Eco-Friendly Nano-Pesticides: A Comprehensive Review of their Applications and Environmental Impacts

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Abstract

This paper reviews the use of nano- particles as nano-pesticides and have discussed the challenges to be solved before using these pesticides. Nanotechnology is a developing field that can ameliorate the growth of plants. Nanoparticles have a characteristic size that is between 1nm to 100nm. Conventional pesticides have innumerable disadvantages for example inadequate delivery of pesticides, the genesis of pollutants, etc. These pesticides need significant input sources of energy and water which is mainly the reason scientists are searching for eco-friendly and more efficient pesticides. Researchers / scientists worked on different nano-metals such as silver, zinc, silica, and ENMs (Engineered Nano-materials) so that these can be used as bio-pesticides. These nanoscopic metals have the potential to enhance the growth and yield of crops. They are "green'' alternatives used in place of traditional pest controls. Currently, there is no optimal knowledge about this nanoscopic matter therefore a better understanding of adverse impacts and their interactions need to be improved before their extensive use in plant production.

Keywords

Nanopesticides, Nanotechnology, Insecticides, Pesticides

1. INRODUCTION

1.1. Nano-Particles

The characteristic size ranges from 1 to 100 nm of nanoparticles (NPs) which are a subclass of ultrafine particles that exhibit characteristics distinct from those of other nano-fragmentsthat have aparallel chemical composition (Auffan, M., *et al*., 2009) Mainly the reason for restricting to 100 nm is that a critical size of < 100 nm is often where special features that distinguish particles from the bulk material occur. However, the initial title "nano" is distinguished for dimensions that are less than 500 nm because other occurrences (namely clarity or turbidity, ultrafiltration, and steady dissemination) which rarely exceed the large demarcation line are taken into consideration (Somani, C., *et al*., 2020) Size,shape, crystalline, amorphous, and chemical composition are important factors that explain the properties of these nanomaterials about their use in pesticide application, including toxicity. A wide range of substances, including metal oxides, semiconductor quantum dots (QDs), carbon, silicates, lipids, polymers, dendrimers, emulsions, ceramics, proteins, and metalswere employed to make nanoparticles in different forms and chemical compositions (Oskam, G. *et al*., 2006).

Although there are several substitutes, pest control nevertheless counts on the usage of pest killers, which are substances with an organic chemical foundation that are applied to crops, commodities, or urban areas. Numerous pesticides on the market now still offer dangers to mammals since their main functioning mechanism intervening the insects' neurology. However, advanced assortments are considered worrisome regarding environmental aspects, for example, insect killers which are decomposers of ATP or insect growth regulators (IGRs), that have just been launched for general use and have slowly declined the usage of neuron-damaging compounds. In this respect, pesticide use has been linked to bio accumulation, environmental pollution, and mammalian toxicity.These elements, together with the rising incidence of insect species developing resistance to many of the substances currently in use, provide significant issues for agriculture and may drastically reduce the number of efficient active constituents. It is necessary to implement novel pest-resistive concepts and cutting-edge pest management technology to address these issues (Athanassiou, C., *et al*., 2018)The primary drawbacks of current pest management methods are anticipated to be addressed in this extensive review article on nano pesticides, which will also present a novel, cutting edge nano based formulation.

Recent developments in the field of pesticide research can be summed up as the means of nanotechnology in the conservation of yield. The study of fundamental interactions between nanoscopic matter and insects, the formation of key components into nano-emulsions and dispersions by utilizing contemporary pesticides, the generation of the latest pesticide amalgams using nano substances as main pesticide agents, or by exploiting these nanoscopic materials as carriers for their transportation are all included in this field's broad research aspects (Smith, K.*et al.*, 2008 ; Benelli, G.*et al*., 2016 ; Benelli, G., *et al*.,2017 ; Yasur, J.*et al*.,2013).

1.2. Nanotechnology and Agriculture

The branch of research known as "nano-pesticides" offers innovative methods for producing unique, nanoscale-sized active compounds, along with their composition and distribution. To achieve these objectives, nanotechnology is rapidly becoming a highly enticing study field (Yasur, J.*et al*.,2013). In agriculture, pesticides are unavoidably used in managing plant diseases and insects. However, the mounting application of these chemicals per hectare is leading to numerous environmental and healthcare risks. To alleviate the issues brought on by conventional insecticides, a brand-new branch of research known as nanotechnology has produced pesticides that are more effective while using fewer active components. The proportion of surface area to volume of the conveyer molecule or key component in nanopesticides is quite high, which gives them special exploitable benefits. For different modes of action and diverse uses, some formulations, including nano-emulsions, nanosuspensions, nanogels, and metal compoundbased pesticides, have been created.The main benefit comes from the particles' small size, which aids in evenly dispersing the components on insect surfaces and produces a better effect than traditional pesticides. Due to their increased efficiency and lower dose requirements, the liberty to use nanoparticles as pesticides, fertilizers, and nano-delivery systems is growing every day.

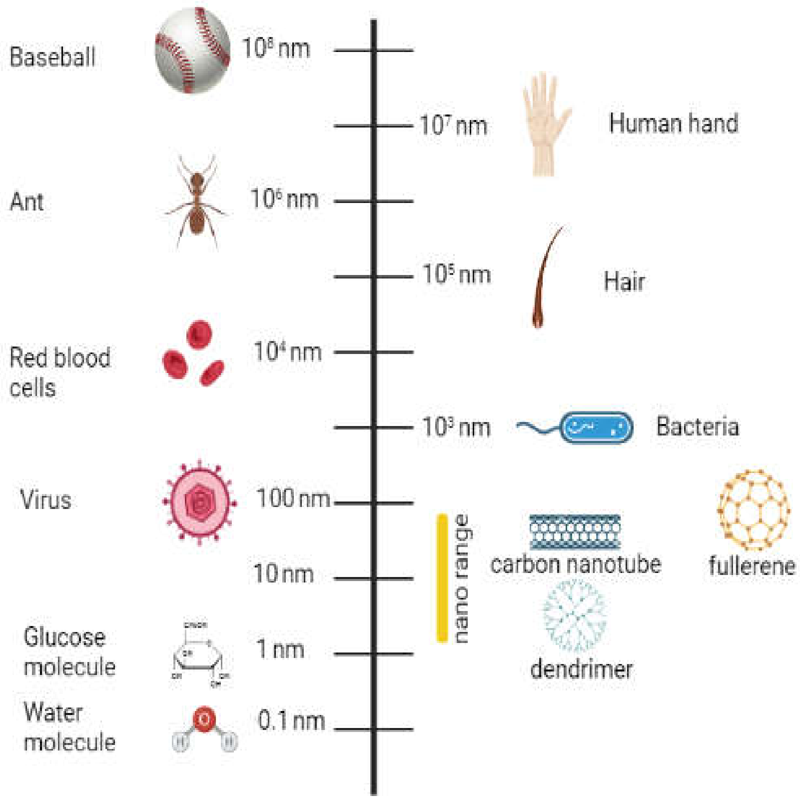

Fig.1: An estimate of nanoparticles from comparison to daily life goods

However, during or after the application, the nano-entities can also affect people and other animals. It is currently mostly unknown how these created nano-entities interact with biological systems. Therefore, for a sustainable transition, a deeper knowledge of their interactions and potential negative effects is also essential before their widespread use in crop production and crop protection. Biopesticides are made from a variety of species, such as fungi, nematodes, plants, bacteria, and other microorganisms. In the texts given below are the key benefits of using biopesticides as natural substances instead of conventional pesticides.

The advantages of NP-based pharmaceutical preparations typically include:

1) Scaling solubility of key ingredients that are water-insoluble.
2) Low exposure, with essentially no environmental issues.
3) Highly powerful in extremely little amounts.

4) Only impact the specific pest and closely related organisms.
5) Improved formulation stability.
6) Substitution of non-conventional insecticides for hazardous organic solvents.
7) The ability to release active substances gradually.
8) Increased stability to stop early deterioration,
9) Increased insecticidal activity and enhanced mobility as a consequence of reduced particle size.
10) A bigger surface area may increase their lifespan (Sasson, Y., *et al.*, 2007 ; Arora *et al.*, 2016).

Thus, as an IPM program component, bio-fertilizers can dramatically reduce the application of traditional pesticides while establishing crop yields to the maximum. The major problem is that for applications to be safe and successful, users must be well-versed in pest management strategies and must follow all label directions (Arora *et al.*, 2016 ; Seiber, J.N., *et al.*, 2014). Two additional downsides include high susceptibility to particular pests and poor stability (Polosky *et al.*, 2015 ; Anwer *et al.*, 2017).

1.3. Nano pesticides: (employment of nano-particles alone as pesticides)

NPs (nano-particles) with insecticidal features are undertaken as active pesticide agents or biopesticides (Elango, G., *et al.*, 2016). The most relatable examples make use of amorphous nano-silica that is formed from a number of organic materials, such as volcanic soil, scorched rice hulls, vegetable skin, and phytoplankton shell walls. These materials contain some particles that are larger than 1m, yet their microscopic pores are significantly smaller than 100 nm (Barik *et al.*, 2008). The cuticular lipids physiosorbed silica nanoparticles, breaking down the buffer zone and destroying the insects only physically. This is akin to the way diatom particles work to keep insects out of grain storage (Barik *et al.*, 2008 ; Kavallieratos, N.G., *et al.*, 2018). The application of NPs on the surface of the leaf and stem of several horticultural and agricultural plants did not influence photosynthesis or respiration. As they did not affect the inheritable expressions inthe trachea of insects, they were approved as a nano-pesticide. According to the World Health Organization (WHO), using silica in pesticide is unharmed for human beings. According to (Debnath, N., *et al.*, 2011) silica nanoparticles killed all mature *Sitophilus oryzae*, rice weevils (*Coleoptera: Curculionidae*). By delicately coating seeds with it, it has been used to successfully stop growth of fungus and enhance grain germination (Robinson, D *et al.*, 2010).

1.4. Nano-pesticide Formulations

The water-resistant single-tail segments are sequestered in the center by the water-absorbing "head" sections interacting with the nearby solvent, and the nano-pesticides may be in the form of particles or an aqueous solution. They may also include organic materials (such as polymers) and elements of inorganic nature (e.g., oxides of metal). It is quite interesting to use technologies like controlled release methods and encapsulation to apply pesticides (Pavel, A. et al., 2005 ; Rai, M. *et al.*, 2012) . Numerous companies provide formulations with NPs ranging in size from 100 to 250 nm. Some employ uniformly dispersed pesticidal nanoparticles (NPs), which can be oil- or water-based and range in size from 200 to 400 nm, in nanoscale suspensions (nano-emulsions). The emulsions are easily merged into gels and fluids and have a variety of applications for the treatment and conservation of the harvested product. Many terpene molecules are thought to be highly volatile and have antifeedant effects.The insecticidal cycle of action and shelf life of certain plant elixirs were dramatically enhanced by formulas that included nano-silica. Similar formulations with a more zeta potential monitored release of the floral ingredient, and longer shelf life of the isolated botanicals increased the biosynthetic pathway of the plant-based substances as well as the sustainability of the formulation (Madhusudhanamurthy *et al*., 2013).

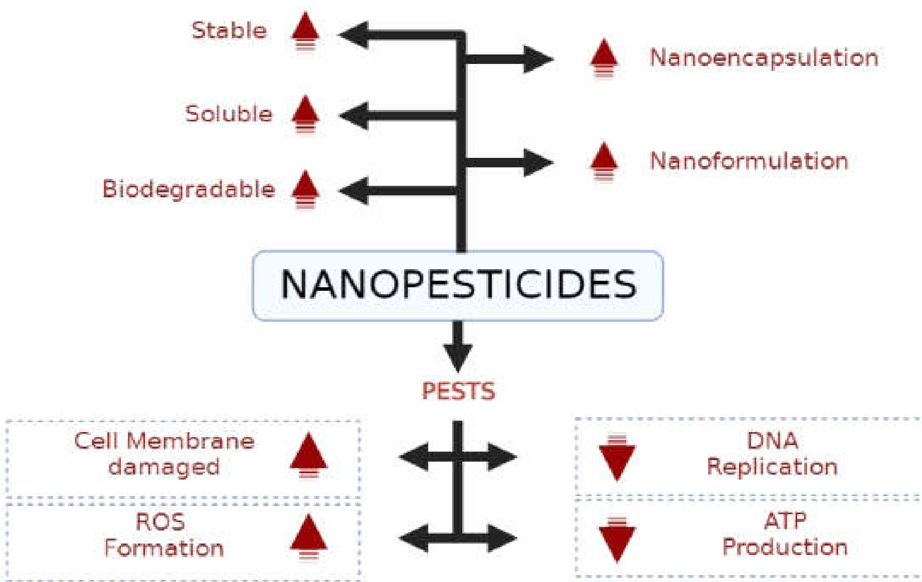

Fig.2:NPs' characteristics and how they affect pests

1.5. System for delivering pesticides that use nanoparticles as nanocarriers

The "pesticide delivery system" (PDS), an analogous strategy for pest management, was created after taking lessons from drug distribution techniques elaborated in medicine, where the employment of NPs to deliver drugs for medical care has been successful (Tsuji, K. *et al*., 2001). The goal is to deliver the active components to a specific target at the appropriate amounts and times. that will provide the desired effect while retaining the optimum degree of biological viability and limiting any unfavorable sideeffects (Ghormade, V. *et al*., 2011). To achieve the greatest biological efficacy and to reduce any possible negative effects, controlled administration is crucial for ensuring the best release of sufficient amounts of pesticides over time (Tsuji, K. *et al*., 2001). It is advantageous to employ NPs as nano carriers because of their increased surface area, ease of attaching single to multiple pesticide corpuscles, and molecular diffusion is fairly quick to the target, which is the body of insects. En-capsulated pesticides are expected to discharge more consistently over time, necessitating their administration less frequently. This is against the initial treatments that are highly concentrated and probably fatal and are followed by recurrent applications. Additionally, NPs delay the loss of potency brought on by degradation.

1.6. Preparations for lipid-based nano-pesticides

Phospholipids, which may assemble themselves into many bilayers to define the aqueous phase, make up lipid-based nano carriers. (Sala, M., *et al*., 2018). Due to their unique characteristics, such as physical and chemical storage stability, environmental protection, maximum adsorption capacity, and target-oriented smart release mechanism, these carriers are particularly effective for regulated active ingredient release (Zheng, M., *et al*., 2013). The usage of lipid-based nanoparticles as pesticide carriers is a relatively new topic of research, with only a few studies supporting this. Compared to alternative active ingredient distribution strategies like nano-polymers and nano-emulsions, several benefits of these lipid-based nanomaterials include reduced chemical depreciation and the consolidation of both hydrophobic and hydrophilic active components., and possible big corporate production (Li, X., *et al*., 2018). Without utilizing any UV absorbers, lipid carriers may be able to prevent the photo-degradation of active substances (Nguyen, H., *et al*., 2012). The biocide's ability to penetrate a plant's roots and then travel through the plant system to the targeted pest species is greatly influenced by the nanocarrier matrix's physical state (Chen, C., *et al*.,2010). Lyophilization is a widely used technique to increase the shelf life of these nanoliposomes (Bang, S., *et al*., 2009) initially disclosed the monitored release of pesticides by generating the nanoliposomes (Kang, M.A., *et al*.,2012) indicated that using traditional and nano-formulated active ingredients simultaneously could decrease the expense of manufacture and, subsequently, the incidence of application.

1.7. Metallic nanoparticles as key substituents and formulations

Metal and metal oxide Nanoparticles have numerous uses in health, environmental protection, and agricultural applications, mainly because of their competency and adaptability. When compared to other traditional formulations and microparticles, these nanoparticles have a high value of surface-to-volume fraction, more pore volumes and pore sizes, effective surface characteristics, and stable thermal behavior (Vellingiri, K. *et al*., 2017 ; Nehra, M., *et al*.,2019). The toxic impacts of traditional formulations could be reduced by these formulations, such as target avoidant activity, inadequate dissolving power, and ecosystem poisoning (Pinto, R.V., *et al*., 2017 ; He, L., *et al*., 2011).

1.8. Porous silica-based nano-pesticide formulations

Due to its simple and low-cost commercial manufacture, silica-based nano-formulations are new to the agriculture industry but are extensively employed in the biomedical industry.

They are extremely effective delivery methods with particular surface characteristics, porosity, biocompatibility, increased loading capacities, and ecological safety (Liu, W. *et al*.,2014 ; Vaculikova, E. *et al*., 2015). Nano-formulations related to porous silica are more suitable for agricultural applications than polymeric materials because they have a more flexible structural design and higher mechanical stability (Lou, X.W.*et al*., 2008). Utilizing silicon particles may increase a plant's resistance to biotic and abiotic stressors (Barik, T. *et al*., 2008). Several pests that are crucial to agriculture have been successfully controlled using surface-charged hydrophobic silica nanoparticles (Ulrichs, C., *et al*. 2006). One of the more recent and well-liked planned infusions of agrochemicals, avermectin, was studied using porous hollow silica nanoparticles (PHSN) as pesticide carriers (Wen, L.X., *et al*. 2005) .They came to the conclusion that PHSNs might be used in targeted pesticide distribution applications because the PHSN carriers substantially slowed the discharge of the pesticide. Due to their enormous surface areas, NPs can more quickly absorb and bond with other substances, circulate effortlessly in lepidopteran systems, and may also be used to manufacture pesticides ((Barik, T. *et al*., 2008).

1.9. Silver-based nano-pesticides

AgNMs (silver materials) have been demonstrated in several in vitro investigations to inhibit the proliferation of a variety of diseases (Dutta *et al*., 2017). Ag NM poisoning mechanism is yet to be comprehended completely, but it is perceived to be predominantly caused by the release of ionic Ag+. A well-known mechanism of action for silver ions is the rupturing pathogen's membrane by binding to proteins having cysteine on the cell membrane (Servin, A., *et al*., 2015). One study found that exposure to biosynthesized sliver NMs significantly decreased the spore count of *Alternaria solani* after 3. In one instance, tomato plants were sprayed with biosynthesized particles to protect them from the early blight disease brought on by *A. solani* in order to demonstrate the antibacterial capabilities of Ag nanoparticles. When compared to infected plants that weren't treated, the Ag nanomaterial slowed the spread of disease by 49% (Kumari, M., *et al*., 2017) Comparatively to the untreated control, in vitro management of silver nano material decreased fungal conidial growth on *Bipolarissorokiniana* (Mishra, S., *et al*., 2014).

The action of petroleum ether extract with silver nanometal particles offers an eco-friendly way to reduce Meloidogyne incognita. According to (Nassar *et al*., 2016), evaluated the efficiency of *Urtica urens* extract with Ag-nano particles against root-knot nematodes (*Meloidogyne incognita*). Three harmful bacteria*, S. aureus*, *E. coli*, and *P. aeruginosa,* and one helpful bacterium (*Bacillus subtilis)* were effectively controlled by the particles made of silver and other materials (Bryaskova, R., *et al*., 2011 ; Krishnaraj, C., *et al*.,2012) explain through his work that all of the plant pathogenic fungi tested (*A.alternata, S.sclerotiorum, M.phaseolina, R.solani, B. cinerea, and C. lunata*) were fungicidal at different concentrations. The pathogenicity of *Xanthomonas perforans* was reduced in vtro by Ag-nanoparticles produced on DNA and graphene oxide (Ocsoy, I. *et al*., 2013).

1.10. Zinc-based nano-pesticides

ZnO nano-particles made from green synthesis have demonstrated activity against bacteria (*P. mirabilis,S. aureus, S. marcescens, and C.freundii*) and fungi (*A. flavus, A,niger, B.s cinerea, P.expansum, and A.nidulans)* (Servin, A., *et al*., 2015; Kumari, M., *et al*., 2017 ; Mishra, S., *et al*., 2014 ; Bryaskova, R., *et al*., 2011). The bacterial cell wall was assumed to have been extensively damaged by the ROS generated on Zinc oxide nanomaterials, resulting in the inactivation of the organisms. Further, *F. graminearum*growth was inhibitedby 75%, when exposed to mung bean broth agar and inhibited by 63% when expose to sand amendment with ZnO NM for 7days (Dimkpa, C.O., *et al*.,2013). Similarly to this, it has been reported that ZnO NMs plate assays can suppress growth (inhibitory zones to 19 and 22 mm) for *A. flavus* and *A. niger* respectively (Jayaseelan, C., *et al*., 2012). Additionally*, B. Cinerea* and *P. expansum* both had their development severely hindered by zinc oxide nanomaterial at 3–12 mmol (He, L., *et al*.,2011). Additionally, in vitro experiments have shown that ZnO particles suppressed Pythium isolates and reduced the radial development of *F. oxysporum* when compared to the corresponding controls (Zabrieski, Z., *et al*., 2015). According to (Jayaseelan, C., *et al*.,2012), zinc nanoparticles have an antimicrobial effect on *P. aeruginosa*. In an open-field pot experiment, a light-activated TiO2/zinc nanomaterial was created and tested for disease suppression (Paret, M. L. *et al*.,2013. Untreated Control comparison with, the bacterial leaf spot disease in rose plants caused by *Xanthomonas sp*was reduced by TiO2/zinc nano material. Although the leaf spot disease was effectively suppressed by the nanoformulation, the concentration utilized was relatively high. To protect the grape fruit plant from the citrus canker lesion disease, two distinct zinc oxide nanomaterials, Zinkicide SG4 and Zinkicide SG6, were used in both field and greenhouse experiments brought on by *Xanthomonas citri subsp. Citri* (Graham, J.H., *et al.,* 2016).

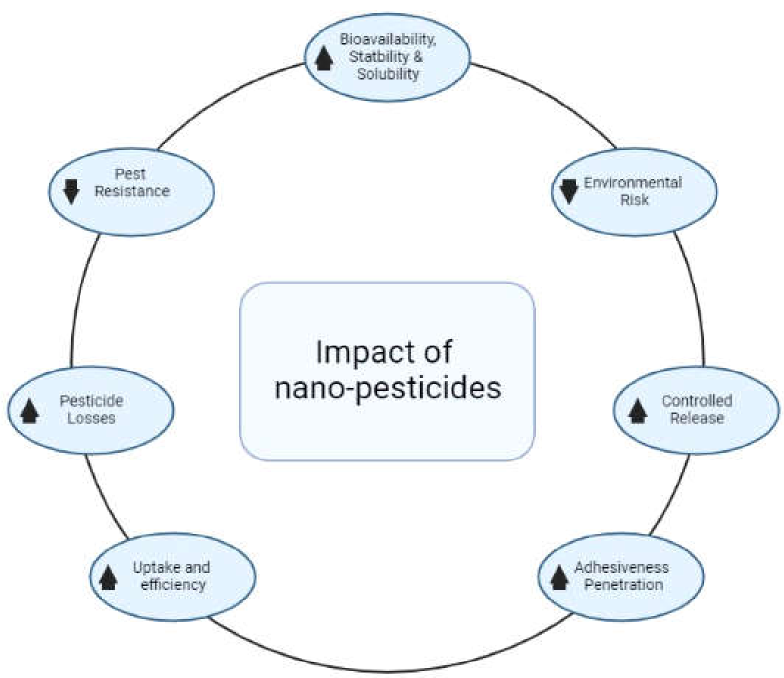

Fig.3: Advantages of Nanopesticides

Engineered nanomaterials (ENMs) as pesticides for controlling pathogenic diseases

The main goal of nano pesticide is to act as a suitable agricultural supplement with an enhanced ability to protect or reduce the severity of fungal, and bacterial diseases in plants. Accordingly, it is anticipated that these amendments will be more effective than conventional treatments with comparable chemical cpmpositions that require lower dosages, and if not improve production, then maintain it. This is because of their nanoscale features. The use of ENMs (Engineered Nano-materials) to protect plants from different types of diseases has recently attracted more attention. Notably, using ENM insecticides at lower rates than their conventional counterparts would prevent over application, and run off of the active ingredients, which cause environmental pollution. Along with these advantages, less energy and water would also be used in the production of the materials. Together, these things will also help farmers' pesticide input costs (Chhipa, H. *et al*., 2017).

The ENMs can function as substitutes for traditional pesticides as shown in studies either as polymers or as stand-alone materials, which has sparked an even greater interest in the development ofactivity against microbes that integrate nanomaterials (Chhipa, H.*et al*., 2017). In order to create nano-enabled versions of conventional antimicrobials, a range of techniques has been used, such as polymeric materials with various morphologies (Kah, M.*et al*., 2014).

ENMs as insecticides

The ENMs enhance plant production as insecticides and pathogenic nematodes, as well as herbicides, are gaining interest. However, compared to ENM use as antimicrobials, significantly less research has been done in this field. The few findings that are currently available imply that ENM platforms might offer efficient methods for the management of weed species and insect pests. Incorporating ENMs into conventional insecticides and herbicides via nano-enabled formulations can be used to enhance the solubility of the active particles. However, these formulations have the potential to be genotoxic by changing the structure of DNA and alternating the function of the electron transport chain.With the combination of these factors, cellular integrity may be impaired, ultimately leading to pathogen death. The documented disintegration of microbial cell walls and cell membranes indicates that this is how chitosan-based NMsmost likelyact (Kumaraswamy, R. *et al.*, 2018). ROS formation may be induced by released ions and ENMs, which could disrupt a number of critical processes for target species penetrability,controlled release, and stabilityfeatures. (Nuruzzaman, M.*et al*., 2016 ; Singh, H.B., *et al*., 2018). Enhancing the accuracy and precision of drug delivery, reduces the amount of material leaked into the environment, similar to nano-activated antimicrobials and nano-fertilizers, thereby reducing unwanted impacts on non-target species and the environment (Yin, J., Y.*et al*., 2018). It has been claimed that *C. maculatus*, *D. melanogaster, S.oryzae*, and *R.dominica* can all be protected against insect pests by using ENM to transport genetic material directly into host tissues (Prasad, R. *et al*., 2014). The gradual release of active chemicals from nanomaterials coated in polyethylene glycol (PEG) and in garlic essential oils serves as a second illustration. This increased the insecticidal efficiency of PEG against adult *Triboliumcastaneum* (Yang, F.-L., *et al*., 2009) *S. oryzae* and *R. dominica* were targeted by nano structured alumina in one of the earliest investigations proving the insecticidal capability of NMs (Stadler, T. *et al*., 2010). The nano alumina against different insects as insecticides has been further demonstrated in subsequent lab and field bio- assays, including the leaf-cutting ant *A.lobicornis* (Buteler, M. *et al*., 2018). Nano-alumina is an amorphous material with significant supportive capabilities, which increases its insecticidal efficacy.

Table 1. Summary of Nanoparticles used as Pesticides to Manage Crop Diseases

Nano-pesticides	Pathogens	Effect	Reference
Lipid-based NPs		Can prevent photo degeneration of active ingredients	Nguyen *et al*., 2012
Lyophilization of lipid-based NPs		Shelf life prolong Control the release of biopesticides	Chen *et al*., 2010 Bang *et al*., 2009
Porous Hollow Silica NPs	Lepidopteran	Controlled delayed release of avermectin pesticides	Wen *et al*., 2005
Sliver NPs	*Alternaria-solani* *Alternaria-solani*	Antifungal activity by reducing spore formation Antimicrobial effect in tomato against early blight disease	Kumari *et al*., 2017 Kumari *et al*., 2017
Ag	*Bipolaris-sorokiniana*	Suppression of spot blotch disease in wheat	Mishra *et al*., 2014
DNA-Directed Ag on graphene oxide	*Xanthomonas-perforans*	Suppression of bacterial spot disease in tomato plant	*Ocsoy et al., 2013*
Ag formulation with *Urticaurens*	Nematodes (*Meloidogyne incognita)*	Against root-knot nematodes	Nassar *et al*, 2016

ZnO NPs	*F.graminearum*	Growth inhibition in wheat	Dimkpa *et al*., 2013
	A. flavus & *A. niger*	Growth inhibition	Jayaseelan *et al.*, 2012
	F. oxysporum	Reduce radial expansion	Elmer and White *et al.*, 2016
TiO/Zn	*Xanthomonas sp*	Reduced bacterial leaf spot disease in rose plant	Paret *et al.*, 2013
ZnoZinkicide SG4 & SG6	*Xanthomonas citri*subsp. *Citri*	Suppression of citrus canker lesion disease in grapefruits	Graham *et al.*, 2016
PEG NPs	*Triboliumcastaneum*	Increased Insecticidal effect	Yang *et al.*, 2009
Nano-structured alumina	*S. oryzae*& *R. dominica*	Insecticidal effect	Stadler *et al.*, 2010

Benefits Of Nano-pesticides

In contrast to standard pesticide formulations, nano formulations are designed to enhance the solubility of poorly soluble active materials and to release the biocide in a specific amount and targeted manner (Margulis-Goshen, K *et al.*, 2013). This means that a lower amount of an active ingredient per area is required for use and sustained delivery of the active ingredients can be provided which can be effective over longer periods. As a result, the reduced dose also results in decreased production costs, non-target impacts, and phytotoxicity. Controlled-release formulations must also be inert until the active component is released, which is crucial.

The most often manufactured controlled-release formulations are nano-capsules, nanospheres, nanogels, and micelles, and different types of physical and chemical procedures are d-etailed for their creation. The regulated release of hydrophobic active components in aqueous solutions with excellent selectivity and without impairing the biocidal action may be made possible by nanoencapsulation with a polymer matrix (Peteu, S.F., *et a*l., 2010).

Limitations and knowledge gap

As the world becomes increasingly populated and industrialized, so too does the number of pests and diseases. To combat this growing problem, researchers are looking to develop new, more effective ways to control these pests. One such method is through the use of nano-scale pesticides. Nano-scale pesticides are those that are smaller than 100 nanometers (nm). They are able to travel deep into cells, disrupting their functions. This makes nano-scale pesticides much more effective than traditional pesticides at controlling pests. One of the main benefits of using nano-scale pesticides is that they are less harmful to humans and the environment.Traditional pesticides can be dangerous if they are ingested or contact the skin. Nano-scale pesticides, on the other hand, are not harmful when they contact the skin or are ingested. Another advantage of using nano-scale pesticides is that they can be used in a variety of settings. Traditional pesticides are only effective in areas that are treated with them. Nano-scale pesticides can be used wherever there is a pest problem. This makes them a more versatile tool for controlling pests. There are still some challenges that need to be overcome before nano-scale pesticides can become mainstream. One such challenge is ensuring that these pesticides are effective at controlling pests. Researchers need to find a way to create nano-scale pesticide products that are effective and safe for use.

This paper reviews the use of nanoparticles as nano-pesticides. Nanotechnology is an emerging field with applications in the improvement of plantyield with less hazardous effects. Researchers/scientists worked on different nano-metals such as silver, zinc, silica, and ENMs so that these can be used as bio-pesticides.These biopesticides are eco-friendly and more efficient pesticides than conventional chemical pesticides. They are "green'' alternatives used in place of traditional pest controls. Currently, there is a lot of work needed to do in the nano-pesticides area because a better understanding of adverse impacts and their interactions need to be improved before their extensive use in plant production.There is great potential for sliver-nano pesticides in the future as they continue to be developed and refined. However, there are many challenges that need to be overcome before these technologies can become widely used. One major challenge is the lack of toxicity data for these chemicals. Until this data is available, it will be difficult for manufacturers and regulators to determine whether or not these pesticides are safe to use. Another challenge is cost. Sliver-nano pesticides typically require more testing and processing than traditional pesticides, which means that they are likely to be more expensive. Finally, there is a need for better understanding of how silica-nano pesticides interact with the environment and other organisms. Until this knowledge is available, it will be difficult to determine whether or not these technologies are effective in controlling pests.

The future of lipid-based nano pesticides looks promising. Nano pesticides are becoming increasingly popular because they are smaller and more efficient than traditional pesticides, and they have fewer environmental impacts. There are a number of reasons why lipid-based nano pesticides may be particularly well suited for use in agriculture. One advantage of using nano pesticides is that they can reach the target plant more effectively than traditional pesticides. Nano pesticides are smaller and faster acting, so they can kill the target plant faster than traditional pesticides. This means that less chemical is required to kill the plant, which reduces the environmental impact of the pesticide. Additionally, nano pesticides are more specific than traditional pesticides. They can target only certain types of bacteria or fungi, which make them more effective at controlling pests. Another advantage of using nano pesticides is that they are less harmful to humans and the environment. Nano pesticides are designed to kill specific types of bacteria or fungi, so they do not produce as many harmful side effects as traditional pesticides. Additionally, nano pesticides are less likely to bioaccumulate in the environment. Bioaccumulation refers to the process by which chemicals accumulate in organisms over time, leading to increased levels in the body and in the environment because they are too small to be absorbed into plants and animals. Overall, there seems to be a lot of potential for lipid-based nano pesticides in agriculture. They are effective, environmentally friendly, and specific enough to target only certain types of pests. While there are some challenges associated with using nano pesticides, such as development costs and limited availability, these problems seem likely to be overcome in future.

The future of engineered nanomaterials as pesticides is promising. There are a number of reasons for this. First, the technology is still relatively new, and there is a lot of research being conducted into how to use these materials in a way that is effective and safe. Second, the potential applications for engineered nanomaterials as pesticides are wide-ranging and varied. This means that it is potential for these materials to be used in a variety of different ways, which could lead to their widespread use in the future. Finally, the growing concern over the health and environmental effects of traditional pesticides has led many farmers and growers to explore alternatives, and engineered nanomaterials could be one such option.

Although ENMs have shown promise in a variety of agricultural applications, significant limitations and knowledge gaps still exist. As mentioned above, more research is needed, including soil and fields, to show the effectiveness and, more importantly, the reproducibility of ENM effects in real farming situations. In addition, several variables including material properties (size/morphology/coating), crop species, exposure dose, presence of pathogens, and timing of application influence the beneficial effects of ENMs as plant disease suppressants. Therefore, choosing the right type, dose, and method of administration of ENM is essential to achieving positive results. It should be noted that most ENMs are metallic in composition. As a result, the widespread use of such ENMs can lead to metal-bearing soils. Therefore, careful drug dose and an effective and targeted administration strategy are required before use. Precautions must be taken to ensure that nano pesticides do not harm symbiotic microbial species in the plant or the soil, or non-target bacteria that promote plant growth. In addition, given the evolutionary pressures leading to microbial pathogens developing resistance after repeated use of conventional pesticides, a critical assessment of the likelihood that ENM-based nano pesticides showing a similar trend should be made. Nano-pesticides and nano-fertilizers undoubtedly hold enormous promise for nanotechnology-assisted agriculture. However, more research is needed before they are widely used.

Environmental Consideration regarding Nano-pesticides

Nano-pesticides are a new and innovative technology and have been shown to be effective in controlling pest populations. However, it is essential to consider the potential environmental impacts that these materials may have. As nano-pesticides are so small, they can travel easily through the environment and are more likely to accumulate and bioaccumulate in soils, water, and other organisms. This could lead to potential environmental damage, such as the accumulation of these materials in the food chain, which could lead to adverse health effects for humans and other organisms. Additionally, as these materials are so small, they could potentially become airborne and travel long distances, leading to potential contamination of pristine areas. It is also important to consider the impact of nano-pesticides on beneficial organisms, such as pollinators, which could be adversely impacted by using these materials. Thus, it is important to ensure that careful consideration is given to the potential environmental impacts of nano-pesticides before they are used.The fact that nano pesticides cause less environmental pollution through lower pesticide application rates and fewer losses is one of the arguments in favor of them over conventional pesticides (Gao, X. and G.V. Lowry *et al*., 2018) On the other hand, because of the improved transit, extended permanence, and increased toxicity, they might present a fresh contamination issue for soils and aquatic bodies. Due to their huge surface area, nanoparticles can degrade quickly in sunlight, decreasing the effectiveness of their active components. Similar to large droplet sizes, small droplet sizes may cause nanodroplets to evaporate before they reach their target. Another important topic that needs research is how nano-formulations interact with different trophic levels of bacteria, plants, and animals. Furthermore, it is unknown how pesticide nano-formulations will affect the soil, groundwater, and creatures that are not their intended targets. The active components' release into the environment is governed by the characteristics of the nanomaterials and their dispersion within the matrix of the nano-formulation According to reports, nontarget creatures may be harmed by the prolonged delayed release of nanoparticles (Kah, M. and T. *et al*., 2014). Most commonly utilized nanocarriers in nano-formulations are easily biodegradable like natural polymers, polysaccharides, or lipids.

However, minimal worry has been expressed over the usage of metal and metal oxides as non-biodegradable nanocarriers. Furthermore, compared to non-encapsulated pesticides, the majority of manufactured nanoparticles are for necessary release, causing exposure to nano-formulations in an inhibited manner. It can be shown that the bulk of studies on evaluating the environmental effects of nano-formulations has been conducted at the laboratory level and on the assessment of the environmental consequences of nano-formulations under field circumstances (Kah, M. *et al*.,2018).

There have also been reports of the phytotoxic effects of nanoparticles on various plant systems. With the application of Ag NPs, rice crops' seed germination and seedling growth decreased (Thuesombat, P., *et al*., 2014) whilst tomatoes' root elongation significantly decreased (Song, U., *et al*.,2013). TiO2 NPs prevented the growth of the leaves, transpiration, and the hydraulic conductivity of the roots in maize seedlings (Asli, S. *et al*., 2009). The possible toxicity of silver nanoparticles on Nicotiana tabacum was reported by (Cvjetko, P., *et al*.,2018). More research is needed to fully analyze the possible dangers of nanoparticles on crop plants because the mechanisms are still poorly understood. The bacteria in the soil have a complex relationship with nanoparticles and influence their environmental fate in a variety of ways. Beneficial bacteria in soil aid in the decomposition of organic matter, recycling of nutrients, suppression of illness, and improvement of growth. According to reports, the use of nano-formulations may have a detrimental effect on the microbial population of the soil, which could ultimately degrade the soil's quality and agricultural viability.

2. CONCLUSION

In conclusion, the development and use of nano-pesticides represents a promising avenue to revolutionize modern agriculture and pest control practices. Over the years, traditional chemical pesticides have demonstrated their effectiveness in controlling pests and increasing crop yields. However, its detrimental effects on human health, non-target organisms and the environment have raised significant concerns, necessitating the search for safer and more sustainable alternatives.

Nanopesticides offer several advantages over traditional pesticides because of their nanoscale size and unique physicochemical properties. They allow for targeted delivery, improved solubility, and controlled release of active ingredients, resulting in improved efficacy and lower application rates. Additionally, its smaller size allows better penetration into insect exoskeletons and plant cuticles, increasing its bioavailability and potency. Another crucial aspect of nanopesticides is their potential to reduce environmental pollution and minimize harmful effects on beneficial insects and organisms. Through the use of nanocarriers and encapsulation techniques, drug release can be more controlled and sustained, resulting in a reduction in off-target effects and surface run-off. However, it is imperative to approach the development of nanopesticides with caution and to carry out comprehensive risk assessments to ensure their safety and minimize potential hazards. Interactions between nanoparticles and biological systems, as well as their long-term fate in the environment, need to be thoroughly investigated in order to mitigate unforeseen adverse impacts. As the field of nanotechnology continues to advance, concerted efforts between scientists, regulators and stakeholders will be crucial to address the challenges and realize the potential benefits of nanopesticides. Transparent communication and education are crucial to fostering public acceptance and understanding of this emerging technology,

Finally, nanopesticides show promise to shape the future of pest management and offer efficient, ecological and sustainable solutions. Through continuous research and responsible implementation, nanotechnology can play a vital role in achieving global food security while protecting human health and the environment.

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