Review Article

Nanopesticides: A Promising Nanoagrochemicals in Crop Protection

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Abstract

Pesticides are now an unavoidable part of Indian agriculture. Due to the increased use of pesticides, agribusiness today faces significant problems with bioaccumulation, insect resistance, environmental contamination, and health risks. An emerging scientific discipline termed nanotechnology has resulted in the creation of nanopesticides, which have fewer active components but greater efficacy, to address problems associated with conventional pesticides. The active ingredient or carrier molecule in these chemicals is nanosized. The distinct physical and chemical characteristics of nanoparticles enhanced the science behind nanotechnology, resulting in a variety of potential and applications that will benefit the agri-food industries. Nanotechnology improves plant defense against pests, weeds, and microbial diseases and promotes soil fertility by precisely delivering nutrients via nano insecticides. The current review examines the applications and limitations of nanopesticides in agriculture, which have revolutionized the agricultural sector.

Keywords: Nanopesticides, Nanoherbicides, Nanofertilizers, Agrochemicals.

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Introduction

The main economic engine of developing and self-sufficient countries has always been agriculture. Through its contributions to globalization, technology, economic growth, environmental improvement, biodiversity preservation, food security, and safety, agriculture can bring about a paradigm change in a nation's economy [1-3]. But because of the growing population, the world's production and distribution are currently under a great deal of stress. According to the most recent survey, the world's population is growing every day, and at the same time, demand is rising by 50% [4]. Furthermore, the agricultural industry is currently dealing with a wide range of issues, including declining crop yields; nutrient deficiencies in the soil; climate change; water scarcity; a decline in soil fertility; deterioration of biological matter in the soil; crop diseases; a lack of awareness of genetically modified organisms; and a shortage of workers (**Figure 1**) [5, 6]. In farming communities, the use of chemical fertilisers and pesticides, genetically modified crops, or crop kinds resistant to disease has been popular over the past fifty years as a way to address this issue [7]. Modern agricultural production systems, based on the extensive use of pesticides and mineral fertilisers, have made it possible to greatly solve the issue of feeding the people, but they have also generated various environmental and medical issues [8-9]. The creation and use of innovative plant protection solutions that are safe for use around people, animals, and the environment is currently a top goal. Recent studies have demonstrated the high application of nanotechnology to enhance the agricultural industry by enhancing the efficacy of agricultural inputs and providing solutions to agricultural and environmental issues for enhancing food output and security [10–12]. By drastically altering crop yields while simultaneously maintaining ecological balance, environmental sustainability, and economic stability, nanotechnology can bring about a revolution in agricultural production [5, 6]. This revolution will completely alter the systems for producing and supplying food. Numerous industries, including medicine, pharmaceutics, electronics, and energy, already use nanotechnology, similar to how it is anticipated to play a crucial role in the agricultural and food industries, boosting crop quality, food safety, and human health [13–16]. It is believed that nanomaterials (NMs) are the best platforms to drive the agri-nanotechnology breakthrough. Due to their extremely small size (less than 100 nm), these nanomaterials are able to penetrate biological barriers and permeate into plant tissue by root or foliar application, opening up new, more effective routes for the administration of nutrients and insecticides [17–18]. While nanoherbicides and nanopesticides can be used to efficiently manage weeds, pests, and herbs, respectively, nanofertilizers improve soil fertility by effectively supplying nutrients [19–21]. Nanosensors can be used to monitor soil moisture, nutrient concentration, disease detection, and other things [22]. The difficulty facing this promising technology for wider applications is that, despite the range of nanotechnology uses in the agriculture and food industries, the demand for nanoproducts is insufficient. This difficulty may be caused by a number of variables. The lack of globally applicable regulations on the use of such nanoproducts, the concerns raised about the potential risks associated with their manufacturing process and utilisation, as well as their disposal methods and overall negative effects on the health of living things and the environment, are some of the contributing factors [23–24]. In this article, we examined the development of agricultural inputs into nanopesticides using nanotechnology.

Figure 1 Main Problems in the agriculture field

Nanotechnology: A novel opportunity in the field of agriculture

Precision farming is predicted to replace conventional farming practices as a result of nanotechnology, which is a tremendous source of hope for the agricultural sector. By keeping an eye on environmental factors and taking targeted, controlled action as needed, precision farming is a well-balanced strategy for increasing crop yield [25]. The science of nanotechnology is concerned with atoms or molecules that fall inside the nanoscale size range [26]. In 1974, the first known use of the phrase "nanotechnology" was used. Norio came up with the name. Despite the fact that there are various applications for nanotechnology that should be considered, including the synthesis of nanoparticles that improves agricultural productivity and was recently produced, this topic is still being researched [27, 28]. Numerous applications of nanotechnology are being made in various sectors of the financial system to advance methods and practices that are good for both human and environmental health [29]. By utilizing NPs as nano carriers for delivering beneficial DNA and boosting the genetic features and breeding of seeds, the breakthrough nanotechnology applications in agriculture have an impact on crop productivity. In order to reduce soil nutrient loss, improve soil quality, and guard against potential negative consequences of nano residues on soil microbiota, it is also important to provide plants with the nanonutrients and nanofertilizers they need (**Figure 2**) [30]. Additionally, by using nanopesticides, nanoherbicides, and nanofungicides, nanotechnology can improve plant protection while also enhancing the ability of plants to withstand adverse environmental conditions including UV-B, drought, and salinity [31, 32]. In order to detect and manage plant health, growth stage, and soil qualities for smart agriculture and precision farming, NPs can also be employed to create nanosensors [33].

Plant growth and fruiting will be improved, the life cycle will be shortened, the soil quality will be improved, and resource efficiency will increase as a result of nanotechnology [34–36]. With innovative nanotools to handle the quick diagnosis of diseases and enhance plants' capacity to absorb nutrients, among other things, nanotechnology aims to improve the agricultural sector. Precision farming is bringing nanotechnology to the agricultural sector's door since it can be used effectively to support the overall structure of sustainable agriculture, particularly by supplying resourceful and environmentally friendly technologies [37–39]. New potential to apply the foundations of nanotechnology to the agriculture sector have emerged as a result of the recent development of nanotechnology in medications and pharmaceuticals [40, 41]. Maximizing output (crop yields), minimising input (fertilisers, insecticides, and herbicides), assessing environmental conditions with sensors, and taking focused action are the primary goals of nanotechnology in agriculture [5, 39]. Despite the abundance of research data in this area, the focus of this survey is on the importance of nanotechnology in agriculture as nanoagrochemicals (nanopesticides).

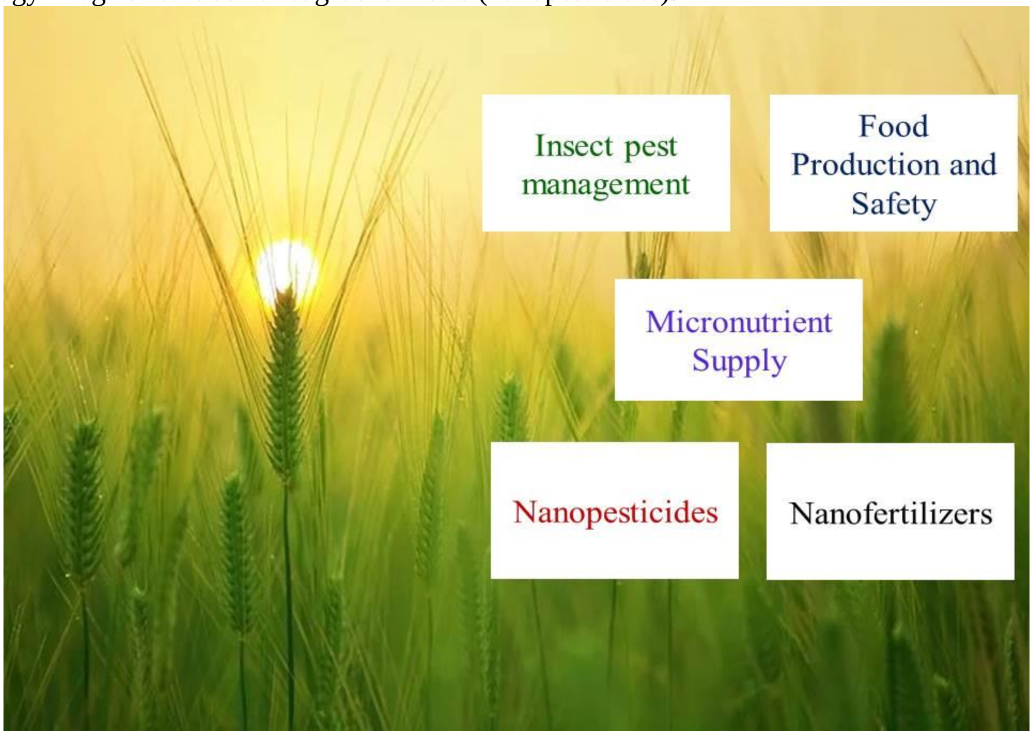

Figure 2 Application of nanotechnology in the agriculture field

Nanopesticides: Protection against Pests, Pathogens, and Weeds

In order to control weeds and pests, it is normal practise in agriculture to employ pesticides. Pesticides and crop protection methods currently in use are inadequate in terms of environmental protection and sustainable development [42–45]. However, there are many problems with using pesticides excessively in agriculture, including disease resistance, the targeting of non-threatened and even helpful species, nitrogen fixation, the loss of soil biodiversity, the buildup of pesticides in the environment, and negative effects on human health [46, 47]. Therefore, inventing new, effective, and environmentally acceptable target-specific insecticides continues to be difficult. In response, various nano-matrices, such as soft nanoparticles like polymers and lipids or hard nanoparticles like silica, carbon nanotubes, or graphene oxides, can be used to dissolve and adsorb, entrap, or encapsulate insecticides [48]. The advantages of nano-based pesticides over synthetic and microbial varieties include the regulated release of active ingredients, the enhanced solubility of poorly soluble constituents, as well as the preservation of pesticides from premature degradation [49, 50]. Compared to traditional pesticides, nanopesticides behave differently [51]. One alternate approach to controlling plant diseases has been the use of nanomaterials. Using aqueous extracts of Punica granatum peels, Olea europaea leaves, green peach aphid (GPA), and Chamaemelum nobile flowers, it was possible to successfully synthesise nanomaterials of CuO, ZnO, MgOH, and MgO [52, 53]. To get rid of insects and pests, a lot of nanoparticles are used in the creation of new compounds like pesticides and insecticides [54]. To defend the host plant from insect pests, these nanoparticles are employed to transport DNA and other desired compounds inside the plant tissues. Nanopesticides, which are employed for their effective delivery systems, cheap cost, availability, and simple application, include nanoinsecticides, nanoweedicides, nanofungicides, and Nanobactericides (**Figure 3**) [55, 56].

In order to defend plants from insects, nanotechnology is also used. Insecticides are chemical or biological substances that kill insects or stop them from engaging in damaging behaviour. They are used to control insects. Effective alternatives to conventional approaches are needed for the management of insects in an environmentally friendly manner because many synthetic insecticides have unintended detrimental and toxic effects on non-target organisms, render the insects physiologically resistant, and have a negative impact on the environment [57]. Inorganic nanoparticles and nanosilicate-alumina are two types of nano-insecticides that have the potential to lead to the creation of environmentally friendly pest control methods. For instance, leaf-cutting ants, Dipteran (Ceratitis capitate), and Coleoptera (Sitophilus oryzae) pests were all effectively controlled by nanostructured alumina (NSApotent)'s insecticidal characteristics [58–61]. The non-toxicity, biocompatibility, lower costs, and eco-friendliness of NSA are well known. Recently, NSA was successfully tested as a seed protectant against Coleoptera seed-eating insects such Tribolium confusum, Stegobium paniceum (L.), and Oryzaephilus surinamensis [62]. In a different study, soil-treated nano-silica was found to be an efficient insecticide against storage insects in maize plants, including Sitophilus oryzae, Rhizopertha dominica, Tribolium castaneum, and Oryzaephilus surinamensis [63]. The insecticidal potential of nano-silica against a variety of insect families has also been demonstrated in several investigations [64–66]. As insecticidal agents for crop protection, inorganic nanoparticles such silver nanoparticles, zinc oxide nanoparticles, and titanium nanoparticles have been widely used [67–70]. These inorganic nanoparticles have demonstrated effectiveness against mosquito vectors, pulse beetles, and white grubs. In terms of agricultural pest management, silver nanoparticles have been shown to be more effective [71–73]. Nanomaterials with specialised antimicrobial activity against plant diseases (phytopathogenic fungi, bacteria, and viruses) can significantly aid in reducing crop losses in addition to their insecticidal abilities. Inorganic NPs have been shown to exhibit antibacterial activity against pathogenic bacteria and fungi in numerous investigations [74–76]. For instance, copper nanoparticles were effective against a number of phytopathogenic fungus, including Fusarium solani, Neofusicoccum sp., and Fusarium oxysporum [77]. The efficacy of cobalt and nickel ferrite nanoparticles against Fusarium oxysporum, Colletotrichum gloeosporioides, and Dematophora necatrix was also examined [78]. It has long been recognised that silver nanoparticles have antibacterial properties and can significantly reduce bacterial development in agricultural contexts [79–82]. In various papers [83-86], the antibacterial activities of titaniumnanoparticles have also been thoroughly examined for crop protection against pathogens. Additionally, the insecticidal and antibacterial activities of inorganic nanoformulations of copper and aluminium in crop plants have been clarified [87–90]. Viruses are known to contribute significantly to crop production losses together with bacterial and fungal illnesses [91–92]. As environmentally benign substitutes for traditional synthetic fungicides, nanofungicides are anticipated to play a significant role in the treatment of plant diseases in the future. However, Penicillium expansum, B. cinerea, Aspergillus flavus, and Aspergillus niger were all sensitive to zinc nanoparticles antifungal properties. Zinc oxide nanoparticles is a popular pesticide alternative since it is less hazardous to plants than Ag NP. Similar to nanosulphur, nanoformulations of hexaconazole are also very efficient against the red spider mite Tetranychus utricae, Erysiphe cichoracearum, and R. solani, plant harmful fungus [93, 94].

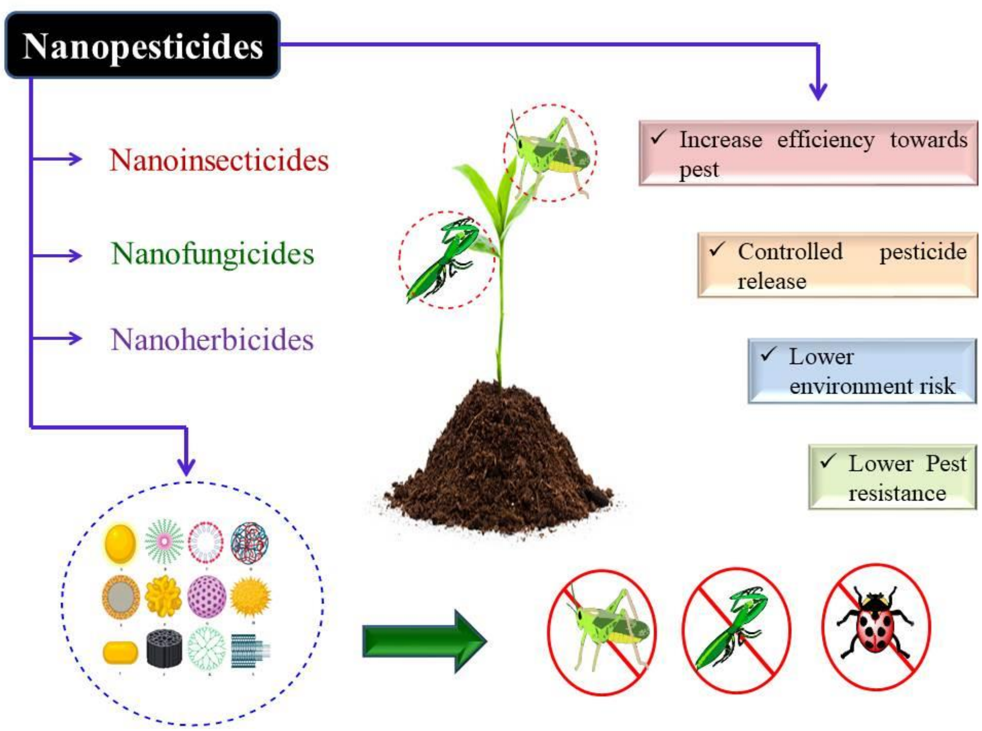

Figure 3 Significant impact of nanopesticides on pest

The development of nano-weedicides and nano-herbicides is specifically intended to target particular weeds and herbs that invade crop environments and cause nutrient exhaustion in crops. The phytotoxicity of herbicides in crops can be decreased by controlling weeds with encapsulated NMs (nanocarriers) [55, 95–96]. Nanoactive herbicides can reduce the need for synthetic herbicides, boosting the profitability of the harvest. Herbicides (namely atrazine, ametryn, simazine, and paraquat) have demonstrated high efficacy against the intended weeds when encapsulated in polymers such poly(epsilon-caprolactone), chitosan, and alginate [97–99]. To prevent the breakdown and sorption of the active ingredients (AI) in soil, herbicides can be loaded into nanocomposites and released under regulated conditions [100, 101]. Recently, other support materials have been looked into for herbicide formulations, including clays, polymeric microparticles, and NPs [102-105]. To sum up, nanopesticides significantly contribute to the effective and long-lasting eradication of pests by reducing the usage of synthetic chemicals and the hazards associated with them. Because it has tremendous potential for increasing agricultural output and maintaining the safety of the environment, the careful application of nanopesticides, their high effectiveness, and their eco-friendliness were the most frequent study fields developed fast in recent years [106].

Side Effects of Nanopesticides

The introduction of nanopesticides into the environment and soil systems is the result of advances in agricultural nanotechnology. Depending on their makeup and the presence of organic or inorganic soil components, nanopesticides may undergo physical, chemical, or biological changes when they penetrate the soil. The nanomaterial’s stability, reactivity, toxicity, and target selectivity may change as a result of transformation or aggregation. Thorough investigations are needed to learn about the fate of nanopesticides in the soil [107, 108]. Through the ingestion of plant-derived goods supplied through delivery systems or processed foods, nanopesticides may enter human food chains. The nanomaterial’s incredibly small particle size and high surface area, which is comparable to our biomolecules, pose the biggest risk (e.g. DNA, RNA, and proteins). They might be hazardous to both people and animals since they can pass through cellular barriers [109, 110]. Untrained employees using nanoagrochemicals improperly run the additional risk of causing their solubility and dispersion in water and soil. Furthermore, as the production and societal use of nanopesticides grows, so will industrial exposure. Concerns regarding the negative impact of manufactured nanopesticides on human health and the environment have been raised as a result of these fears [111, 112]. Before using nanomaterials (nanopesticides) in agriculture, careful knowledge of nanomaterials as products in food processing and agriculture, NP-plant interactions, bio-distribution, entrance into food chains, and toxicological implications must be attained.

Conclusion and Future Prospects

Nanotechnology offers a lot of potential for agriculture since it improves the quality of life through sustainable field applications. Nanopesticides improve a plant's resistance against infections, weeds, and pests. Before being used, these nanoproducts must be thoroughly evaluated. The majority of this field's research findings are restricted to laboratories, and the laws and regulations that apply are similarly poorly recorded. Due to costly product investments and inadequate cost benefits, farmers and industrial workers are very hesitant to make investments in this industry. These technologies might not be very successful from a commercial standpoint, and they can't keep up with the constant demands of food delivery and manufacturing. There aren't many examples of commercial products on the market, so something needs to be done right away. It is also uncertain how nanomaterials affect human health, safety, and ecological ramifications. To lower the hazards related to the plant, a thorough investigation of the physical and chemical properties of the soil in the fields prior to applying nanoparticles is required.

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