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Chapter

Applications of Nanotechnology in Agriculture

Alaa Y. Ghidan and Tawfiq M. Al Antary

Abstract

Nanotechnology has gained intense attention in the recent years due to its wide applications in several areas like medicine, medical drugs, catalysis, energy and materials. Those nanoparticles with small size to large surface area (1–100 nm) have several potential functions. These days, sustainable agriculture is needed. The development of nanochemicals has appeared as promising agents for the plant growth, fertilizers and pesticides. In recent years, the use of nanomaterials has been considered as an alternative solution to control plant pests including insects, fungi and weeds. Several nanomaterials are used as antimicrobial agents in food packing in which several nanoparticles such as silver nanomaterials are in great interest. Many nanoparticles (Ag, Fe, Cu, Si, Al, Zn, ZnO, TiO_2, CeO_2, Al_2O_3 and carbon nanotubes) have been reported to have some adverse effects on plant growth apart from the antimicrobial properties. In food industries, nanoparticles are leading in forming the food with high quality and good nutritive value.

Keywords: agriculture, food industries, applications, nanoparticles, pesticides, fertilizers, antimicrobial

1. Introduction

Nanotechnology has gained intense attention in recent years due to its wide applications in several areas like medicine, medical drugs, catalysis, energy and materials. Those nanoparticles with small size to large surface area (1–100 nm) have potential medical, industrial and agricultural applications. Scientists have carried out significant efforts toward the synthesis of nanoparticles by different means, including physical, chemical and biological methods [1]. These methods have many disadvantages due to the difficulty of scale-up of the process, separation and purification of nanoparticles from the micro-emulsion (oil, surfactant, co-surfactant and aqueous phase) and consuming large amount of surfactants [2]. Green methods for synthesizing nanoparticles with plant extracts are advantageous as it is simple, convenient, eco-friendly and require less reaction time. Nanomaterials prepared by eco-friendly and green methods could increase agriculture potential for improving the fertilization process, plant growth regulators and pesticides [3]. In addition, they minimize the amount of harmful chemicals that pollutes the environment. Hence, this technology helps in reducing the environmental pollutants [4], and nanotechnology has recently gained attention due to its wide applications in different fields such as in medicine, environment and agriculture [5]. Particularly, the large surface area offered by the tiny nanoparticles, which have high surface area, makes them attractive to address challenges not met by physical, chemical pesticides and biological control methods.

Nanotechnology in agriculture has gained good momentum in the last decade with an abundance of public funding, but the stage of development is good, even though many methods became under the umbrella of agriculture. This might be attributed to a unique nature of farm production, which functions as an open system whereby energy and matter are exchanged freely. The scale of demand of input materials is always being large in contrast with industrial nanoproducts with the absence of control over the input of the nanomaterials in contrast with industrial nanoproducts [6]. Nanotechnology provides new agrochemical agents and new delivery mechanisms to improve crop productivity, and it promises to reduce pesticide applications. Nanotechnology can increase agricultural production, and its applications include: (1) nanoformulations of agrochemicals for applying pesticides and fertilizers for crop improvement; (2) the application of nanosensors in crop protection for the identification of diseases and residues of agrochemicals; (3) nanodevices for the genetic engineering of plants; (4) plant disease diagnostics; (5) animal health, animal breeding, poultry production; and (6) postharvest management. Precision farming techniques might be used to further improve the crop yields but not damage soil and water. In addition, it can reduce nitrogen loss due to leaching and emissions, and soil microorganisms. Nanotechnology applications include nanoparticle-mediated gene or DNA transfer in plants for the development of insect-resistant varieties, food processing and storage and increased product shelf life. Nanotechnology may increase the development of biomass-to-fuel production. Experts feel that the potential benefits of nanotechnology for agriculture, food, fisheries and aquaculture need to be balanced against concerns for the soil, water and environment and the occupational health of workers [7]. Nanotechnology uses are currently being researched, tested and in some cases already applied in food technology [8]. Nanomaterials are considered with specific chemical, physical and mechanical properties. In recent years, agricultural waste products have attracted attention as source of renewable raw materials to be processed in substitution of several different applications as well as a raw material for nonmaterial production. Insecticide resistance is one of the best examples of evolution occurring on an ecological time scale. The study of insecticide resistance is needed, both because it leads to understanding mechanisms operating in real time and because of its economic importance. It has become in insects an increasing problem for agriculture and public health. Agricultural practices could include wide range of selective regimes [1]. Nanotechnology applications are being tested in food technology and agriculture. The applications of nanomaterials in agriculture aim to reduce spraying of plant protection products and to increase plant yields. Nanotechnology means like nanocapsules, and nanoparticles are examples of uses for the detection and treatment of diseases. Nanotechnology derived devices are also explored in the field of plant breeding and genetic transformation. The potential of nanotechnology in agriculture is large, but a few issues are still to be addressed as the risk assessment. In this respect, some nanoparticle attractants are derived from biopolymers such as proteins and carbohydrates with low effect on human health and the environment. Nanotechnology has many uses in all stages of production, processing, storing, packaging and transport of agricultural products. Nanotechnology will revolutionize agriculture and food industry such as in case of farming techniques, enhancing the ability of plants to absorb nutrients, disease detection and control pests.

2. Nanotechnology in pesticides and fertilizers

These days, sustainable agriculture is needed. It may be understood to present a good approach of ecosystem for long run. Practices that can cause long-term

damage to *soil* include excessive *tilling* of the soil which leads to *erosion* and *irrigation* without needed drainage. This will lead to *salinization*. This is to satisfy human being food, animal feed and fiber needs.

Long-term experiments are required to show the effect of different practices on soil properties which are essential to sustainability and to provide important data on this objective. In the United States, a federal agency, the development of nano-chemicals has appeared as promising agents for the plant growth and pest control. The fertilizers are required in plants growth. Nanomaterials act as fertilizers might have the properties such as crop improvement and with less eco-toxicity. Plants can give an important way for their bioaccumulation into the food chain. The recent developments in agriculture cover the applications of NPs for more effective and safe use of chemicals for plants. The effects of different NPs on plant growth and phytotoxicity were reported by several workers including magnetite (Fe_3O_4) nanoparticles and plant growth [9], alumina, zinc, and zinc oxide on seed germination and root growth of five higher plant species; radish, rape, lettuce, corn, and cucumber, silver nanoparticles and seedling growth in wheat [10], sulfur nanoparticles on tomato [11], zinc oxide in mungbean, nanoparticles of AlO, CuO, FeO, MnO, NiO, and ZnO [12]. Silver nanoparticles can stimulate wheat growth and yield. Soil applied 25 ppm SNPs had highly favorable growth promoting effects on wheat growth and yield.

Zinc has been considered as an essential micronutrient for metabolic activities in plants although it is required in trace amounts in plants. It was found that zinc has an important role in management of reactive oxygen species and protection of plant cells against oxidative stresses. Zinc has important functions in the synthesis of auxin or indoleacetic acid (IAA) from tryptophan as well as in biochemical reactions required for formation of chlorophyll and carbohydrates. The crop yield and quality of produce can be affected by deficiency of Zn. The development of insecticide resistance in pest insects has been an increasing problem for agriculture and public health.

Magnesium oxide (MgO) is important inorganic materials with many uses such as adsorbents, fire retardants, advanced ceramics, toxic waste remediation, and photo electronic materials. Therefore, various techniques and routes for synthesis of MgONPs have been reported [1]. MgOH was synthesized by green methods using nontoxic *neem* leaves extract [13], *Citrus limon* leaves extract, *acacia* gum [14].

2.1 Control of plant pests

Fusarium wilt is a destructive disease of tomato and lettuce in several countries due to its severe production loss, prolonged survival of fungus in soil and generation of resistant races. The disease can be reduced to some extent with the use of resistant cultivars and chemicals. However, the occurrence and development of new pathogenic races is a continuing problem, and the use of chemicals is expensive and not always effective. In recent years, the use of nanomaterials has been considered as an alternative solution to control plant pathogens. Ghidan et al. [15] has synthesized nanoparticles of magnesium oxide (MgO) and tested the effect of different concentrations on the green peach aphid (GPA) under the greenhouse conditions [16–19]. The synthesis of nanomaterials of copper oxide (CuO), zinc oxide (ZnO), magnesium hydroxide (MgOH) and magnesium oxide (MgO) has been carried out successfully by using aqueous extracts of *Punica granatum* peels, *Olea europaea* leaves and *Chamaemelum nobile* flowers [1]. The screening of synthesized bio-nanoparticles revealed that these nanoparticles were effective in increasing the mortality percent of green peach aphid. After the glasshouse experiments, the metal oxide nanoparticle accumulations were analyzed in the fruits and leaves of green

sweet pepper. The results showed that there was no any metal accumulation in any of the plant fruits. Foliar spray by synthesized of MgOH nanoparticles for green pepper leaves revealed that the foliar spraying leaves with 100–800 ppm metal nanoparticles are very beneficial to plant growth and produced healthy plants with greener leaves and high fruit quality compared to the control. Researchers made significant efforts toward the synthesis of nanoparticles by various means, including physical, chemical and biological methods [1]. Green methods for synthesizing nanoparticles with plant extracts are advantageous as it is simple, convenient, environment friendly and require less reaction time. Nanomaterials prepared by eco-friendly and green methods may increase agriculture potential for improving the fertilization process, plant growth and pesticides. In addition, this technology minimizes the amount of harmful chemicals that pollutes the environment [4]. The green peach aphid is considered as a key pest on peach and globally important pest of a broad range of arable and horticultural crops, including Jordan. The pest is categorized as of the most important agricultural pest in the world. This devastated pest combats organophosphorus and carbamate insecticides by overproducing insecticide-degrading carboxyl esterases. Moreover, control of such a pest is becoming increasingly difficult, because the overproduction of resistance for aphid individuals when using chemical insecticides such as carbamates, organophosphates and pyrethroids [20].

Nanomaterials such as copper oxide (CuONPs), zinc oxide (ZnONPs), magnesium hydroxide (MgOHNPs) and magnesium oxide (MgONPs) were synthesized by different physical and chemical methods [21]. With the growing needs to minimize the use of environmental-risk substances, such as insecticides, the biosynthesis of nanoparticles as an emerging highlight of the intersection of nanotechnology and biotechnology has received increasing attention. The rate of reduction of metal ions using plants has been found to be much faster as compared to microorganisms and stable formation of nanoparticles has been reported.

2.2 Nanoinsicticidal potential

Copper oxide nanoparticles (CuONPs) are synthesized through different methods [22] such as precipitation [23] and chemical reduction [24]. Many plant aqueous extracts have been reported such as *Citrus limon* juice [25] and carob leaves [26]. Applications led many researchers to develop different ways to synthesis ZnONPs such as chemical route [27], precipitation method [28], hydrolyzed in polar organic solvents [29] and microwave synthesis [30]. Different plant extracts have been reported in the open literature for green synthesis of ZnONPs such as *Olea europaea*, *Solanum nigrum* leaves [31] and *Azadirachta indica* [20]. Different methods for synthesis MgOHNPs and MgONPs have been reported such as hydrothermal route, water-in-oil microemulsion and microwave reaction [32]. MgOH was synthesized by green methods using nontoxic and eco-friendly such as *Neem* leaves extract, *Citrus limon* leaves extract, *acacia* gum, *Brassica oleracea* and *Punica granatum* peels [3, 22]. In agriculture sector, there are several uses available like nanotech based pesticides and fertilizers with effective impact on plant growth and molecular farming with the help of nanovectors which is hoping to take the place of viral vectors [33].

2.3 Antimicrobial activity

Several nanomaterials are used as antimicrobial agents in food packing in which silver nanoparticles are in great interest. This is because of its extended use. Some

other nanoparticles currently used are titanium dioxide (TiO_2), zinc oxide (ZnO), silicon oxide (SiO_2), magnesium oxide (MgO), gold and silver. All of them have specific characteristics and functions, for example, zinc nanocrystal shows antimicrobial and antifungal activity [34]. Silver was a disinfectant and sterilizing agent used by NASA and Russian Space station for water [35], silver zeolite and silver. Gold has high temperature stability and low volatility and good antifungal and antimicrobial effects against 150 different bacteria [36]. FDA in 2009 approves the direct use of silver as disinfectant in commercial water, since with effective result against microorganisms. The antimicrobial effect of these are *E. coli, L. monocytogenes* and *Staphylococcus aureus* [37], and nanosilver particles coated with cellulose acetate phthalate also provided similar results [37]. Some nanoparticles have shown their antifungal activity. These fungi include *Candida albicans*, *Aspergillus niger* [38] and yeast [39]. AgNPs are also found to be effective against methicillin resistant *Staphylococcus aureus* [39]. Other nanoparticles besides silver are also found to have antimicrobial characteristics like titanium oxide (TiO_2). Its antimicrobial activity in UV light was obvious. Zinc oxide is reported to have antimicrobial activity in packaging material [39].

Zinc oxide nanoparticles synthesized using *Punica granatum* peel aqueous extract has shown effectiveness as antibacterial agents against standard strains of Gram-positive *Staphylococcus aureus* and Gram-negative *Escherichia coli* [1, 40].

2.4 Nanotechnology application as nanofungicides

The use of nanosilver has been studied recently against phytopathogen *Colletotrichum gloeosporioides* [41]. Other nanoparticles (Fe, Cu, Si, Al, Zn, ZnO, TiO_2, CeO_2, Al_2O_3 and carbon nanotubes) have been reported to have some adverse effects on plant growth apart from the antimicrobial properties [42]. Sometimes, nanoparticles also have an effect on the growth of useful soil bacteria, such as *Pseudomonas putida KT2440* [43]. Various research groups focused their interest on the usage of eco-friendly pesticides. Similar to chemical pesticides, nanoparticle-based pesticides and herbicides are being explored for the application of the antimicrobial agents to protect crops from various diseases. Extensive studies on nanoparticle-based systems may eliminate the intensive use of pesticides in the agricultural sector [44]. The antifungal properties of nanoparticles can help to formulate nanoparticle-based pesticides [41]. Among the different inorganic nanoparticle-based antimicrobial agents, silver has been extensively studied by many researchers because of its several advantages over other nanoparticles such as copper, zinc, gold, ZnO, Al_2O_3 and TiO_2.

2.4.1 Effect of nickel nanoparticles on fungal mycelial growth

Both the concentrations of nickel nanoparticles (50 and 100 ppm) inhibited the fungal mycelial growth on solid media, and the inhibitions were significant ($p \leq 0.05$) over control (**Figure 1**). Nickel nanoparticles at 100 ppm concentration inhibited the mycelial growth of *F. oxysporum* f. sp. *lactucae* and *F. oxysporum* f. sp. *lycopersici* by 60.23 and 59.77%, respectively, over control.

The inhibitory effects of nickel nanoparticles were also assessed in liquid medium, and the results were similar with solid media. In the liquid media, the fresh mycelial weight of the tested fungal pathogens decreased significantly and more than 50% reduction was recorded with the use of nickel nanoparticles at the concentration of 100 ppm. The results revealed that mycelial growth of tested pathogens was inhibited in a concentration dependent manner. These results

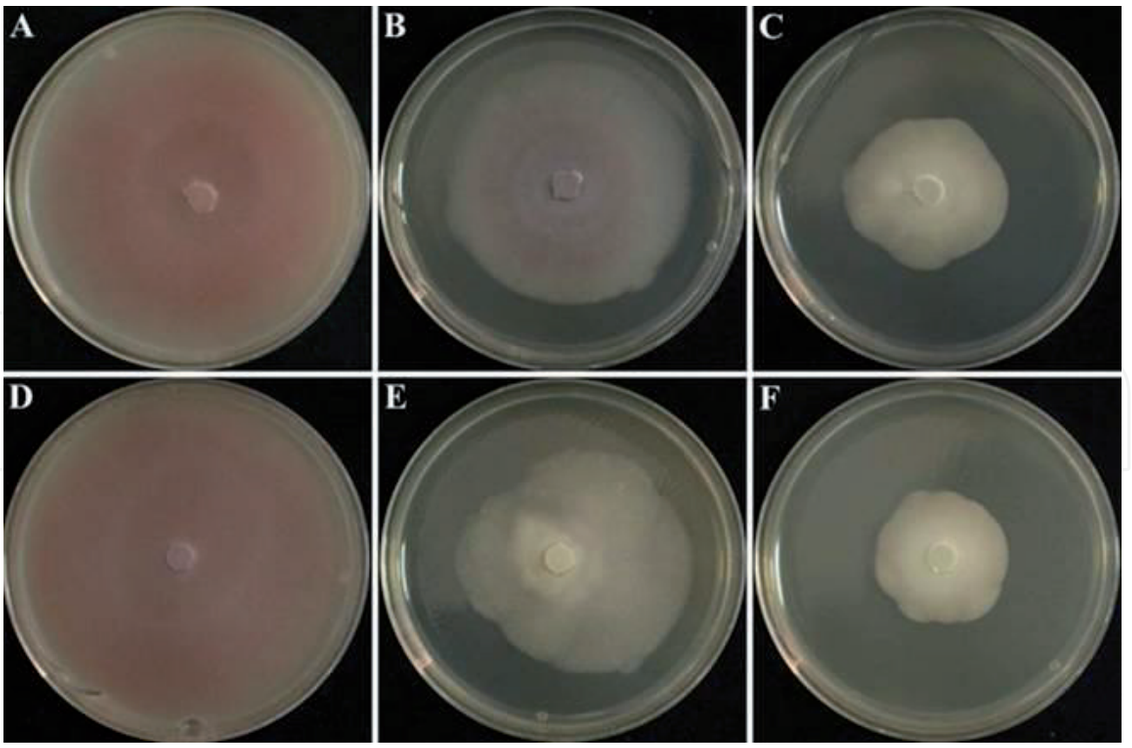


Figure 1.
Petri dishes showing inhibition of Fusarium wilt causing pathogens: first row, Fusarium oxysporum f. sp. lycopersici [(A) control; (B) 50 ppm nickel nanoparticles; (C) 100 ppm nickel nanoparticles]; second row, Fusarium oxysporum f. sp. lactucae [(D) control; (E) 50 ppm nickel nanoparticles; (F) 100 ppm nickel nanoparticles] [45].

suggest that using Ni nanoparticle solution can significantly increase the surface areas acting on the mycelia of *Fusarium* and mycelial growth.

Nickel nanoparticles at the concentration of 100 ppm decreased the number of spore development by 81.40 and 74.60% in *F. oxysporum* f. sp. *lactucae* and *F. oxysporum* f. sp. *lycopersici*, respectively. The conidial germination was negatively affected by nickel nanoparticles (**Figure 2**).

The inhibitory effect of Ni nanoparticles on spore germination could be due to their fungicidal effect. These results agreed with the results obtained from other workers on antifungal effects of different metal nanoparticles against some pathogenic fungi such as silver nanoparticles and zinc nanoparticles against copper nanoparticles [46]. Inhibitory effect of Ni nanoparticles could be due to producing of extracellular enzymes from fungi as survival agents caused by stress of toxic materials [47] or could be due to large surface areas (**Figure 3**) and small sizes to penetrate into the cell membrane of pathogen and work in the cytosols [48].

2.5 Nanotechnology for controlling plant virus

Plant virus particularly spherical virus is considered to be the naturally occurring nanomaterials. The smallest plant viruses known till date are satellite tobacco necrosis virus measuring only 18 nm in diameter [49]. Plant viruses are made up of single or double stranded RNA/DNA as genome which is encapsulated by a protein coat. Their ability to infect, deliver nucleic acid genome to a specific site in host cell, replicate, package nucleic acid and come out of host cell precisely in an orderly manner have necessitated them to be used in nanotechnology. A complete review on use of plant viruses as bio templates for nanomaterials and their uses has been done recently by Young et al. [50].

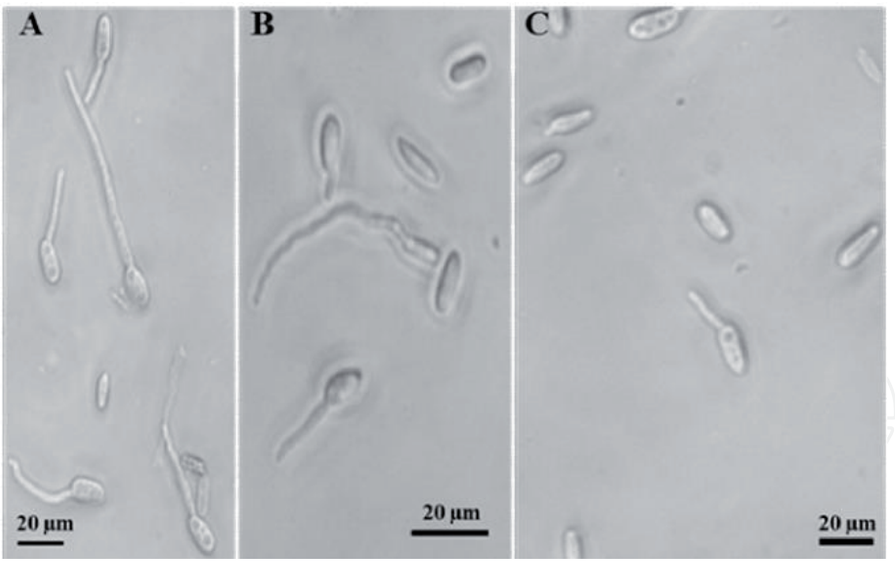


Figure 2.
Germination of Fusarium oxysporum f. sp. lycopersici conidia: (A) control; (B) 50 ppm nickel nanoparticles; and (C) 100 ppm nickel nanoparticles [45].

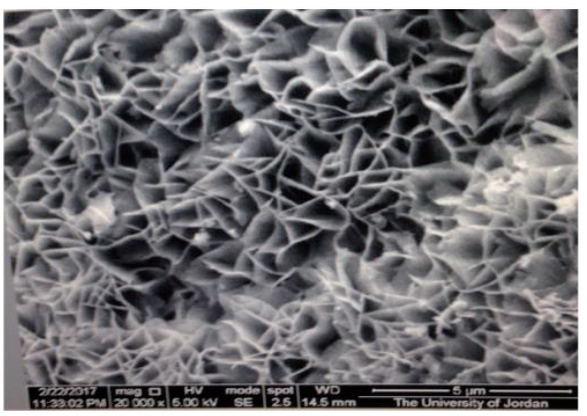


Figure 3.
SEM, nanoflex of large surface areas of MgONPs [1].

3. Nanotechnology in food packaging

Food industries are leading in forming the food with good nutritive value. For example, high impermeable packaging nanomaterials are used for protection of food from UV radiations and providing more strength to maintain the food protected from environment, increasing their shelf lives. Nanosensors are used for the detection of chemicals, gases and pathogens in food. In modern terminology, a word is given to such type of packaging as smart packaging. Some studies suggested that people are not accepting the direct involvement of nanoparticles in food due to some risk factors. Therefore, it is needed to provide some safety measurements to reduce the risk and human safety.

4. Conclusions

The occurrence and development of new pathogenic races is a continuing problem, and the use of chemicals to control pests is expensive and not always effective. In recent years, the use of nanomaterials has been considered as an alternative solution to control plant pathogens. Agricultural practices usually include the

systematic application of a wide array of active compounds at variable dosages and frequencies, which represent a wide range of selective regimes.

Metal oxide nanoparticles have controlled the green peach aphid. Magnesium hydroxide, bionanoparticles synthesized were the best control to *Myzus persicae* compared to other synthetic nanoparticles. Zinc oxide nanoparticles synthesized using aqueous *Punica granatum* peel extract was tested for its potential antimicrobial activity against some selected microbes. Also this research work determined the effect of synthesized ZnONPs on green peach aphid and antibacterial efficacy against standard strains of Gram-positive *Staphylococcus aureus* and Gram-negative *Escherichia coli*. Other nanoparticles (Fe, Cu, Si, Al, Zn, ZnO, TiO_2, CeO_2, Al_2O_3 and carbon nanotubes) have also been reported to have some adverse effects on plant growth. Sometimes nanoparticles also have an adverse effect on the growth of useful soil bacteria, such as *Pseudomonas putida* KT2440. Both the concentrations of nickel nanoparticles (50 and 100 ppm) inhibited the fungal mycelial growth on solid media, and the inhibitions were significant over control. Nickel nanoparticles at 100 ppm concentration inhibited the mycelial growth of F. *oxysporum* f. sp. *lactucae* and F. *oxysporum* f. sp. *Lycopersici*.

Green methods for synthesizing nanoparticles with plant extracts are advantageous as it is simple, convenient, environment friendly and require less reaction time. Nanomaterials prepared by eco-friendly and green methods may increase agriculture potential for improving the fertilization process, plant growth regulators, pesticides delivery of active component to the desired target sites, treatment of wastewater and also enhancing the absorption of nutrients in plant. In addition, they minimize the amount of harmful chemicals that pollutes the environment. Hence, this technology helps in reducing the environmental pollutants. Nanotechnology has recently gained attention due to wide applications in different fields such as in agriculture medicine and environment. The large surface area offered by the tiny nanoparticles, which have high surface area, makes them attractive to address challenges not met by different control methods.

Nanotechnology applications are currently being researched, tested and in some cases already applied across the entire spectrum of food technology, from agriculture to food processing, packaging and food supplements. They are with unique chemical, physical, and mechanical properties. In recent years, agricultural waste products have attracted attention as source of renewable raw materials. Insecticide resistance is one of the best examples of evolution occurring on an ecological time scale. The study of insecticide resistance is important, because it leads to a better understanding of evolutionary mechanisms operating in real time. The development of insecticide resistance in pest insects has been an increasing problem for agriculture and public health. Agricultural practices usually include the systematic application of a wide array of active compounds at variable dosages and frequencies.

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Conflict of interest

The authors declare no conflict of interest.

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