We are IntechOpen, the world's leading publisher of Open Access books Built by scientists, for scientists

6,900
Open access books available

185,000
International authors and editors

200M
Downloads

Our authors are among the

154
Countries delivered to

TOP 1%
most cited scientists

12.2%
Contributors from top 500 universities



WEB OF SCIENCE™

Selection of our books indexed in the Book Citation Index in Web of Science™ Core Collection (BKCI)

Interested in publishing with us?
Contact book.department@intechopen.com

Numbers displayed above are based on latest data collected.
For more information visit www.intechopen.com



Chapter

Nanotechnology: Past, Present and Future Prospects in Crop Protection

Kallol Das, Pijush Kanti Jhan, Srijan Chandra Das, F.M. Aminuzzaman and Benjamin Yaw Ayim

Abstract

Nanotechnology is an advanced and evolving discipline in the field of science and technology with various applications in other fields such as the life sciences, and is increasingly important in the plant sciences as well. It is estimated that 20–40% of crops are lost each year due to plant pests and pathogens. The current plant disease management, which primarily relies on toxic pesticides that may be harmful to humans and the environment, has the benefit of utilizing nanotechnology. It has capabilities in determining the outbreak of an epidemic as well as diagnosing different types of diseases. It can also distinguish between similar microbes like bacteria, fungi, viruses, complex genomic portions, and how two versions of genes on an individual chromosome differ. This chapter will cover the plant disease management implementation of this technology.

Keywords: Crop Protection, Nanotechnology, Nanoparticles, Pathogens, Plant Disease Management

1. Introduction

Nanotechnology is a versatile discipline which embraces information from natural science, chemistry, physics and other fields. Sustainable crop production experiences approximately 20–30% of its total annual loss due to plant infection [1]. Food sustainability has been identified as one of the biggest problems of humanity faces. Conflict has plagued nations, societies, and administrations for a long time. Attack by plant pathogens on either cash crops or food crops results in decreased yields, economic loss, and possible crop damage [2, 3]. There is a constant increase in the global population therefore the main challenge is how to meet the growing population's needs while reducing the stress on the environment. Controlling the spread of disease appears to be a main task at times. Nanotechnology is described as the operation or assemblies of discrete atoms, molecule, or molecular collections into structures in order to generate novel or extremely diverse assets [4]. The application of nanotechnology in agriculture can modify the agricultural science with advanced apparatuses for quick infection recognition, directed dealing, improved plant nutrient absorption, microbial infection resistance, and ecological stress resistance. Agronomic production will benefit from smart sensors and smart delivery systems to combat viruses and boost the harvest.

Moreover, the early and efficient pathogen detection is critical for infection resistance and disease management, thus helping to reduce yield damage. Magnetic nanoparticles, quantum dots, and gold nanoparticles are all commonly used nanoparticles for molecular detection. Gold nanoparticles, because of their unique characteristics such as small size, catalytic and surface effects, are frequently utilized for rapid insusceptible identification. Gold nanoparticles are capable of exhibiting covalent bonding with DNA, which allows it to be used for DNA assessment and reorganization. At the preliminary phase, nano-based applications are used for detection, diagnosis, and controlling of plant pathogens due to the application of safeguards for plant harvesting.

2. Defining nanotechnology in agriculture

The US Environmental Protection Agency has defined nanotechnology as the science of understanding and control of matter at dimensions of roughly 1–100 nm, where unique physical properties make novel applications possible [5]. This definition is somewhat inflexible when it comes to size dimensions. Materials could have received a greater emphasis on their problem-solving abilities. The particles referred to in this definition have "particulate between 10 and 1,000 nm in size dimensions that are simultaneously colloidal particulate" [6, 7]. Ultimately, When the research into nanotechnology has been completely explored, it can be said to be the science of designing and building machines in which every atom and chemical bond is precisely specified. Rather, it is not a particular collection of techniques, devices, or products, but rather the full capabilities that we will be able to attain when our technology nears the theoretical limits set by atomic physics [8]. The "assembler" is Drexler's ultimate goal for nanomachine technology. The assembler is a nano-machined machine that is used to conduct routine operations at the atomic level [9]. The various types of nanoparticles are described below, along with their definitions and potential applications in plant pathology (**Table 1**).

2.1 Nanoparticle for plant fungal disease management

Nanotechnology may play a key role in providing healthier food by promoting precision farming [11], in particular when facing huge losses due to a wide range of phytopathogens [12]. Agrochemicals use in farming are seeing a dramatic reduction due to the increasing popularity of metallic NPs. With the potential to eliminate targeted microbes from plants, soil, and hydroponics, they have outstanding capabilities [13, 14]. NPs can be used to combat phytopathogens directly, as well as in developing fungicides [15]. Foliar sprays can be used to eliminate pathogens by NP application and also helps in plants growth [16]. Coefficient of variation is increased in low concentrations to control pathogens [13, 17]. Metallic NPs cause hyphal plasmolysis, damaging fungal cell walls, resulting in cell death [18]. Some scientists believe that each agent has a different mechanism of action, whereas others claim the different mechanisms of action vary [19–21]. They include:

1. Permeability of plasma membrane, which is disturbed preventing a proper functioning due to attachment of the NPs proteins sulfur groups.

2. DNA damage.

3. Disturbance of electron transport chain and protein oxidation.

Type	Definition	Potential Use in Plant Pathology
Metalloids, metallic oxides, nonmetals, and their composites	Engineered metals at nanoscale in cubes, spheres, bars, and sheets	Bactericides/Fungicides Nanofertilizers Delivery vehicle for antimicrobials and genetic materials
Carbon nanomaterials	Allotropes of carbon designed at the nanoscale	Multiple uses
Single-walled or multiwalled nanotubes	Graphene sheets rolled into single or multiple tubes	Antimicrobial agents Delivery vehicle for antimicrobials and genetic materials
Fullerenes (bucky balls)	60 carbon atoms in a specific soccer-ball arrangement	Antimicrobial agents Delivery vehicle for antimicrobials and genetic materials
Graphene oxide sheet (reduced or oxide forms)	Graphene oxide sheet	Antimicrobial agents Delivery vehicle for antimicrobials and genetic materials
Liposomes	A lipid enclosing a water core	Delivery vehicle for genetic or antimicrobial products
Dendrimers	Nanomaterial with tree-like appendages that radiate from a central core	Delivery vehicle for genetic or antimicrobial products
Nanobiosensor	A nanoparticle that combines a biological component for detection	Diagnostics, research tool
Nanoshell	Nanoparticles composed of a gold shell surrounding a semiconductor	Diagnostics, research tool
Quantum dots	Inorganic fluorescent, crystalline semiconductor nanoparticles used in biosensors	Diagnostics, research tool

Sources of description [10].

Table 1.
Types of nanoparticles and their definitions and potential uses in plant pathology.

4. Reactive oxygen species (ROS) may be generated, which cause cellular damage.

5. Hindrance in nutrients uptake.

All of the mechanisms mentioned above have interconnected and exert interdependent effects on pathogens [22, 23]. As part of a new technology that attempts to synthesize metallic nanoparticles, bio-reduction reactions have been evaluated for bio-reduction of different metals (e.g. iron, silver, zinc, gold, copper). In vitro and in vivo tests have also been done to see if metallic NPs have antimicrobial potential.

2.2 Nanotechnology based detection of plant diseases

Several plant species have been designated as hyper-accumulators, meaning that they have a high capacity to concentrate trace metals and then use those NPs [24]. Silver, silica, gold, zinc, and copper are frequently used metallic nanoparticles as antimicrobial agents. Silver nanoparticles were shown to be antimicrobial in both ionic and nano forms, and when tested and studied, the particles were shown to be capable of killing plant pathogens [25]. Silver has a strong antifungal and

antimicrobial mode of action against bacterial and fungal pathogens [26–28]. Fungicides' hydroxyl radicals-like degradation of fungal and bacterial cell material is achievable with copper NPs [29, 30]. Since the size of these nanoscale copper particles helped control bacterial blight of rice and mung bean leaf spot disease, they were considered useful [31]. This is something you could try if you have plants that are ill or weak. Silica NPs would assist in the acquisition of resistance to diseases and in the activation of plant physiological mechanisms [32]. Iron NPs come into direct contact with fungal cell membranes and disturb the cell's permeability, reducing the cell's growth and eventually causing death through the development of oxidative stress [33]. In solution, zinc NPs release hydroxyl and superoxide radicals, destroying fungal cell walls, hyphae, and preventing conidiogenesis, all of which leads to cellular death [34, 35]. The gold NPs had greater toxic effects on *Salmonella* than on its macroform [4]. As of now, there is no evidence to suggest that silica itself has any antimicrobial capability, but it can indirectly promote plant disease resistance and other stress resistance [36, 37]. For some plant diseases, nano-silver was found to be highly effective [13]. Nano-sized mesoporous silica particles feature a regular pattern of pores with increased surface area. It's improved delivery, efficiency, and effectiveness for site-specific chemicals.

2.3 A Brief Guide to Fungicides, Herbicides and Insecticides

2.3.1 Fungicides (Nano fungicides)

Nano-scale materials development has seen considerable progress in the recent years, with distinct characteristics from corresponding bulk materials. Nanotechnology promises a bright future while delivering pesticides in a safer manner [38]. Agrochemicals have enhanced solubility when polymeric Nano fungicide formulations deliver them at a slow rate, thus increasing their bioavailability [39, 40]. Nanofungicide developed and tested so far proved effective in plant protection strategies [41, 42]. For developing Nano fungicides, we should opt for Nano emulsions (NEs) with smaller size, lower viscosity, and higher stability [43]. The active fungicide ingredient is placed within a core surrounded by a membrane in a nanocapsule. Additionally, nanoencapsulation could be utilized in nanopesticide formulations. Polymers and inorganic compounds have been tested for their possible use in nanopesticide formulations for crop protection [44]. For these formulations to be as potent and stable as possible, while still meeting the safety criteria of the systems to the environment and human beings, it is critical that more work be done. Nanotechnology has a large capacity to develop completely new systems and formulations [45].

2.3.2 Herbicides

They aimed to improve low water solubility, decrease volatility and to deliver the active molecules slowly. Organic solvents are needed to help solubilize insecticides that have low water-solubility, which increases the cost and toxicity. To decrease toxicity, nanoparticles may be used to increase solubility. Another problem that occurs following insecticide application is the evaporation or volatilization of the active ingredient. Even though essential oils have a reputation for causing insecticidal effects, the unstable chemical nature of the substances in the presence of air, light, moisture, and heat causes them to rapidly evaporate. Another motivation for the development of Nano-insecticides is to make the active molecules more stable, which would help ensure that they release at consistent rates over time, resulting in a reduction in insecticide usage while also improving the safety of humans and animals. Whereas fipronil, a commercial insecticide, extended the 100 percent mortality window by 3 days,

compared to that commercial product, fipronil-loaded silica extended the 100% mortality window by 3 days, allowing better control of the colony. In groundnut bruchid storage conditions, utilized azadirachtin-loaded zinc oxide or chitosan nanoparticles, and examined the effectiveness over 180 days. The groundnut bruchid, 54.61% of the total weight, was found in the Neem seed kernel extract, loaded into zinc oxide nanoparticles, when compared to the other formulations tested [46]. If the gradual release of active molecules decreases toxicity, then this could also potentially lower the toxicity of insecticides. The results of these studies are promising, but additional studies are required to fully confirm the reductions in insecticide toxicity.

2.3.3 Insecticides

The use of nanosized preparations or nano-materials based herbicide formulations offers unique opportunities for delivering chemical or biological pesticides. Herbicide formulations based on nanomaterials may be more effective, have better solubility, and reduce toxicity than conventional herbicides. If early-stage weed control is employed with the use of nanoparticle-based herbicide release systems, the resistance potential will be minimized while the active ingredient's effectiveness will be maintained and prolonged release will be prolonged [47]. Herbicides can be selective, killing only target weeds, or non-selective and potentially hazardous to people and the environment if they kill all vegetation. Before seedlings sprout up from the soil, you can apply a pre-plant, pre-emergence, or post-emergence herbicide (weed seedlings already emerged from the soil).

2.4 Types of nanoparticles for plant disease management

2.4.1 Nano-phytopathology

New techniques such as nanotechnology will remain novel for this century, but as time passes and extensive research is done in the field, they will be more widely used in the treatment of plant infection. Plant pathology is set to offer an exciting future of research with regard to their antibacterial and antifungal properties in the context of nanotechnology. Using nanoparticles to protect the seeds and foliage from pathogens that would otherwise intrude can be the most effective method. Therefore, it can be summarized here that nanoparticles can play their role in plant disease management in following ways-.

- Nanoparticles being used as pesticides themselves and being applied to plants directly for the control of disease.

- Nanoparticles as carriers of other pesticides/nanoparticles for their controlled and targeted release and to increase their effect.

- Nanodevices to detect diseases at early stages.

Nanoparticles can be successfully applied to disease affected plants with enhanced and effective results due to their extremely reactivity/affectability. This increased reactivity can be attributed to their extremely small size and large surface area.

2.4.2 Effect of nanoparticles on the pathogens/microorganisms

After scientific testing, scientists have confirmed that the chemical and physical properties of nanoforms of materials actually shift between their macroform and

nanoform. All of these properties transformations ultimately end up with useful real-world applications in plant defense and plant protection. Since nanoparticles have the advantages of both small size and surface area, they influence plant pathogens in a more precise way. Larger macroscopic entities are less likely to interact with microorganisms because they are farther away from them. There is an abundant amount of evidence available to bolster this claim.

2.4.3 Effect of nanoparticles on Bacteria

New research shows that nanoparticles have antibacterial properties, which is most likely the result of the cell wall of the bacteria being broken or of high levels of reactive oxygen species (ROS) being produced [48–50]. Bacterial infection is a leading cause of contamination and mortality due to prolonged presence of pathogens. Due to low cost and positive results, antibiotics have been selected for the treatment of bacterial contamination. Although multiple studies have demonstrated that overuse of antibiotics leads to multidrug-resistant bacteria strains, this has not yet been confirmed though. A very powerful strain of antibiotic-resistant bacteria has emerged. Previous researches states that, these kinds of bacteria consist of gene, which are super resistant [51]. The mode of action of nanoparticles is directly linked with the bacterial cell wall, which enables the nanoparticles to control super-resistant bacteria. Bacteria may become resistant to nanoparticles if they are exposed to them. If these new NP-based materials are able to perform antibacterial activity, it's entirely possible [52–54].

2.4.4 Nanotechnology for plant viral diseases

The various types of nanoparticles were investigated and used to control *Sitophilus oryzae* and baculovirus BmNPV (*Bombyx mori* nuclear polyhedrosis virus) in silkworm (*B. mori*) disease caused by *S. oryzae* and BmNPV [55]. To complete their investigation, the researchers performed bioassay, which involved preparing the nanoparticles' solid and liquid formulations; after which, they applied these formulations to rice and stored it in a plastic box with 20 adult *S. oryzae* for seven days. On the first day, the researchers reported that hydrophilic silver nanoparticles were most effective. More than 90% of mortality was gained on day 2, and silver and aluminum nanoparticles were the primary source. Seventy-three percent of the insects died after seven days of exposure to lipophilic silver nanoparticles. But with respect to nanoparticles of aluminum, 100% mortality was observed. Thus, a significant decrease in viral load was found in a hydrophobic aluminosilicate nanoparticle suspension when *B. mori* leaves were used in an ethanolic treatment of grasserie disease.

2.4.5 Metallic nanoparticles: effective tool for plant disease management

There are different nanotechnology approaches for the detection of plant diseases (**Figure 1**).

2.4.6 Bio-nano materials

There are some bio-nano materials which are categorized through X-ray diffraction (XRD) technique, X-ray photoelectron spectroscopy (XPS), Energy-dispersive X-ray spectroscopy (EDS), UV visible spectroscopy, scanning electron microscopy (SEM), Fourier transforms infrared spectroscopy (FTlR), Coupled plasma spectrometry (ICP), Transmissions electron microscope (TEM) and Atomic force

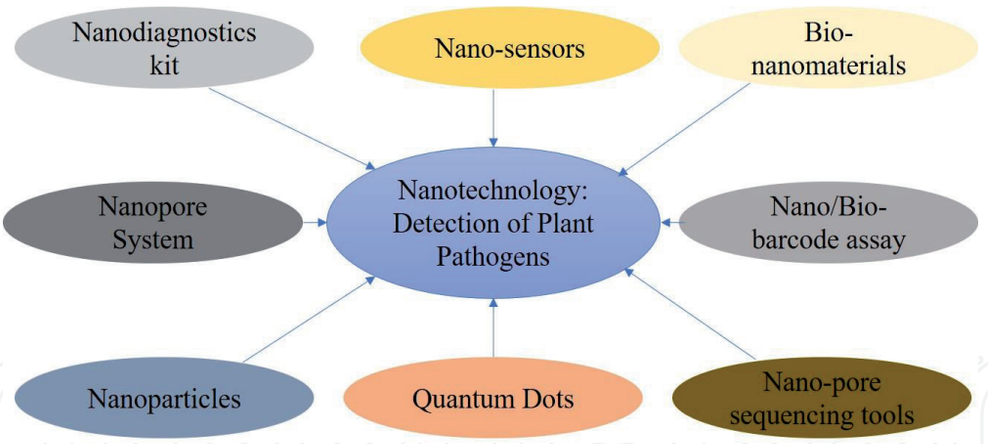


Figure 1.
Different nanotechnology approaches for the detection of plant diseases.

microscopy (AFM) techniques. These bio-nano materials played noteworthy role in field of agriculture, medicine and biology. The increasing usage of bio- nano materials in many areas will enhance their productivity in the atmosphere by developing more analytical tools in nanotechnology for controlled environmental risk management [56]. Bio-synthesis of bio-nanomaterials can be also achieved by using plant extracts [57], microbial cultures or their enzymes and proteins.

2.4.7 Nano bio-barcode assay

The technology of biological barcodes is improving in nanotechnology and incorporating new advancements in nanotechnology to aid in the identification of non-enzyme-containing ultra-sensitive proteins and DNAs. Instead of using an orthodox ELISA, a protein barcode assay could be employed, which is both more complicated and far more sensitive and profound. Because of its dependence on nanoparticles, the nanoparticle-based biobarcode assay is more sensitive to finding pathogens than traditional techniques like ELISA, Real-time PCR, etc. [58, 59]. It can also help in early detection of plant diseases. The biobarcode technique consists of two probes.

1. Magnetic micro beads (MMB): Target recognition and carry an antibody or DNA as a biological probe.

2. Gold nanoparticles (Au-NP): It has a polyclonal antibody or an oligonucleotide (Bio-barcode) Bio-barcode is a developing technique with the help of advancements in nanotechnology. It is an enzyme free, PCR free technique and highly sensitive for protein and DNA detection.

Moreover, the advancement has been made on different aspects of Bio-barcodes to make it more applicable in fields. DNA barcoding has been suggested for fungal identification [60]. It has been reported to be reliable and rapid method of detection. A DNA barcode should be standardized and scalable. And also, the similar techniques can be developed for speedy and onsite detection of plant pathogens particularly viruses to decrease the losses to crops.

2.4.8 Nanopore system

Nano pore used in nano-pore systems can be used to examine genetic information at a low cost, have low sample preparation requirements, and operate quickly [61]. In fact, nanopore is a nano-sized pore through which a flow of nanoparticle

ions is flowing. When there is a change in the current, it shows that an analysis of the biological molecule is in progress. Nanopore-based systems determine nucleotides through conductivity changes, which enables them to identify nucleotides because of their lipid membrane [62]. A protein nanopore is injected into a polymer bilayer membrane, which contains a sensory chip to measure current that is associated with the identity of the molecule [63].

Newly, nanopore based sequencing (Nano-SBS) distinguished four DNA bases through discovering four different sized tags released from 5′-phosphate-modified nucleotides at the particular molecule level for sequence determination [64].

Recently, UK-based nanopore technology, a portable DNA sequencing machine (MinION) has been released. It enables researchers to sequence a 10 kb sample of single-stranded DNA as well as double-stranded DNA, making next-generation sequencing easily approachable [65].

The discovery of this new technique offers both the ability to detect and track the spread of an epidemic, as well as the ability to differentiate between various bacteria, fungi, viruses, complex genomic components, and difference between two different gene sequences located on the same chromosome. In other words, a nanopore platform that is already inside a current diagnostic machine can conduct whole genome analysis in minutes. It could be used for analyzing plant and pathogen genomics for the purpose of increasing agricultural crops.

2.4.9 Nanodiagnostic kit

Nanodiagnostic kit also called “lab in a box” is used as a small box for measuring important tasks in plants which can be done in small space [66]. A smart kit helps to detect the plant pathogens and can help the farmers in prevention of wide spread diseases [1, 67]. Nanodiagnostic kit contained four myco-sensors which can detect the of ZEA, T-2/HT-2, DON and FB1/FB2 myco-toxins on only one strip used for cash crops like wheat, barley and corn [68]. This method is fast, convenient, and less expensive for finding out if crops have a fungal infection. Antigen and antibodies, the nucleotide sequence in which nano kit can be used, all have multiple additional purposes. Moreover, it can also detect particular gene target, isolation and purification of specific genes. But nano kit has not fully checked practically for the plant pathogen detection in field conditions. More extensive research works are still needed in this field.

2.4.10 Quantum dot (QDs)

This is another level of nanocrystals that release specific wavelengths of light: Quantum Dots (QDs). There are three-dimensional nanoparticles that have a broad excitation spectrum [69]. Narrow-tunable emission peak, extensive fluorescence lifetime, resistance to photo bleaching, and molar extinction coefficient ten to one hundred times higher than for most QDs. However, one of the findings revealed multiple enzymatic properties of QD-based nanosensors [70] and stated CdTe quantum dots usage as biosensors with specific antibiotic coatings against *Polymyxa betae* specific glutathione-S-transferase (GST) protein [71]. Because of the interaction of CdTe quantum dots and rhodamine, which cause a resonance dipole–dipole coupling, the resonance dipole–dipole coupler, which is required for fluorescence resonance energy transfer, is created (FRET). For more efficient results, this device can be used to test plants in under 30 minutes. Although it was concluded that there was a highly sensitive detection of diseased lime trees by showing 100% specificity with a sensitive detection limit for *P. aurantifolia*, the opposite appears to be true in this instance, according to the findings of this study what [72].

In the near future, quantum dots will be used in almost every form of diagnostics and medical testing. For example, fluorescent QDs can be used for a variety of molecular diagnostics and genotyping procedures. Additionally, these studies contribute to the complex diagnosis and combination with therapies which help lead to possible cancer diagnosis applications. QD bio conjugates enable the visualization of living cancer cells in animals and the visual differentiation of cancer cells in the context of a fluorescence microscope.

3. Future prospects of nanotechnology in plant disease management

To find out more about using NMs in plant sciences, we have covered all relevant aspects here. According to recent researches, the use of nanotechnology has resulted in considerable advancements in the development of NMs and their implementation in medicine for the detection and treatment of illnesses. This is where NMs (naturally occurring mini-molecules) for plants has fallen short. Concluding remarks: Additional studies are likely needed to optimize this synthesis and biofunctionalization direction for plant applications, but also to investigate further the underlying mechanisms of plant uptake, especially with regards to sustainable agriculture. The significant aspects of plant physiology that have thus far gone undocumented are something that the applications will need to support. Nanobiosensors for monitoring plant development and interactions with the environment, especially in controlling growth conditions, could be a means of improvement. Polymeric and hydrogel-based NPs, because of their safety profile, high loading capacity, and resistance to degradation, offer undeniable advantages for drug delivery. This unique NMs strategy is elegant in that it allows for the spatial and temporal cargo release from cell and animal models based on environmental cues (e.g., UV, NIR, ultrasound, etc.) [73–75]. Finally, as a final remark, we encourage multidisciplinary approaches for designing and synthesizing smart nanomaterials, in order to help expedite plant nanotechnology. The point of such a project is to open new horizons in phytonanotechnology by uniting complementary professional competencies, including those of plant biologists, geneticists, chemists, biochemists, and engineers.

Every sanitation/quarantine strategy requires that infested or infected material be discovered ahead of time, because any greenhouse, field, state, or country where this treatment is used is inevitably where you find infested or infected material. In order for this operation to succeed, prompt detection of pathogens is critical. There are large advances in the speed and sensitivity of pathogen probes with the introduction of nanotechnology. Nanoparticles can be used as rapid diagnostics for the detection of bacterial, fungal, nematode, and viral pathogens, which can help in the early detection of diseases [76, 77]. Pathogen detection has only recently been explored with super paramagnetic iron oxide nanoparticles, though the techniques have been pursued in other applications for nearly a decade [78, 79]. Nanoanalytical devices employ a biologically-integrated sensing element with a transducer built into it to form an electronic signal when they come into contact with the analyte of interest (pathogen). However, Nanotechnology innovations in the last decade have greatly reduced the technical barriers of making biosensors with a variety of nanoparticles and nanostructures [80].

Moreover, this novel use of nano-enabled biosensors to monitor, map, and treat specific areas in a field prior to or during the onset of symptoms can be coupled with robotics and GPS systems to produce smart delivery systems that monitor, map, and treat locations prior to or during symptoms appearing. This new technology could help farmers reduce their use of agrochemicals while also increasing yield and profits [81, 82]. Biosensors, being capable of detecting pathogens with a higher level of sensitivity, can also be used in ports of entry,

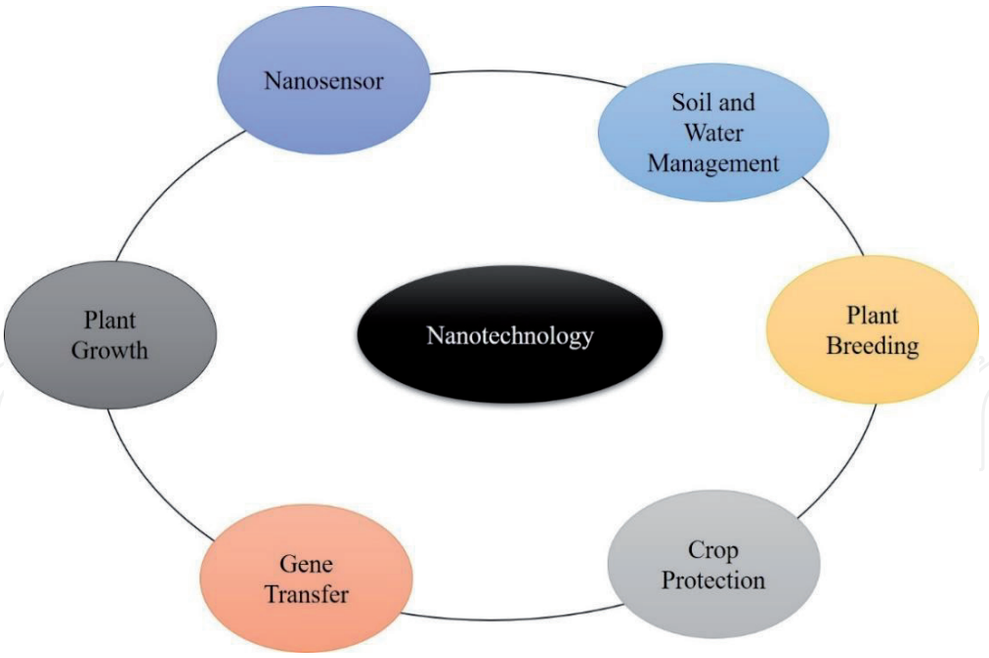


Figure 2.
Applications of nanotechnology in plant disease management and crop improvement.

where quarantined pathogens can be apprehended with greater efficiency. When food pathogens and mycotoxins are detected quickly, the value of rapid analysis is obvious [83–85]. Applications of nanotechnology in plant disease management and crop improvement are shown in **Figure 2**.

4. Limitations and future directions of nanotechnology

Nanotechnology with promising results in the agricultural sector, such as its unique method of applying pesticides, fertilizers, and so on, may finally allow the human population to visualize the dream of achieving sustainable and ecofriendly agricultural technology. Recent findings have shown that nanomaterials could potentially harm a beneficial soil organism, the earthworm [86]. Xu et al. [87] summarized increased safety concerns regarding nanomaterials in food and agriculture. They concentrated on the most common exposure routes and factors involved in nanotoxicity. More and more engineered nanomaterials are reaching the environment, due to new technologies. Production scale and cost currently limit the application of nanocarriers in agriculture. Large-scale manufacturing of nanomaterials and its effective application to agriculture will greatly reduce the cost. The difficult commercialization of nanomaterials for agricultural applications necessitates well-protected materials, superior testing priorities, a clear-cut risk assessment, and international regulatory guidance [88]. However, a concern has been raised on the impact of increased nanomaterial production on ecosystem health. Many commercial nanomaterials are more toxic than their bulk-form counterparts, even though bulk-form nanomaterials are legally allowed for sale. There still needs to be further research on the various applications of nanomaterials, such as synthesis, toxicity, and its use at the field level. Even the dream of utilizing nanotechnological methods in agriculture is still in its infancy. As a result, the focus areas that require further investigation are the development of systems that would improve the release profile of herbicides without altering their characteristics and novel carriers with enriched activity without significant environmental damage. There are some examples of recent breakthroughs in nanotechnology in agriculture (**Table 2**) [89].

Product	Application	Institution
Nanocides	Pesticides encapsulated in nanoparticles for controlled release Nanoemulsions for greater efficiency	BASF, Ludwigshafen, Germany Syngenta, Greensboro, NC, USA
Buckyball fertilizer	Ammonia from buckyballs	Kyoto University, Kyoto, Japan
Nanoparticles	Adhesion-specific nanoparticles for removal of Campylobacter jejuni from poultry	Clemson University, Clemson, SC, USA
Food packaging	Airtight plastic packaging with silicate nanoparticles	Bayer AG, Leverkusen, Germany
Use of agricultural waste	Nanofibers from cotton waste for improved strength of clothing	Cornell University, Ithaca, NY, USA
Nanosensors	Contamination of packaged food Pathogen detection	Nestle, Kraft, Chicago, USA Cornell University, Vevey, Switzerland
Precision farming	Nanosensors linked to a global positioning system tracking unit for real-time monitoring of soil conditions and crop growth	US Department of Agriculture, Washington, DC, USA
Livestock and fisheries	Nanoveterinary medicine (nanoparticles, buckyballs, dendrimers, nanocapsules for drug delivery, nanovaccines; smart herds, cleaning fish ponds (Nanocheck [Nano-Ditech Corp., Cranbury, NJ, USA]), and feed (iron nanoparticles)).	Cornell University NanoVic, Dingley, Australia

Sources of description [89].

Table 2.
Some examples of recent breakthroughs in nanotechnology in agriculture.

5. Conclusion

Nanotechnology has the potential to improve plant growth, disease resistance and nutrient use with controlled delivery of agrochemicals. More efficient and targeted use of fungicides, herbicides and insecticides may be seen through using environmentally friendly nanocapsules. In order to preserve the freshness and quality and help in disease prevention, post-harvest nanotechnology research and development is needed. As the use of nanotechnology progresses, applications of green chemistry have reduced the use of toxic solvents, allowing for crop protection. Through use of biotechnology and nanotechnology, crop protection and production are now available to a much larger portion of the population. Despite being unverified, the effects of nanomaterials on the environment are clearly noticeable because of their unique physical and chemical properties. Nanomaterials application in agriculture is new, and further research is required. Nanomaterials are expected to have a huge impact on the pricing and environmental friendliness of crop protection techniques. With the application of nanotechnology, new methods will be developed for managing disease in greenhouses and fields, while advancements in disease diagnostics and the construction of molecular manipulations of plants and pathogens will be made possible. However, only a few laboratories are currently exploring the incorporation of nanotechnology into phytopathology, but we expect that as new research is geared toward discovering, adapting and applying nanotechnology, the barriers to global food production will be lessened.

Acknowledgements

We would like to express our gratitude to the management of INTECHOPEN LIMITED for inviting us to write the book chapter and for providing the assistance during the chapter's preparation.

Conflict of interest

The authors declare no conflict of interest.

Author details

Kallol Das[1*], Pijush Kanti Jhan[2], Srijan Chandra Das[3], F.M. Aminuzzaman[4] and Benjamin Yaw Ayim[5]

1 College of Agriculture and Life Sciences, Kyungpook National University, Daegu, Korea

2 Department of Agriculture, Noakhali Science and Technology University, Noakhali, Bangladesh

3 Breeder Seed Production Center, Bangladesh Agricultural Research Institute, Panchagarh, Bangladesh

4 Department of Plant Pathology, Faculty of Agriculture, Sher-e-Bangla Agricultural University, Dhaka, Bangladesh

5 Ministry of Food and Agriculture, Plant Protection and Regulatory Services Directorate, Ashanti, Ghana

*Address all correspondence to: kalloldas91@gmail.com

IntechOpen

© 2021 The Author(s). Licensee IntechOpen. This chapter is distributed under the terms of the Creative Commons Attribution License (http://creativecommons.org/licenses/by/3.0), which permits unrestricted use, distribution, and reproduction in any medium, provided the original work is properly cited. CC BY

References

[1] Nezhad AS. Future of portable devices for plant pathogen diagnosis. Lab Chip. 2014;14:2887-2904.

[2] Pan L, Qiu H, Dou C, Li Y, Pu L, Xu J, Shi Y. Conducting polymer nanostructures: template synthesis and applications in energy storage. International Journal of Molecular Sciences. 2010;11:2636-2657.

[3] Thind TS. Phytopathogenic Procaryotes and plant diseases. Research in Plant Disease. 2012;27:125-125.

[4] Joseph T, Morrison M. Nanotechnology in agriculture and food. Institute of Nanotechnology: London; 2006.

[5] US Environmental Protection Agency. Nanotechnology White Paper. Report EPA 100/B-07/001, Washington, DC, USA; 2007. Available from: http://www.epa.gov/osainter/pdfs/nanotech/epananotechnologywhitepaper-0207.pdf. Accessed June 9, 2014.

[6] United States Department of Agriculture. Nanoscale science and engineering for agriculture and food systems. Report submitted to Cooperative State Research, Education and Extension Service, United States Department of Agriculture, National Planning Workshop; 18-19 November 2002; Washington, DC, USA. 2002.

[7] Nakache E, Poulain N, Candau F, Orecchioni AM, Irache JM. Biopolymer and polymer nanoparticles and their biomedical applications. In: Nalwa HS, editor. Handbook of Nanostructured Materials and Nanotechnology. Academic Press; New York, NY, USA. 1999.

[8] Storrs Hall J. Nanofuture: What's Next for Nanotechnology? Amherst, NY, USA: Prometheus Books; 2006.

[9] Drexler KE. Engines of creation: the coming era of nanotechnology. 1986. Available from: http://e-drexler.com/p/06/00/EOC_Cover.html. Accessed June 9, 2014.

[10] Elmer W, Jason CW. The Future of Nanotechnology in Plant Pathology. Annual Review of Phytopathology. 2018; 56:111-33.

[11] Gruère GP. Implications of nanotechnology growth in food and agriculture in OECD countries. Food Policy. 2012;37:191-198.

[12] Tournas VH. Spoilage of vegetable crops by bacteria and fungi and related health hazards. Critical Reviews in Microbiology. 2005; 31:33-44.

[13] Park HJ, Kim SH, Kim HJ, Choi SH. A new composition of nanosized silicasilver for control of various plant diseases. The Plant Pathology Journal. 2006;22: 295-302.

[14] Sharma K, Sharma R, Shit S, Gupata S. Nanotechnological application on diagnosis of a plant disease. International Conferences on Advances in Biological and Medical Sciences (ICABMS'2012); July 15-16, 2012; Singapore. 2012.

[15] Khan MR, Rizvi TF. Nanotechnology: Scope and application in plant disease management. Plant Pathology Journal. 2014;13:214-231.

[16] Agrawal S, Rathore P. Nanotechnology pros and cons to agriculture: A review. International Journal of Current Microbiology and Applied Sciences. 2014;3:43-55.

[17] Nel A, Xia T, Madler L, Li N. Toxic potential of materials at the nano level. Science. 2003;311: 622-627.

[18] Min JS, Kim KS, Kim SW, Jung JH, Lamsal K, Kim SB, Lee YS. Effects of colloidal silver nanoparticles on sclerotium-forming phytopathogenic

fungi. Plant Pathology Journal. 2009;25: 376-380.

[19] Zeng H, Li XF, Zhang GY, Dong JF. Preparation and characterization of beta cypermethrin nanosuspensions by diluting O/W microemulsions. Journal of Dispersion Science and Technology. 2008;29:358-361.

[20] Prabhu S, Poulose EK. Silver nanoparticles: Mechanism of antimicrobial action, synthesis, medical applications, and toxicity effects. International Nano Letters. 2012;2:32.

[21] Lemire JA, Harrison JJ, Turner RJ. Antimicrobial activity of metals: Mechanisms, molecular targets and applications. Nature Reviews. Microbiology. 2013;11:371.

[22] Alghuthaymi MA, Almoammar H, Rai M, Said-Galiev E, Abd-Elsalam KA. Myconanoparticles: Synthesis and their role in phytopathogens management. Biotechnology and Biotechnological Equipment 2015;29:221-236.

[23] Abd-Elsalam, K. A., & Prasad, R. (2018). Nanobiotechnology applications in plant protection. Dordrecht: Springer. https://www.springer.com/us/book/9783319911601.

[24] Dubey M, Bhadauria S, Kushwah BS. Green synthesis of nanosilver particles from extract of Eucalyptus hybrida (safeda) leaf. Digest Journal of Nanomaterials and Biostructures. 2009; 4:537-543.

[25] Sharon M, Choudhary AK, Kumar R. Nanotechnology in agricultural diseases and food safety. Journal of Phytopathology. 2010;2:83-92.

[26] Clement JL, Jarrett PS. Antibacterial silver. Metal-Based Drugs. 1994;1: 467-482.

[27] Kim YH, Lee DK, Cha HG, Kim CW, Kang YC, Kang YS. Preparation and characterization of the antibacterial Cu nanoparticle formed on the surface of SiO2 nanoparticles. The Journal of Physical Chemistry. 2006;110: 24923-24928.

[28] Wei D, Sun W, Qian W, Ye Y, Ma X. The synthesis of chitosan-based silver nanoparticles and their antibacterial activity. Carbohydrate Research. 2009; 344:2375-2382.

[29] Esteban TL, MalpartidaF, Esteban CA, Pecharroman C, Moya JS. Antibacterial and antifungal activity of a soda-lime glass containing copper nanoparticles. Nanotechnology. 2009; 20:505701.

[30] Brunel F, El Gueddari NE, Moerschbacher B M. Complexation of copper (II) with chitosan nanogels: Toward control of microbial growth. Carbohydrate Polymers. 2013;92: 1348-1356.

[31] Gogoi R, Dureja P, Singh PK. Nanoformulations – A safer and effective option for agrochemicals. Indian Farming. 2009;59:7-12.

[32] Brecht MO, Datnoff LE, Kucharek TA, Nagata RT. Influence of silicon and chlorothalonil on the suppression of gray leaf spot and increase plant growth in St. Augustine grass. Plant Disease 2004;88:338-344.

[33] Xie Y, He Y, Irwin PL, Jin T, Shi X. Antibacterial activity and mechanism of action of zinc oxide nanoparticles against *Campylobacter jejuni*. Applied and Environmental Microbiology. 2011;77: 2325-2331.

[34] Borkow G, Gabbay J. Copper as a biocidal tool. Current Medicinal Chemistry. 2005;12:2163-2175.

[35] Patra P, Mitra S, Debnath N, Goswami A. Biochemical-, biophysical-, and microarray-based antifungal evaluation of the buffer-mediated

synthesized nano zinc oxide: An in vivo and in vitro toxicity study. Langmuir. 2012;28:16966-16978.

[36] Wang S, Lawson R, Ray PC, Yu H. Toxic effects of gold nanoparticles on *Salmonella typhimurium* bacteria. Toxicology and Industrial Health. 2011; 27:547-554.

[37] Brecht M, Datnoff L, Nagata R, Kucharek T. The role of silicon in suppressing tray leaf spot development in St. Augustine grass (pp. 1-4). Gainesville: Publication in University of Florida. 2003.

[38] Ghormade V, Deshpande MV, Paknikar KM. Perspectives for nano-biotechnology enabled protection and nutrition of plants. Biotechnology Advances. 2011;29:792-803.

[39] Lauterwasser C. Small sizes that matter: Opportunities and risks of nanotechnologies. Report in cooperation with the OECD International Futures Programme. Munchen: Allianz Center for Technology. 2006. pp. 45.

[40] Kah M, Hofmann T. Nanopesticide research: Current trends and future priorities. Environment International. 2014;63:224-235.

[41] Bordes P, Pollet E, Avérous L. Nano-biocomposites: Biodegradable polyester/nanoclay systems. Progress in Polymer Science. 2009;34:125-155.

[42] Bergeson LL. Nanosilver pesticide products: What does the future hold? Environmental Quality Management. 2010;19:73-82.

[43] Bernardes PC, Nélio JDA, Nilda de Fátima FS. Nanotechnology in the food industry. Bioscience Journal. 2014;30: 1919-1932.

[44] Chuan L, He P, Pampolino MF, Johnston AM, Jin J, Xu X, Zhou W. Establishing a scientific basis for fertilizer recommendations for wheat in China: Yield response and agronomic efficiency. Field Crops Research. 2013;140:1-8.

[45] Kanto T, Miyoshi A, Ogawa T, Maekawa K, Aino M. Suppressive effect of potassium silicate on powdery mildew of strawberry in hydroponics. Journal of General Plant Pathology. 2004;70: 207-211.

[46] Jenne M, Kambham M, Tollamadugu NP, Karanam HP, Tirupati MK, Balam RR, Shameer S, Yagireddy M. The use of slow releasing nanoparticle encapsulated Azadirachtin formulations for the management of *Caryedon serratus* (groundnut bruchid). IET Nanobiotechnology. 2018;12:963-967.

[47] Worrall EA, Hamid A, Mody KT, Mitter N, Pappu HR. Nanotechnology for Plant Disease Management. Agronomy. 2018;8:285.doi:10.3390/agronomy 8120285.

[48] Zhang L, Jiang Y, Ding Y, Daskalakis N, Jeuken L, Povey M, O'Neill AJ, York DW. Mechanism investigation into antibacterial behaviour of suspension of ZnO nanoparticles against *E. coli*. Journal of Nanoparticle Research. 2010;12:1625-1636.

[49] Cabiscol E, Tamarit J, Ros. Oxidative stress in bacteria and protein damage by reactive oxygen species. International Journal of Microbiology. 2007;3:3-8.

[50] Wiesner MR, Lowry GV, Alvarez P, Dionysiou D, Biswas P. Assesing the risk of manufactured nanomaterials. Environmental Science & Technology. 2006;15:4336-4345.

[51] Hsueh PR. New Delhi metallo-β-lactamase-1 (NDM-1): an emerging threat among Enterobacteriaceae. Journal of the Formosan Medical Association. 2010;109:685-687.

[52] Wang C, Zhao M, Li J, Yu J, Sun S, Ge S, Huang Y. Silver nanoparticles/

graphene oxide decorated carbon fiber synergistic reinforcement in epoxy-based composites. Polymer. 2017a;131:263-271.

[53] Wang J, Qiufang Y, Chengmin S, Chunde J, Qingfeng S. One-step preparation of graphene oxide/cellulose nanofibril hybrid aerogel for adsorptive removal of four kinds of antibiotics. Journal of Nanomaterials. 2017b:5150613. https://doi.org/10.1155/2017/5150613.

[54] Wang L, Hu C, Shao L. The antimicrobial activity of nanoparticles: present situation and prospects for the future. International Journal of Nanomedicine. 2017c;12:1227-1249.

[55] Goswami A, Roy I, Sengupta S, Debnath N. Novel applications of solid and liquid formulations of nanoparticles against insect pests and pathogens. Thin Solid Films. 2010;519:1252-1257.

[56] Sahayaraj K. Bionanomaterials: synthesis and applications. In: Proceedings of the first national seminar on new materials research and nanotechnology (NSNMRN'2012); 12-14 September 2012; Government Arts College, Ooty, Tamil Nadu, 2012.

[57] Sahayaraj K, Roobadevi M, Rajesh S, Azizi S. Vernonia cinerea (L.) Less. silver nanocomposite and its antibacterial activity against a cotton pathogen. Research on Chemical Intermediates. 2015;41:5495-5507.

[58] Bao YP, Wei TF, Lefebvre PA, An H, He L, Kunkel GT, Müller UR. Detection of protein analytes via nanoparticle-based bio bar code technology. Analytical Chemistry. 2006;78:2055-2059.

[59] Nam JM, Thaxton CS, Mirkin CA. Nanoparticle-based bio-bar codes for the ultrasensitive detection of proteins. Science. 2003;301:1884-1886.

[60] Xu J. Fungal DNA barcoding. Genome. 2016;59:913-932.

[61] Branton D, Deamer DW, Marziali A, Bayley H, Benner SA, Butler T, Di Ventra M, Garaj S, Hibbs A, Huang X, Jovanovich SB et al. The potential and challenges of nanopore sequencing. Nature Biotechnology. 200;6:1146-1153.

[62] Egan AN, Schlueter J, Spooner DM. Applications of next-generation sequencing in plant biology. American Journal of Botany. 2012;99:175-185.

[63] Clarke J, Wu HC, Jayasinghe L, Patel A, Reid S, Bayley H. Continuous base identification for single-molecule nanopore DNA sequencing. National Nanotechnology Initiative. 2009;4:265.

[64] Kumar S, Tao C, Chien M, Hellner B, Balijepalli A, Robertson JW, Ju J. PEG-labeled nucleotides and nanopore detection for single molecule DNA sequencing by synthesis. Scientific Reports. 2012;2:684.

[65] Hayden CE. Pint-sized DNA sequencer impresses first users. Natural News. 2015;521(7550):15.

[66] Khiyami MA, Hassan A, Yasser MA, Mousa AA, Kamel AAE. Plant pathogen diagnostic techniques: forthcoming changes? Biotechnology & Bio-technological Equipment. 2014;28: 775-785.

[67] Pimentel D. Invasive plants: their role in species extinctions and economic losses to agriculture in the USA. In: Management of invasive weeds, invading nature – Springer Series in invasion ecology. Dordrecht: Springer; 2009.pp 1-7.

[68] Lattanzio VMT, Nivarlet N, Lippolis V, Gatta SD, Huet AC, Delahaut P, Granier B, Visconti *A. multiplex* dipstick immunoassay for semi-quantitative determination of Fusarium mycotoxins in cereals. Analytica Chimica Acta. 2012;718:99-108.

[69] Edmundson MC, Capeness M, Horsfall L. Exploring the potential of

metallic nanoparticles within synthetic biology. New Biotechnology. 2015;31: 572-578.

[70] Knudsen BR, Jepsen ML, Ho YP. Quantum dot-based nanosensors for diagnosis via enzyme activity measurement. Expert Review of Molecular Diagnostics. 2013;13:367-375.

[71] Safarpour H, Safarnejad MR, Tabatabaei M, Mohsenifar A, Rad F, Basirat M, Shahryari F, Hasanzadeh F. Development of a quantum dots FRET-based biosensor for efficient detection of *Polymyxa betae*. Canadian Journal of Plant Pathology. 2012;34:507-515.

[72] Rad F, Mohsenifar A, Tabatabaei M, Safarnejad MR, Shahryari F, Safarpour H, Foroutan A, Mardi M, Davoudi D, Fotokian M. Detection of Candidatus Phytoplasma aurantifolia with a quantum dots FRET-based biosensor. Journal of Plant Pathology. 2012;94:525-534.

[73] Ma J, Du LF, Chen M, Wang HH, Xing LX, Jing LF, Li YH. Drug-loaded nano-microcapsules delivery system mediated by ultrasoundtargeted microbubble destruction: a promising therapy method. Biomedical Reports. 2013;1:506-510. doi: 10.3892/br.2013.110.

[74] Ambrosone A, Marchesano V, Carregal-Romero S, Intartaglia D, Parak WJ, Tortiglione C. Control of Wnt/β-catenin signaling pathway in vivo via light responsive capsules. ACS Nano. 2016;10: 4828-4834. doi: 10.1021/acsnano.5b07817

[75] Linsley CS, Wu BM. Recent advances in light responsive on-demand drug-delivery systems. Therapeutic Delivery. 2017;8:89-107. doi: 10.4155/tde-2016-0060

[76] Boonham N, Glover R, Tomlinson J, Mumford R. Exploiting generic platform technologies for the detection and identification of plant pathogens. In Sustainable Disease Management in a European Context, ed. DB Collinge, L Munk, BM Cooke. Berlin: Springer; 2008. pp.355-63.

[77] Yao KS, Li SJ, Tzeng KC, Cheng TC, Chang CY, Chiu CY, Liao CY, Hsu JJ, Lin ZP. Fluorescence silica nanoprobe as a biomarker for rapid detection of plant pathogens. Advanced Materials Research. 2009;79:513-16.

[78] Li XM, Xu G, Liu Y, He T. Magnetic Fe3O4 nanoparticles: synthesis and application in water treatment. Journal of Nanoscience and Nanotechnology. 2011;1:14-24.

[79] Tartaj P, del Puerto Morales M, Veintemillas-Verdaguer S, Gonzalez-Carre ´ no T, Serna CJ. The preparation of magnetic nanoparticles for applications in biomedicine. Journal of Physics D. 2003;36:182.

[80] Fang Y, Ramasamy RP. Current and prospective methods for plant disease detection. Biosensors. 2015; 5:537-61.

[81] Bergeson LL. Nano silver pesticide products: What does the future hold? Environmental Quality Management. 2010;19:73-82.

[82] Khot LR, Sankaran S, Maja JM, Ehsani R, Schuster E. Application of nanomaterials in agricultural production and crop protection: a review. Crop Protection. 2012;35:64-70.

[83] Alonso-Lomilloa MA, Dom'ınguez-Renedoa O, Ferreira-Gonc¸alves L, Arcos-Mart'ıneza MJ. Sensitive enzyme-biosensor based on screen-printed electrodes for ochratoxin A. Biosensors and Bioelectronics. 2010; 25:1333-37.

[84] Ansari AA, Kaushik A, Solanki PR, Malhotra BD. Nanostructured zinc oxide platform for mycotoxin detection. Bioelectrochemistry. 2010;77:75-81.

[85] Tothill IE. Biosensors and nanomaterials and their application for mycotoxin determination. World Mycotoxin Journal. 2011;4:361-74.

[86] Ruitenberg R. Earthworm Health Hurt by Nanoparticles in Soil in Alterra Study, Bloomberg. 2013.

[87] Xu L, Liu Y, Bai R, Chen C. Applications and toxicological issues surrounding nanotechnology in the food industry. Pure and Applied Chemistry. 2010;82:349-372.

[88] Chen H and Yada R. Nanotechnologies in agriculture: New tools for sustainable development. Trends in Food Science & Technology. 2011;22: 585-594.

[89] Kalpana-Sastry R, Rashmi HB, Rao NH, Ilyas SM. Nanotechnology and Agriculture in India: The Second Green Revolution? Presented at the OECD Conference on "Potential Environmental Benefits of Nanotechnology: Fostering Safe Innovation-Led Growth" Session 7. Agricultural Nanotechnology, Paris, France, July 15-17, 2009.

IntechOpen