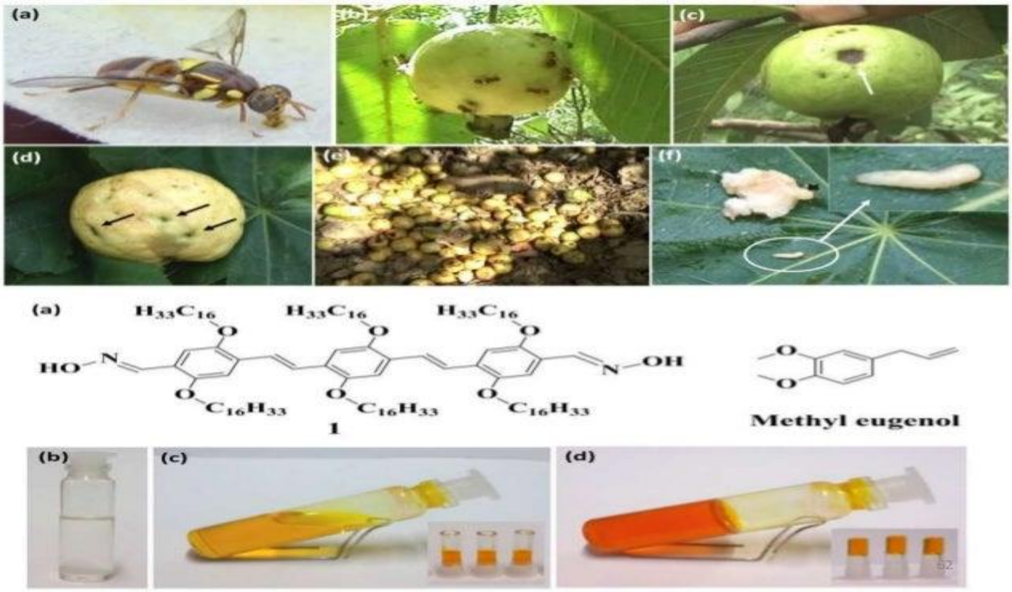

Figure 4: Diagrammatic representation of role of nanoparticles in management of fruit flies (a) damaging various tropical and temperate fruits and vegetables. The chemical formula of nanoparticle Methyl eugenol is given in figure (source: Cancino et al. 2012; https://www.slideshare.net/bajaru/role-of-nanotechnology-in-insect-pest-management-44797198).

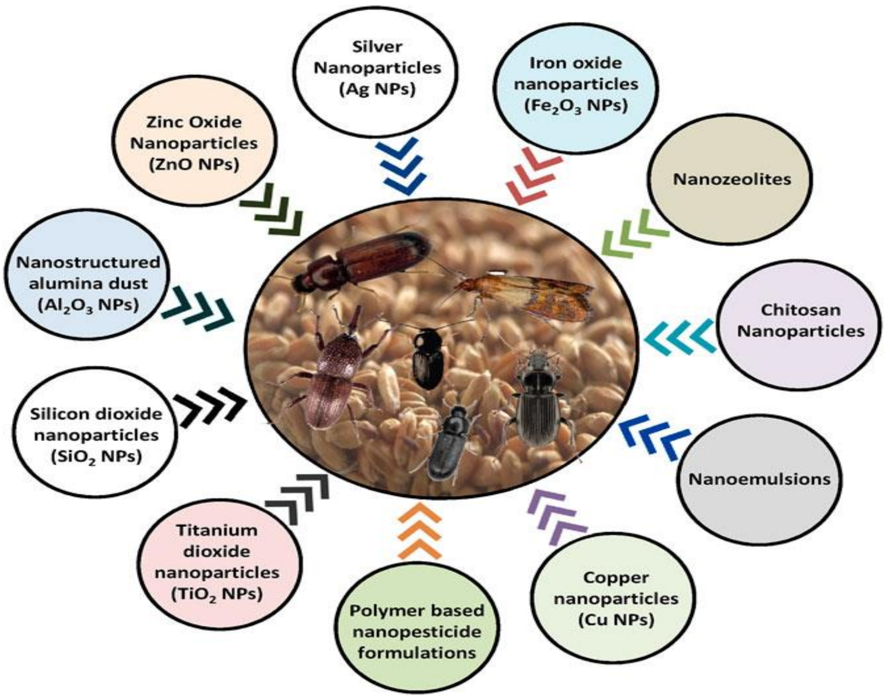

Figure 5: Diagrammatic representation of use of various nanoparticles for management of insect pests of stored grain food items. Since stored grain pest control is facing major challenges of environmental contamination, pest resistance, bioaccumulation, and health hazards therefore the nanotechnology is emanating as a highly attractive tool to achieve the

target of lowering the quantity of pesticide used by offering new methods for the formulation and delivery of pesticide active ingredients, as well as novel active ingredients

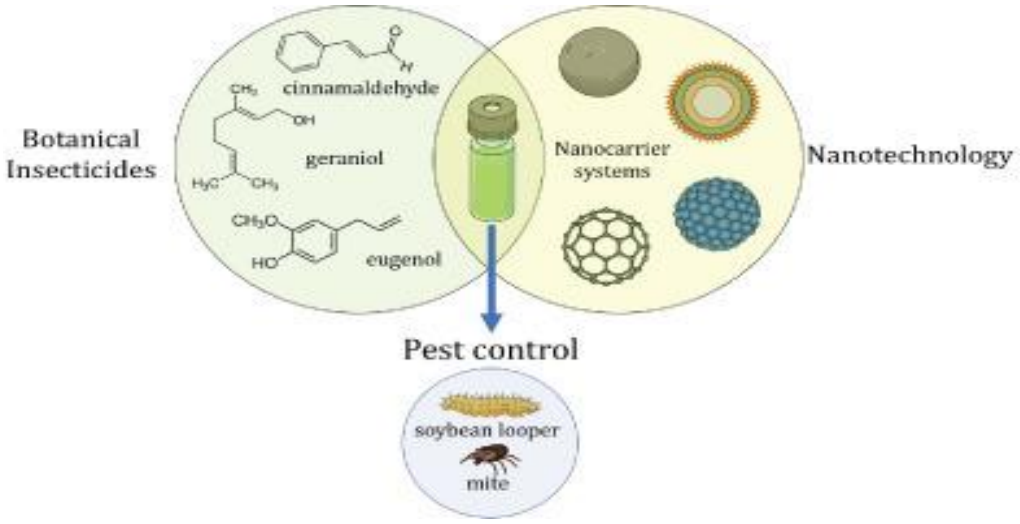

Figure 6: Diagram showing the use of botanical compounds from plant species having pesticidal activity against various insects used under IPM program. Various nanoparticles are incorporated in the botanical insecticides and the performance were found improved

Figure 7: Diagrammatic representation of control of Arboviruses causing yellow fever, dengue, chikungunya and zika transmitted by the mosquito vector Aedes aegypti

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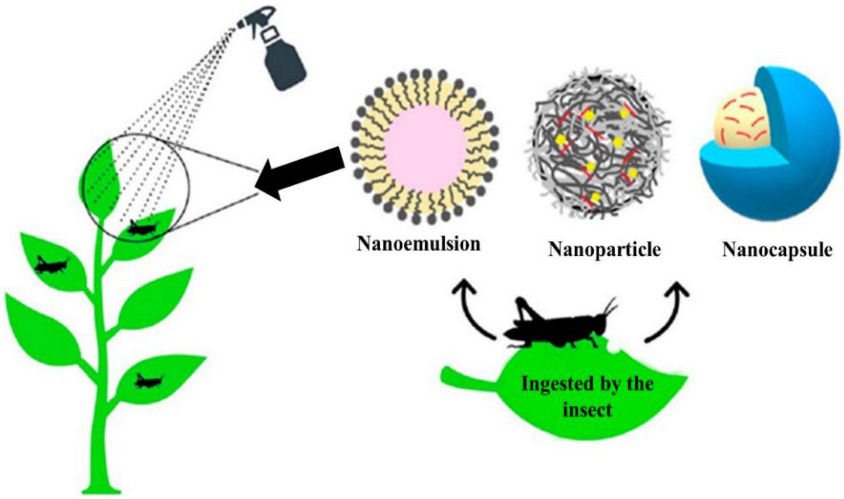

Figure 8: Diagram showing the applications of Nanoparticle based pesticides on crops for the control of various pests

CONCLUSIONS AND RECOMMENDATIONS

According to research, 2.5 million tonnes of synthetic conventional pesticides are used annually in agriculture to manage insect pests. However, due to high toxicity, extended pesticide persistence, lack of scientific formulations, leaching, and loss during application travelling into soil, water bodies, and atmosphere, the overall consumption is anticipated to increase and pose risks on a global scale. It is anticipated that the contamination will have an adverse effect on ecological and public health through pollution or leftovers on crop surfaces. Additionally, IPM application is insufficient to bring the insect population beneath the economic threshold. Therefore, it is imperative to create fresh, contemporary approaches to the control of insect pests. The use of nanomaterials to combat insect pest infestation is one of the new ways being used by nanotechnology to reduce environmental pollution (as illustrated in Figures 5-8 above). Because nanotechnology is needed for current scientific research, it will soon be applied widely to manage pests in an ecologically friendly way. the affordability of producing nanoparticles from biological resources. This manufacturing method offers numerous benefits over synthetic chemical pesticides due to its low ecotoxicity. The current review study describes how nanoparticles are used to effectively reduce insect populations as well as possible uses for them in the future.

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