Nanobiotechnology: A Solution To Food Insecurity, Safety and Sustainability

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Abstract

The problems of food insecurity, safety and sustainability occur mostly through the activities of pest and pathogens. The resistance of the causative agents on agricultural production coupled with potential health hazards posed on the environment by synthetic pesticides led to the search for an alternative to synthetic chemicals. Nanotechnology is currently the best candidate for ensuring food security, safety and water quality. National governments especially in developing countries are advised to mount regulating agencies that will be responsible for achieving food security and safety as already done in countries like USA, India and Indonesia among others. Considering the fact that we are now in a period when global population is steadily increasing and there is a very high demand for health food but high cost of production and need for sustainable agriculture has limited the profit margin made by farmers. The cause of naturally-occurring products with interesting antimicrobial eliciting properties and their derivatives has been getting more attention in recent years. Nanotechnology may have concrete solutions against many agriculture-related problems like insect pest management using traditional methods, adverse effects of chemical pesticides; development of improved crop varieties. As with any other technology, controversy surrounding nanotechnology is no exception in a heterogeneous society. Several concerns need to be addressed on different issues like food safety and beneficiaries of the technology.

Key words: Food-insecurity, pathogen, pest, safety, chemicals, materials, benefits, nanoparticles, biotechnology

Introduction

Materials with particle sizes less than 100 nanometers (nm) in at least one dimension are generally classified as nanomaterials. The development of nanotechnology in conjunction with biotechnology has significantly expanded the application domain of nanomaterials in various fields (Wu, 2013). The potential uses and benefits of nanotechnology are enormous. These benefits include insect pests management through the formulations of nanomaterial-based pesticides and enhancement of agricultural productivity using bio-conjugated nanoparticles (encapsulation) for slow release of nutrients and water (Atanu *et al*., 2010). Applicability and phytotoxicity of silver (Ag) nanomaterials in agriculture have been well debated by the United States Environmental Protection Agency (USEPA). As reported by Bergeson (2010), there are more than 100 pesticides that contain Ag due to its anti-microbial properties. However, toxicity of nanosilver to ecosystems and humans is a major concern. Lu *et al.* (2010) have reported that the citrate-coated colloidal Ag nanoparticles showed no genotoxicity (genetic), no cytotoxicity (cell), and no phototoxicity (toxicity through photo-degradation) to humans; however; citrate-coated Ag nanoparticles in powder form were toxic to humans. According to Furno *et al.* (2004), metallic nanoparticles were not toxic chemicals and had no adverse effects on food. Nanoparticles especially nano silver have been applied for use in wound dressing, water purification, catheters and various household products due to their antimicrobial activities (Furno *et al*., 2004).

Many earlier researchers on conventional pesticides have reported that they have potential health hazards and are a threat to food security globally (Furno *et al*., 2004). Some pests are difficult to control with available technologies and large differences exist in their efficacy of pest control (Zeledon *et al*., 2008). The Food and Agriculture Organization (FAO) reported that climate change is likely to increase pest pressure and the incidence of mycotoxins (FAO, 2013). This paper, therefore, examines the prospects of nanoscience (nanobiotechnology) with respect to pest and disease control for food security and safety in relation to earlier technologies.

Pesticide Development Trends

Use of synthetic pesticides: In a broad sense, a pesticide is any agent used to kill or control undesired insects, weeds, rodents, fungi, bacteria or other organisms. Pesticides are classified according to their function: insecticides control insects, rodenticides control rodents, herbicides control weeds and fungicides control fungi. Some benefits have been derived from pesticides application such as profitable crop growth in unsuitable locations, extending growing seasons and maintaining yield quality (Johnson, 2013). Nevertheless, these chemicals pose some risks if used improperly or used too frequently. Schillhorn, in his review of agricultural pest management, noted that in Asia pesticides are often sold through unlicensed dealers and shopkeepers (Schillhorn, 1999). Some of these may be familiar with agro-chemicals, but in many rural shops one may find pesticides sold next to food products such as milk or bread. Although the availability of pesticides in rural areas is important, the benefit of such availability has to be weighed against consumer safety, proper storage, and the need to educate farmers about proper use. However, there is insufficient data to really assess the risk, especially of newer products. For example, it has been claimed that in certain parts of India, the daily food borne intake of pesticide residues is approximately 0.51 mg (Alam, 1994). This is well above accepted levels, but the impact on public health and reproduction has not yet been fully investigated.

Biopesticide Application: The superior characteristics of biopesticides attracted more attention than ever before and made them a topical issue of research in biotechnology institutions and companies. The research and application of biopesticides have been well developed and gradually replace the use of highly toxic conventional pesticides in the market (Cheng *et al*., 2010). In recent years, production of conventional pesticides has declined by 2% annually while biopesticides output has increased at the annual rate of 20% (Cheng *et al*., 2010). In China, the research and application of biopesticides began in early 1950s. In 2005, the total demand for all kinds of biopesticides in China reached 145,000 tons, while the total sales were valued at about USD 8 million. Zhu predicted that biopesticides could replace more than 20% of conventional chemical pesticides during the next 10 years (2009 to 2019) (Zhu, 2009). However, there were more than 30 research institutions and 200 biopesticide enterprises (about 2000 conventional pesticide manufacturing enterprises) in China, with annual production of approximately 100,000 tons.

Nanoparticle properties: Nanomaterials of inorganic and organic origin are used for nanoparticles (NPs) synthesis by a variety of physical and chemical methods. Synthesis of NPs involves size reduction by top-down methods such as milling, high pressure homogenization and sonication, while bottom-up processes involve reactive precipitation and solvent displacement (Sasson *et al*., 2005). Among inorganic materials, metal oxide NPs such as, TiO_2, ZnO, AgO and MgO are of particular interest as they are physically and optically stable with tunable optical properties (Makhluf *et al.,* 2005). These products can be used in a number of ways to reduce disease levels and prevent the development and spread of pathogens, thus preserving yield and quality crop products. Abdelbasset *et al*. (2010) reported that both chitin and chitosan have demonstrated antiviral, antibacterial, and antifungal properties, and have been explored for many agricultural uses. As more and more derivatives of chitosan (*N*-alkyl-, *N*-benzyl chitosans) are made available through chemical synthesis, their insecticidal activities are being reported using an oral larvae feeding bioassay (Badawy *et al*., 2005).

Comparison of nanopesticide and nanobiopesticide delivery: The current development of resistance to insecticides and fungicides by pest and pathogens has called for nanotechnology (Choy *et al*., 2007; Bin *et al*., 2009). Nanotechnology has potential for efficient delivery of chemical and biological pesticides using nano-sized preparations or nano materials based agrochemical formulations. The benefits of nano materials based formulations include but are not limited to the improvement of efficacy due to higher surface area, higher solubility, induction of systemic activity due to smaller particle size and higher mobility and lower toxicity due to elimination of organic solvents in comparison to conventionally used pesticides and their formulations (Smith *et al*., 2008). In case of biopesticides, NPs can play a major role in enhancing the efficacy and stability of whole cells, enzymes and other natural products used. Controlled release of nano-clays was engineered by surface coating with different polymers that manipulated electrostatic interactions between the chemical load and clay particles (Lee and Fu, 2003). Nanosized aqueous dispersion or nano suspensions eliminated the need for organic solvents and provided a process for stabilizing formulations of two or more immiscible pesticides. Storm *et al*. (2001) used milling technologies in presence of grinding media (polymer beads) and surface active agents to obtain stable suspensions of various fungicides and insecticides with particle sizes around 148–314 nm (Storm *et al*., 2001). Recently, one of the pesticide companies released a nano-sized aqueous dispersion formulation with broad spectrum systemic fungicidal action for the control of leaf spots, blights, rusts and powdery mildew diseases on ornamentals, turf, and other landscape plantings (Wong and Midland, 2004; Latin, 2006).

Nano formulations using plant extracts: Plants provide a non-toxic source of molecules with proven biological efficacy that are usually non-persistent in fresh water and soil (Wong and Midland, 2004). In the case of essential oils, their chemical instability in the presence of air, light, moisture, and high temperatures that causes rapid evaporation and degradation of some active components is a major concern in their effectiveness. Incorporation of essential oils into a controlled-release nano formulation prevents rapid evaporation and degradation; enhances stability and maintains the minimum effective dosage/application (Lai *et al*., 2006). The essential oil from garlic was loaded on polymer NPs (240 nm) coated with polyethylene glycol (PEG) to evaluate their insecticidal activity against adult *Tribolium castaneum* (Yang *et al*., 2009). Sichuan Academy of Agricultural Science succeeded in developing nanopesticides (<100 nm) from a plant source, with advantages of environmental protection, high efficiency and low toxicity, which had a direct effect on pest control practices (Gao, 2006). Leaves extracts of *Euphorbia prostrata* is a simple, non-toxic and ecofriendly green material. In Tamil Nadu, India, silver nano particles (Ag NPs) synthesized using aqueous leaves extracts of *Euphorbia prostrata* were successfully used to control *Sitophilus oryzae* in rice and showed potential of being used as an ideal eco-friendly approach (Abduz, 2012). The advantage of using plants for the synthesis of nano pesticides is that they are easily available, safe to handle and possess a broad variability of metabolites that may aid in reduction to nanoparticle size. A number of plants are being currently investigated for their role in the nanoparticle usage. Gold Nanoparticles with a size range of 2- 20 nm have been synthesized using live alfalfa plants (Torney *et al*., 2002). Nanoparticles of silver, nickel, cobalt, zinc and copper have also been synthesized inside live plants of *Brassica juncea* (Indian mustard), *Medicago sativa* (Alfalfa) and *Heliantu sannus* (Sunflower). Certain plants are known to accumulate higher concentrations of metals compared to others and such plants are termed as hyper accumulators. Among all the plants investigated by Bali *et al*. (2006), *Brassica juncea* had better metal accumulating ability and later assimilating it as nano particle.

Challenges of Nano formulations using microbes: The use of nano formulations may offer new ways to enhance the stability of these biological agents. Fungal biocontrol agents or mycopesticides are promising as they act by contact and do not need ingestion, can be easily mass produced, and are relatively specific (Nahar *et al.,* 2004). In the rapidly developing field of nano biotechnology, the integration of biomolecules such as enzymes, metabolites or whole cells with nanostructures leads to hybrid systems that have numerous applications in many fields including agriculture (Bailey *et al*., 2010). The spraying of pesticides with knapsacks involving large droplets of 9-266 um can be reduced to smaller droplets of 3-28 um by nanotechnology (Vijayakumar *et al*., 2010). Constraints due to droplet size may be overcome by using NP encapsulated or nanosized pesticides that will contribute to efficient spraying and reduction of spray drift and splash losses.

To circumvent the above mentioned obstacles, NPs were employed to develop efficient gene transformation vehicles. Use of NPs expanded the application of this technology to both dicotyledonous and monocotyledonous plants and also makes it tissue specific. Gold NPs (5–25 nm) embedded carbon matrices were employed for the delivery of DNA during transformation of plant cells that carried higher amount of genetic material as compared to the micro particles (Torney *et al*., 2007). Further, Torney *et al*. (2007) demonstrated that a honeycomb surface functionalized mesoporous silica NP system with 3 nm pores capped with disulphide bond held gold NPs (10–15 nm) transported DNA and chemicals into isolated plant cells and intact leaves with the help of gene gun and uncapping of the gold NPs, by disulphide reduction in cellular environment, released the chemicals and triggered gene expression in the plants under controlled release conditions (Torney *et al*., 2007). Again, Liu *et al.* (2008) reported that starch NPs (50–100 nm) conjugated with fluorescent material Tris-(2,2′-bipyridine) ruthenium — (Ru (bpy)3)$^{2+}$ was used to transport plasmid DNA through *Dioscrea sp* plant cell wall, cell membrane and nuclear membrane in presence of ultrasound.

Detection of plant pathogens using nanosensors: Detection of a single bacterial cell was possible using this technique. Studies reported by Zhao *et al*. (2004) showed that pesticides such as atrazine, molinate, and chlorpyrifos are susceptible to degradation with nano sized zero valent iron (ZVI, 1–100 nm). Other approaches such as photocatalytic decomposition of pesticide residues using titanium doped with Fe_2O_3 or other metals sprayed directly on crops or even incorporated into the pesticide formulation are promising (Zhang, 2007). Layer-by-layer surface (LbL) nano-engineering is a novel strategy for direct surface modification of colloidal entities, which utilizes sequential adsorption of oppositely charged polyelectrolytes to form a complex assembly via electrostatic interactions.

Detection of pesticides using nanobiosensors: Development of sensors and diagnostic devices for on-site monitoring will allow farmers to closely monitor environmental conditions for plant growth and protection. These detection systems can contribute to increased productivity and decrease the use of synthetic conventional agrochemicals (example; antibiotics, pesticides, nutrients) by early intervention. Application of nano materials according to Gabaldon *et al*. (1999) adds further advantages to such systems, as measurement of more variables for greater sensitivity with less sample material required and faster detection rates, read-outs in real time and application of novel detection methodologies, for example electronic, colorimetric, fluorometric, and mass changes (Gabaldon *et al.*, 1999).

Currently uni-molecular and array type of nano material based biosensors are being developed for detection of pesticides (Lisa *et al.,* 2009). Interaction of the target with the biosensor can be measured either directly or indirectly by recording the changes in color, fluorescence or electrical potential. In array technologies, multiple biomolecules are fixed to a substrate allowing multiple analytes to be measured simultaneously. The gold NP based dipstick technique was suitable for the detection of several toxins in food and environmental samples and can be applied for rapid on-site testing of pesticides (Lisa *et al.,* 2009). Cadmium telluride quantum dots (CdTe QDs), semiconductor fluorescent NPs, in a fluoroimmuno assay was used to detect 2, 4-dichlorophenoxyacetic acid (2, 4-D), an herbicide (Vinayaka *et al*., 2009). Again, Zirconium oxide NPs (~50 nm) was developed by Wang *et al*., (2009), based immunoassay for sensitive detection of (0.02 nM) of organophosphate pesticides using phosphorylated enzyme acetylcholinesterase as a potential biomarker.

The ability to integrate enzymes for catalytic detection with the capability to detect chemical agents may potentially extend the versatility of the array nano-biosensor to both biological and chemical contaminants. The widespread use of various pesticides and their mixtures in the agricultural fields causes the multi-residue retention problem in the environment. Thus, it is necessary to simultaneously identify several pesticides in a complex sample.

Field application of Nano formulations: In the rapidly developing field of nanobiotechnology the integration of biomolecules such as enzymes, metabolites or whole cells with nanostructures leads to hybrid systems that have numerous applications in many fields including agriculture (Bailey *et al*., 2010). According to Mathews (2008) the mode of pesticide and fertilizer application influences their efficiency and environmental impact. Constraints due to droplet size may be overcome by using NP encapsulated or nano-sized pesticides that will contribute to efficient spraying and reduction of spray drift and splash losses.

According to Vijayakumar *et al*. (2010) the DNA coated NPs gained easy access to the plant cell due to its size increasing the transformation efficiency in both monocotyledonous *Oryza sativa* (rice), and dicotyledenous *Nicotiana tabacum* (tobacco) and *Leucaena leucocephala* (white lead tree) NPs had lower plasmid and gold requirement as compared to the commercial micrometer-sized gold particles (Vinayaka *et al*., 2009). Moreover, plant-cell damage with the NPs was minimal with increased plant regeneration. Furthermore, Torney *et al.* (2007) demonstrated that a honeycomb surface functionalized mesoporous silica NP system with 3 nm pores capped with disulphide bond held gold NPs (10–15 nm) transported DNA and chemicals into isolated plant cells and intact leaves with the help of gene gun (Vinayaka *et al*., 2009). Uncapping of the gold NPs, by disulphide reduction in cellular environment, released the chemicals and triggered gene expression in the plants under controlled release conditions. Apart from the advantage of acceptance by a wide host range, the starch (Ru (bpy) $3)^{2+}$ NPs also offered the possibility of tracking in the cell and foliar application of a chitosan pentamer affected the net photosynthetic rate of soybean and maize one day after application (Liu *et al*., 2008). Nano-encapsulation is currently the most promising technology for protection of host plants against insect pests. Nano-encapsulation is a process through which a chemical such as an insecticide is slowly but efficiently released to a particular host plant for insect pest control. Nano-encapsulation with nano particles in form of pesticides allows for proper absorption of the chemical into the plants unlike the case of larger particles (Kulkarni, 2007).

Future prospect of nanotechnology: The future of nanotechnology is uncertain due to many reasons, such as lack of public awareness, initial negative reaction of the public towards novel breakthroughs, lack of many of the requisite skills in public agricultural research organizations for this type of research and ill-equipped and somewhat hesitant regulatory structures to deal with these new technologies in Nigeria. Specific polling questions examined opinions on the safety of our food system as well as the use of nanotechnology in pest control for food products. There is need to create sensible nanotechnology oversight policies that will help ensure the safe and sustainable application of nanotechnologies to climate change, food security, water purification, health care, and other pressing global problems. Regulatory bodies for biosafety of nanoparticles such as the National Institute for Occupational Safety and Health are actively conducting research on potential health effects stemming from exposures to nanoparticles (Matthew and Thomas, 2000). Regulators from the EPA reported that since 2007 they had received some applications for registration of pesticides containing nanomaterials (Oerke, 2006).

Given that the development of nanotechnology involves numerous scientific disciplines, it is clear that nanoscale products have been and will be used in agriculture for purposes of controlling disease vectors and urban pests control prior to a complete evaluation of exposure and risk (Baruah and Dutta, 2009). There is need for public awareness with this rapidly progressing technology to inform the public at large about the advantages of nanotechnology (Bergeson, 2010). This will result in a tremendous increase in interest and discovery of new applications in all the domains. Mathews (2008) predicated that by 2014, a projected \$2.6 trillion in global manufactured goods will incorporate nanotech, and this would usher in new industrial revolution. With a variety of potential applications, nanotechnology is a key technology for the future and governments have invested billions of dollars in its research (Benitez *et al*., 2004). Public awareness on nanotechnology has not kept pace with the growth of this new technology and this is likely to increase the danger that the slightest bump, even a false alarm about safety or health could undermine public confidence, engender consumer mistrust, and, as a result, damage the future of nanotechnology (El-Nahhal *et al*., 1999; Bailey *et al*., 2010).

Conclusion

In an era of high demand for blemish-free food and high cost inputs, sustainable agriculture has only a slim margin to make profits while guaranteeing food supply to a growing population. The cause of naturally-occurring products with interesting antimicrobial properties and their derivatives has been getting more attention in recent years. Nanotechnology may have concrete solutions against many agriculture-related problems like insect pest management, adverse effects of chemical pesticides; development of improved crop varieties. Nanotechnology has the potential to revolutionize the existing technologies used in various sectors including agriculture in the near future. Its products can be used in a number of ways to reduce disease levels and prevent the development and spread of pathogen, thus promoting crop yield and quality of crop produce. As with any other technology, controversy surrounding nanotechnology is no exception in a heterogeneous society. Several concerns need to be addressed on different issues like food safety and beneficiaries of the technology. All people require food, and the policy makers have the responsibility to make the correct decisions for its adequate implementation and delivery. Therefore, it is high time that we strengthened research in this direction to garner long term benefits from nanotechnology. More so, governments and agencies should make a complex decision about the suitability of existing regulatory systems and determine whether new measures are needed for nanoparticles to be adopted into the market. Increasing agricultural productivity is necessary, while keeping in mind the damage to the ecosystem, therefore new approaches need to be considered. Nanotechnology is becoming increasingly important for the agricultural sector. Promising results and applications are already being developed in the areas of delivery of pesticides, biopesticides and genetic material for plant transformation. The use of nano materials for delivery of pesticides and biopesticides is expected to reduce the dosage and ensure controlled slow delivery. Application of nanoparticles is anticipated to stabilize biocontrol preparations that will go a long way in reducing environmental hazards. Nanotechnology, by exploiting the unique properties of nanomaterials, has developed nanosensors capable of detecting pathogens at levels as low as parts per billion.

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