Agriways 9 (2) : 98-105, December 2021

ISSN: 2321-8614 (Print)
ISSN: 2454-2318 (Online)

Review Article

Role of Nanotechnology in Agriculture: A review

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Received: 18 August 2021/Accepted: 20 October 2021

Abstract: In agriculture, nanotechnology involves the use of nanoparticle in insect pest management programmes. These nanoparticles can be used in agricultural practices to increase crop productivity while decreasing harmful effects on human health and the environment. When the particle size becomes too small, it can reach any large surface area, allowing a large volume of pesticide to come into contact with pests. Farmers prefer to use chemical pesticides on a large scale, which has a number of adverse effects on humans as well on the environment. The use of nanotechnology can provide an environmentally friendly alternative to insect pest management. Mainly, the focus is on using nanoparticles in integrated pest management as nanoemulsions, nanopesticides, nanosuspensions and controlled release formulations (CRF). This review summarizes modern approaches to nanotechnology that involve integrated pest management.

Keywords: Nanoemulsion, Nanospheres, Nanogels, Solid particles, Nanotechnology Applications

Introduction

The importance of pesticides has been expanding over the last few decades, driven by the need to improve overall agricultural productivity in order to safeguard adequate food availability and to meet the needs of the growing global population. In India, approximately 15-25% of food produce is eaten by pests and damaged by diseases every year (Rathe and Dalal 2018). Pesticides have been used on crops for ages to combat losses caused by insect pests and to fight diseases. Pesticides, on the other hand, are routinely detected in various components of the environment and pose a threat to human health as a result of indiscriminate use. The pesticide formulation is a blend of active ingredients and other intentionally added inert ingredients. Active ingredients are the primary drivers of their targeted toxicity and are generally water-insoluble organic compounds. Other ingredients can be solvent, carrier, adjuvant, emulsifier, dispersant and auxiliary ingredients that facilitate spray application in the field. Because pesticides are generally applied to crops by spraying, only a small number of agrochemicals are able to reach the target sites of crops using traditional methods. The actual utilization of biological target uptake is only less than 0.1% after dust, drift, rainwater and leaching (Massinon et al. 2017). Off-target loss is the crucial problem for inefficient usage of conventional pesticide formulations (Pandey et al. 2018; Xue et al. 2021). Studies in several areas of insecticide usage have resulted in the development of more effective and non-persistent pesticides, such as controlled release formulations (CRF) or nanoformulations that can be used in crop protection for example nano-insecticides, nano-herbicides, nano-fungicides and nano-nematicide (Ghormade et al. 2011; Perlatti et al. 2013). All of these are made up of active ingredients, carrier molecules, and surfactants. Nanopesticide formulations are intended to improve solubility, slow the release of active ingredients, and prevent soil degradation while also improving soil quality (Perlatti et al. 2013; Durán and Marcato 2013; Gogos et al. 2012). In order to achieve all these purposes, carrier molecules have been modified and classified as organic polymer-based formulations, lipid-based formulations, nanosized metals and metal oxides, clay based nanomaterials etc. Notably, nanomaterials enhance the productivity of crops by increasing the efficiency of agricultural inputs to facilitate site-targeted controlled delivery of nutrients, thereby ensuring the minimal use of agri-inputs (Shang et al. 2019). Nanoformulations help to produce new pesticides, insecticides and insect repellants (Owolade et al. 2008). Some principal nano-formulations are mentioned in this article.

Nanoformulations Used in Agriculture

Nanoemulsion

Nanoemulsion can be defined as a homogenous mixture of two immiscible liquids which are thermodynamically unstable. Nanoemulsion consists of a dispersed phase and a dispersed medium and both are formed by liquids (McClements 2012; Ashraf et al. 2021). Nanoemulsion consists of droplets with a diameter ranging between 10~200 nm and each droplet has a protective covering of an emulsifier molecule (Acosta 2009; Cerpnjak et al. 2013; Gibaud and Attivi 2012; Rehman et al. 2017). The most commonly preferred nanoemulsion is oil-in water emulsion, which is generally used where the active or mobile ingredient of the chemical is dispersed as nanosized droplets in water, with surfactant molecules restricted at the pesticide-water interface. According to Wang et al. (2007), oil in water (nano-emulsion) was useful for the formulations of pesticides and these could be effective against the various insect pests in agriculture.

Nano-emulsions are either thermodynamically stable or kinetically stable. In thermodynamically stable nano-emulsion, when surfactant, pesticide and water components are brought together, then the pesticide is partially soluble in the aqueous phase. The insolubility of the active ingredient makes the pesticide and surfactant initially form a two phase system and shearing without interruption makes them mix together. Thus, pesticide droplets in the nano-emulsion will remain dispersed for an extended period of time and are considered to be kinetically stable. For example, Neem oil has been developed as oil in water emulsion for insect management using Tween 20 as the surfactant (Rabelo et al. 2021). Oil in water nanoemulsions are used for preparing various pesticide formulations. Silica is used to create nanomaterials such as nano-silica. Induced resistance in plants, due to application of silica, against many herbivorous arthropods has been well documented (Keeping and Kvedaras, 2008). It has ample applications in medicine and drug development, where nano-silica is used as a catalyst. The mechanism of using nanosilica as a pesticide is that insects use a diversity of cuticular lipids to keep their water barrier intact. However, nanosilica is absorbed into the cuticular lipids via physiosorption and causes cuticle desiccation, resulting in the death of insects with purely physical resources (Zahran et al. 2021). Liu et al. (2004) has reported that Porous hollow silica nanoparticles (PHSNs) stacked with validamycin (pesticide) can be effectively used for controlled release of pesticide. Such controlled release behaviour of PHSNs makes it a promising carrier in agriculture, especially for pesticide controlled delivery whose immediate as well as prolonged release is needed for plants.

Components of Nanoemulsion

Oils, lipids, surfactants, water-soluble co-solvents and water are the components of nanoemulsion. In the formulation of nanoemulsions, the oil phase may include triglycerides like vegetable oils, mineral oils, free fatty acids etc. (Goncalves et al. 2017). Oil selection is mainly based on the drug solubility. Oil phases with higher drug loading capacity are typically used in the development of nanoemulsions (Qadir et al. 2016). The surfactants used in the nanoemulsion systems for drug transport and food ingredients are spans (sorbitan fatty acid esters), tweens (polyoxyethylene (POE), derivatives of sorbitan fatty acid ester), Cremophor® EL (polyoxyl-35 castor oil), lauroylmacro-golglycerides (Gelucire® 44/14), polysaccharides that include gums and starch, egg, soy, or dairy lecithin (phospholipids) and amphiphilic proteins (whey protein isolate and caseinate) (Komaiko and McClements, 2016; Singh et al. 2017).

Nanosuspension

They are sub-micron colloidal dispersions of nanosized drug particles stabilized by surfactants, also known as nano-disperse (Jacob et al. 2020). The surfactant atoms become restricted at the molecule's surface, where polar parcels stretch out into a watery arrangement and non-polar parts partner with the solid pesticide (Sabri 2020). Nano-permethin, Novaluron and ?-Cypermethrin in their aqueous dispersions are used as nanosuspension.

Polymer Based Nanoparticles

Polymer-based pesticide nanocarriers are majorly involved in the moderate and controlled release of active elements to the target site (Vrignaud et al. 2011). Moreover, they can be used to improve dispersion in aqueous media and also as a protective reservoir. Polymer nanoparticles include nano-encapsulation, nano-gels, nanoospheres, nano-fibers etc (Santo Pereiera et al. 2019). Few of these are discussed below.

Nanoencapsulation

It is the technique of packaging nanoparticles also known as the core or active, within a secondary material (matrix or shell) to form micro or nanocapsules and is one of the promising approaches to check insect pests in host plants. The core contains functional elements, e.g., drugs, perfumes, biocides, vitamins, while the shell separates and protects the core from the surrounding environment. This protection of the core can be permanent or temporal. The core is often released by diffusion or in response to a trigger such as shear, pH, or enzyme action. Thus enabling it's controlled and timed transport to a targeted site (Desai et al. 2005; Jyothi et al. 2010; Bernela et al. 2021). The active ingredients contained within the core can be either hydrophobic or hydrophillic. It can be adsorbed, attached, encapsulated and entrapped. The active ingredient in the neem-azadiractin formulation can be protected through this formulation. A controlled-release nano-formulation of the neonicotinoid insecticides, e.g, acetamipirid and imidacloprid have also been developed for pest control (Rajna et al. 2019). Nanotube filled with aluminosilicate can stick to plant surfaces, while ingredients of nanotube have the ability to stick to the surface hair of insect pests and ultimately enter the body and influence certain physiological functions (Patil et al. 2009). Encapsulated citronella oil nano-emulsion is prepared by high-pressure homogenization of 2.5% surfactant and 100% glycerol, to create stable droplets that increase the retention of the oil and slow release. The release rate depends upon the protection time; consequently a decrease in release rate can prolong mosquito protection time (Sakulk et al. 2009). Bhagat et al. (2013) stated that environment-friendly management of fruit flies involving pheromones is useful in reducing the undesirable pest populations responsible for decreasing the yield and the crop quality. During the past few years, a few researchers published studies on natural pesticides with nano-encapsulated covers such as Moretti et al. (2002) investigated the effect of microcapsule and emulsions of R. officinalis L and Thymus herbal-Barona Loisel on Lymantria dispar L. that is one of the most serious pests cork oak forests.

Nanospheres and Nanogels

Nanospheres are compact solid polymeric matrixes where the drug is either placed in the center or dispersed over the surface for example Polymer stabilized bifenthrin nanoparticles are developed as nanospheres (Joshi et al. 2019). Nanogels are also known as hydrogel nanopartciles. These are formed when polymeric particles with hydrophilic groups are cross linked in such a way that allows them to absorb a large amount of water (Bhagat et al. 2013). He also stated that environment-friendly management of fruit flies involving pheromones is useful in reducing the undesirable pest populations responsible for decreasing the yield and the crop quality.

Biosynthesis Solid Nanoparticles

Nanoparticles are syntheized from chemical methods that involve the use of toxic chemicals. Therefore, we have to shift towards environmentally friendly routes. Ecofriendly alternatives involve the use of various organisms such as viruses, fungi, bacteria etc. Distinct biological sources have been used for the synthesis of nanoparticles and are being used in agriculture (Bansal et al. 2014).

Synthesis of Silver Nanoparticles

Silver nanoparticles are advantageous over bulk silver as the former one has a large surface area and fraction of surface atoms; as a result of this, silver nanoparticles have high antimicrobial activity when compared with bulk silver (Cho et al. 2005). The antimicrobial property of silver nanoparticles has been utilized against a vast variety of human microbes (Morones et al. 2005; Tian et al. 2007; Prakash et al. 2013; Oves et al. 2013). However, the entire capability still remains to be searched for crop protection. Therefore, there is an increasing interest in utilizing the antimicrobial properties of silver nanoparticles for plant disease management (Mishra et al. 2014). Silver nanoparticles have been experimenting as insecticides to decrease the burden of pests from crops. Silver nanoparticles can be obtained by physical, chemical and biological methods. Owing to the requirement of extreme conditions and toxic chemicals in physical and chemical methods for the synthesis of nanoparticles require extreme conditions along with toxic chemicals. Therefore, ecofriendly methods are used that involve the synthesis of silver nanoparticles from various sources like plants, bacteria, fungi etc. Biological synthesis of silver nanoparticles in sizes starting from 6 to 38 nm from Raphanus sativus (white radish) has been documented (Kumar et al. 2019). When the snails were exposed to silver nanoparticles, then hatching delay and morphological alterations were also observed in snail embryos (Goncalves et al. 2017). Spherical shaped silver nanoparticles in the size range of 10 to 20 nm are also obtained using culture supernatant of Serratia sp. Antifungal activity of silver nanoparticles is also determined against Bipolaris sorokiniana (the spot blotch pathogen of wheat) (Mishra et al. 2014). The effects of silver nanoparticles with diameters of 20 nm on seeds of fenugreek have been investigated (Hojjat 2015). Various concentrations of silver nanoparticles resulted in increased seed germination, speed of germination and root length. These findings showed that silver nanoparticles could significantly improve seed germination potential.

Zinc Oxide Nanoparticles

Zinc deficiency in the soil has led to the production of alkaline soils with increased calcium carbonate content (Takkar and Walker 1993). The restriction of zinc availability to plants in soil with an excess of calcium carbonate content is due to the alkaline pH that increased the precipitation of zinc (Alloway 2009; Rashid and Ryan 2004). Thus, to overcome the deficiency of zinc in the soil, zinc oxides (ZnO) and zinc sulphates (ZnSO4.H2O) or (ZnSO4.7H2O) are commonly used as fertlizers (Mortvedt et al. 1992). However, their applications as fertilizer are limited because of the non-availability of zinc to plants. To overcome this problem, zinc oxide nanoparticles can be used. The use of zinc oxide nanoparticles enhances zinc dissolution and its bioavailability even in soil with increased calcium carbonate content (Chippa et al. 2017). Zinc oxide nanoparticles having a size less than 100nm have a large surface to volume ratio and posses increased antimicrobial activity than large zinc particles (Xie et al. 2011). Zinc oxide nanoparticles increase the generation of reactive oxygen species (ROS), which can result in cell death of microbes (Xia et al. 2006, Ryter et al. 2007, Long et al. 2006). Zinc oxide nanoparticles can be used as bactericide and fungicide. Zincoxide nanoparticles synthesized using Moringa oleifera leaf extract size had fungicidal activities and antimicrobial activity against Candida tropicalis, Candida albicans, Bacillus subtilis, Staphylococcus aureus, Pseudomonas aeruginosa, Escherichia coli and Proteus mirabilis (Elumalai et al. 2015).

Applications in Agriculture

Nanotechnology has the ability to revolutionize and create massive changes in agricultural systems. It is developing as the sixth revolutionary technology in the current era. It is also forecasted that over the next two decades, the 'green revolution' would be accelerated by means of nanotechnology. The use of nanotechnology in agriculture is getting importance because it is possible advantages vary from enhanced food values, reduced agricultural inputs, improved nutrient contents and longer shelf life. Several studies have reported an enhancement in the efficacy of certain biological substances on pests, a decrease in toxicity towards humans and the environment (De Oliveira et al. 2014). Nanotechnology can be used as new techniques to discover and manage plant disease causing microbes (Mousavi and Rezaei 2011). Use of nanotechnology can revolutionize agriculture by providing new methods for disease detection, focused treatment, improving the capability of plants to take in nutrients, combat pests and resist ecological pressures. Nanotechnology has supplied new manners to identify troubles in plants (post harvest products) and provides new procedures for the rational choice of raw elements or enhances the quality of plant products by processing of such elements (Sharon et al. 2010). Nanomaterials are safer than conventional pesticides, herbicides, and fertilizers as their release can be controlled (Kuzma and VerHage 2006) and can be used in the preparation of new formulations like pesticides, insecticides and insect repellants (Barik et al. 2008; Gajbhiye et al. 2009; Owolade et al. 2008). Thus, nanotechnology could contribute to the development of less toxic biopesticides with favorable safety profiles and increased stability of the active agents, enhanced activity on target pests, and increased adoption by the end-users (Khot et al. 2012; Agrawal and Rathore, 2014)

Nanobiotechnology in Plant Protection and Plant Nutrition

A well-known truth is that micronutrients like manganese, copper, boron, iron, molybdenum, zinc etc. are vital for growth and development of plants. A vast boom in crop yields with the green revolution and new farming practices has led to the reduction of the micronutrients of soil like zinc, iron and molybdenum (Alloway 2008). Foliar utility of micronutrients can be enhanced by uptake via. Leaves (Martens and Westermann 1991). Nanotechnology may be used to increase the supply of micronutrients to flora. Nano formulations of micronutrients may be sprayed on flora or may be provided to soil for uptake by roots to enhance soil fitness and vigor (Peteu et al. 2010). Different nanoparticles have been tested to provide an appropriate level of micronutrients in plants. The use of nanotechnology in agriculture involves transport of nanocides pesticides encapsulated in nanomaterials for managed release and also establishment of biopesticides with nano-materials for safer crop protection (Debnath et al. 2012). For controlling insect pests, about 2 million metric tons of pesticides have been used worldwide annually (worth US $35 billion), a major part of which is released into the air during spraying and as run-off, affecting both the atmosphere and farmers (Stephenson 2003). Resistance of pests has increased because of excessive pesticide usage (Tilman et al. 2002). Nanoparticles and nanocapsules can lower environmental pollutants are more effective and environmentally friendly. Nanocrystals increase the pesticide effectiveness by applying the least effective dose of insecticides. Application of nano-silica to the tomato plants may minimize Spodoptera littoralis infestation. Nano-silica sprays affect the feeding preference of the Spodoptera littoralis, thus increasing the resistance of tomato plants. Also it affects biological parameters of the insect such as longevity and nymph production, thus reducing the reproductive potential. It affects the reproductive potential of insect females causing a reduction in population density of insect, damages and crop yield (El-bendary and El-Helaly 2013). It provides a moderate degree of resistance, but presents the advantage of being feasibly integrated to other management tactics in controlling this pest. In future, nanoparticles can be used for transporting of lively additives for recovery of all pathological sufferings of plants (Gonçalves; Kale et al. 2021).

Nanotechnology Risks

The properties of nanoparticles and other nanomaterials that provide novel and desirable attributes for a variety of industrial and agricultural uses can also be the source of new environmental and human risks, such as toxicity and pollution (Ranjan et al. 2021). There is little known about the health implications of ingesting products containing nanoparticles. A report by the British Royal Society has warned of the serious risks of nanotoxicity (Royal Society and the Royal Academy of Engineering 2004). The major concerns about human exposure to nanoscale particles are that they can enter the body through a variety of routes, including inhalation, digestion and skin contact. They may also be able to enter the bloodstream, penetrate cells, avoid immunologic reactions, enter in the lungs, and can cross the blood brain barrier from there (Scrinis 2006). The small size of nanoparticles can cause adverse effect on health and environment, animals and plants when used non-judiciously.

Conclusion and Future Prospects

Nanoformulations or nanoencapsulations have many advantages over conventional formulations of pesticides dues to smart or better controlled release mechanism and high target specificity. The dose of pesticide used is also minimal as a result as a result of this pest fail to develop resistance. Controlled release formulations are related to higher crop yield and pest control when compared to commercial formulation. Even the residues of pesticides in seed or soil at harvest were below the detectable limits. Thus, nanopesticides hold a great chance to revolutionize modern agriculture by reducing the environmental footprint left by conventional pesticides. Nanotechnology applications have the huge potential to change agricultural production by allowing better scientific management and conservation efforts to plant production. Scientists in nanotechnology can do countless contributions for the betterment of society by applying this technology in agriculture and food production systems. Nanotechnology provides a much better effective way of environment detection, sensing and bioremediation.

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