Review Article

Role of Nanotechnology in Crop Protection and Production: A Review

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Abstract | Agriculture provides food for human beings directly and indirectly. As the world population is increasing, therefore need of the time is to use new technologies in agriculture like nanotechnology for sustainable agriculture production. Nanoparticles have physical, biological and chemical characteristics with size range of 10^{-9} nanometer in diameter. Nanotechnology will serve as an innovation in agriculture and food industry i.e. nanopesticides to manage insect pests of different crops, nanofungicides to control pathogens, plant diseases and nanoherbicides for the management of weeds. It also facilitate in precision farming, targeted use of inputs i.e. nanofertilizers and to overcome the environmental stress seed treatments with nanoparticles, to improve the crop yield use of smart gene delivery system. This technology can also be useful for sustainable water use and irrigation water filtration. It also plays an important role in pollution reduction. Green revolution of any developing countries can be achieved by adopting nanotechnology.

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1. Introduction

Richard Phillips Feynman an American theoretical physicist was awarded Nobel Prize in physics, who first time gave the idea of nanotechnology in 1965. "Nanotechnology" term was first time used by a Japanese scientist, Norio Taniguchi in 1974, a Greek word meaning 'dwarf' which means 10^{-9} or one billionth part of a meter. Generally, nanotechnology word is applicable for the material with size range of 1-100 nm which show different properties from their bulk (Leiderer and Dekorsy, 2008; Bhatcharya *et al*., 2010; Sabour, 2013).

Nanotechnology acts as an interdisciplinary field that is being used in different fields of applied sciences i.e. chemistry, physics, biology, medicine and engineering. According to Bhattacharyya *et al*. (2010) in near future nanotechnology will change the agriculture scenario including pest management. Nanotechnology has the capability to modernize the agriculture with advanced techniques of controlling pests, diseases and pathogen detection and their management. The yield and nutritional values of plants can be enhanced by increasing the plants ability of nutrients and pesticides absorption, as well as development of better system to monitor the conditions of the environment and protection (Welch and Graham, 1999; Suman *et al*., 2010; Tarafdar *et al*., 2013).

In agriculture sector, new challenges are to grow safe and healthy foods, including greater risk in agricultural production with increasing diseases due to change in climatic conditions (Biswal *et al*., 2012). In this sector, the dramatic effect on society as a whole will be due to research and development in nanotechnology by enhancing the development of advance level of genetically modified crops, techniques for the precision farming and synthetic chemical pesticides (Prasad *et al*., 2012a).

1.1 Application of nanotechnology in crop protection and production

This review is focusing on modern approaches of nanotechnology used for insect pests, pathogens and weeds management. Furthermore, it is also being used in precision farming, nutrients management, seed treatment, water treatment, pollution reduction and possible ability of nanomaterials in sustainable agriculture management. To reshape the modern agriculture, there is need to change agricultural technology.

This technology will be helpful to solve the problem of food shortage in all over the world by increasing the crop yields as well as food quality. Among the latest innovations in technologies nanotechnology has attained the well known position in transforming the agriculture and food production. The applications of nanotechnology in the field of agriculture are listed below:

1.2 Nanopesticides

Today the easy and quick way to control pests is the use of synthetic chemicals i.e. pesticides, fungicides and herbicides. The over use of pesticides has resulted many adverse effects on health, disturbed the beneficial fauna and polluting the soil, water and environment. Use of these chemicals on nano scale is the solution of these problems which also reduces the amount of sprayed chemicals (Scrinis and Lyons, 2007). The nanoparticles found to be effective against the insect pests, therefore they can be used for the preparation of new formulations like insecticides, pesticides, and insect repellents (Barik *et al*., 2008; Owolade *et al*., 2008; Gajbhiye *et al*., 2009; Goswami *et al*., 2010; Esteban-Tejeda *et al*., 2010; Zahir *et al*., 2012). Through nanoparticles DNA and relevant desired chemicals are also delivered to plant tissues to protect the plants from insect pest attack (Torney, 2009).

The poly-ethylene glycol-coated nanoparticles loaded with garlic essential oil possessing insecticidal activities were found to be effective about 80%. This was due to persistent and slow release of active components against adult *T. castaneum* insects (Yang *et al*., 2009). Various types of nanoparticles i.e. silver, aluminium oxide, titanium dioxide and zinc oxide are used to control rice weevil *Sitophilus oryzae* (Goswami *et al*., 2010). Nanostructure alumina also have been found to be effective controlling the two major insects of stored foods throughout in the world i.e. *Rhyzopertha dominica* Fand *S. oryzae* L. Wheat treated with nanostructure alumina showed significant mortality after continuously exposure of three days. Nanostructure alumina provides better control as compared to commercial insecticides and can be utilized alternative to pesticides (Teodoro *et al*., 2010). Silica product like nanosilica can be effectively utilized as nanopesticides. The controlling mechanism of nanosilica to insect pest involves absorption into the cuticular lipids when applied on plant surfaces and insect death is caused due to physical action (Barik *et al*., 2008). TiO_2 nanoparticles showed maximum toxicity against 2nd instar larva of Egyptian cotton leaf worm, *Spodoptera littoralis* (Boisd.) (Lepidoptera: Noctuidae) (Shakir *et al*., 2017).

In future it has been assumed that due to the availability of nanostructure catalysts, there will be increase in efficacy of commercial pesticides with reduction in level of doses used in crop plants (Joseph and Morrison, 2006). Nano-particles can be utilized to prepare new formulations of pesticides, insecticides and insect repellents as nano-pesticides, nanofungicides and nanoherbicides (Owolade *et al*., 2008).

1.3 Plants disease management

The potential of nanoparticles in plant disease management is higher in as comparison to conventional pesticides (Park *et al*., 2006) due to slow release and target specific. Silver is used as an inhibitory action to microorganism (Young, 2009). Through this various plant diseases can be controlled in safer ways than conventional pesticides. Similarly, the antimicrobial activity is present in metallic copper. The copper nano-compounds based on polymer have been determined with antifungal properties against the fungi infecting on plants (Cioffi *et al*., 2004). Park *et al*. (2006) studied the efficacy of silica-silver nanoparticles for the management of plants infecting fungi. The pumpkin and powdery mildew disease pathogens on leaves were vanished within three days by the application of nano based products.

Links Researchers

The alone and combine application of nanoparticles have been determined as antifungal action against different types of plants infecting fungi *Bipolaris sorokiniana*, *Raffaelea* sp. Fusarium, *M. grisea*, Phoma and both bacteria (gram-negative and positive) (Gajbhiye *et al.*, 2009; Kim *et al.*, 2009; Esteban-Tejeda *et al.*, 2010). On the basis of different experiments, it was concluded that silver and copper nanoparticles have inhibitory action on fungal hyphae growth and conidial germination. It was concluded that the nanoparticles serve as effective, alternative, cost effective and ecofriendly approach for the control of plants pathogens (Kumar and Yadave, 2009; Parasad *et al.*, 2011; Prasad and Swamy, 2013).

1.4 Weeds management

The agriculture production or crop production can be reduced due to different weeds. The soils infected with either weeds or weed seeds result in lower agricultural production. The weeds can be eliminated easily by destruction of seeds bank in the soil to prevent their germination even the presence of favourable condition of soil and weather. The nanotechnology can be used to improve the efficacy of herbicides resulting increase in crop yields and without harmful effects on agricultural workers. The use of pesticides and herbicides with encapsulation with controlled release technologies have revolutionized. The pesticides are being developed inside the nanoparticles and their timely release takes place with environmental trigger. The use of nano herbicides were considered the ecofriendly way for the management of conventional herbicides resistant weeds without producing toxic effects on soil. The slow and regular discharge of active substances, with successful penetration of herbicides into cuticles and tissues is possible through nanocapsules. It also performs in the form of 'magic bullets' which contains herbicides chemicals which exact target the plants parts for the liberation of their substances (Perez-de-Luque and Rubiales, 2009).

1.5 Precision farming

Precision agriculture in the farm management is new attitude. In agriculture to get maximum output (crop yield) with minimum input (fertilizers, pesticides, herbicides) have been long objective of the agriculturist. In Precision farming, sensors and satellite system are used which will enhance the agricultural yields by providing the precise information of the environmental conditions. Nano sensors make it possible the accurate use of agricultural inputs like water, nutrients and chemicals during farming. These sensors also help the farmers to monitor the insect pests and stress or drought on crop by the application of nanomaterials and satellite imaging of fields with global positioning systems.

Plant viruses and level of nutrients in the soil can also be monitored by the use of these sensors which will detect even the small part of fields how much needed fertilizer and chemical pesticides (Ingale and Chaudhari, 2013). There will be safe and optimal use of inputs with increase in economic efficiency due to less consumption of fertilizer. As a result, the environmental pollution will also be reduced. Nano sensors facilitate the farmers to maintain the farm in accurate manner with timely report of needs of the plants. In this way farmers use nutrients, irrigation, insecticides, fungicides and herbicides on only need bases (Cioffee *et al.*, 2004; Rai and Ingle, 2012; Ramzan *et al.*, 2019).

1.6 Nanofertilizer

In agriculture production fertilizers are playing an important role (35 to 40%). Through this nanotechnology in agriculture sector the nutrients use effectiveness and crop production increases by the application of nanofertilizers. The release of nutrients depending on the crop requirements, nano-fertilizers synthesized which are more proficient than the conventional fertilizers (Liu *et al.*, 2006a). Nano-fertilizers are being used as nano-encapsulated for slow release of nutrients throughout the crop growth period that is completely and rapidly absorbed by the plants that are excellent alternatives to soluble fertilizer.

Most of the nutrients are taken up by the plants without waste by leaching and to save fertilizer consumption with minimal environmental pollution (Liu *et al.*, 2006; DeRosa *et al.*, 2010). Soil and water decontamination is reduced due to reduction of nitrogen leaching. The toxic effects of over usage of fertilizers in soil conditions can be improved by slow and controlled release of fertilizers (Suman *et al.*, 2010).

1.7 Seed treatment

Seeds treated with nanotechnology can grow faster and steadier and have quick ability to recover environmental stress (Adhikari *et al.*, 2016). Strength of longevity and seedling growth also increases with the help of nanotechnology (Khodakovskaya *et al.*, 2009; Dehkourdi and Mosavi, 2013; Adak *et* *al*., 2016). Water absorption by the seeds increases with the application of nanomaterial as in case of nanosilver (Adhikari *et al*., 2016). About 73% vegetable dry weight increases with the application of nanoparticles along with increase in vitamins contents in seeds (Yang *et al*., 2007; Jaleel *et al*., 2009; Khodakovskaya *et al*., 2009; Fordsmand, 2016). Seeds treated with nanoparticles also showed 80% drought resistance (Rahimi *et al*., 2016). The longevity of seeds in storage increases 16.5% (Adak *et al*., 2016).

1.8 Irrigation water filtration

The farmers in the world especially developing countries will be benefitted through emerging technologies in which different types of nonmaterials are used for the purification of irrigation water. Chemical and UV light is conventionally used for purification of irrigation water but water purification by nano based techniques involves membrane filters which are derived from the nanoporus ceramics, magnetic nanoparticles and nanotubes (Hillie and Hlophe, 2007). Potable water contaminants and toxicants can be removed by using filters made up of carbon nanotubes. Carbon nanotubes combine to form mesh that serve as removal of water born pathogens, heavy metals (lead, uranium and arsenic). Microorganism like bacteria and viruses with negative charge can be trapped by nanoceram filter with positive charge. This type of sophisticated filtering machines can be used to remove the microbial endotoxins, pathogenic viruses, genetic materials and micro-sized particles (Argonide, 2005).

1.9 Sustainable water use

Nano-hydrogel can be used for optimum water use and to make more sustainable agricultural production that leads to efficient use of water by absorbing and release of water and nutrients in cycles (Vundavalli, 2015; Montesano and Serio, 2016; Demetri, 2016). Silver coated hydrogel when added to soil can hold 7.5% more water as compared to soils without (Vundavalli, 2015). The ability of hydrogel to store irrigation or rain water is between 130-190 times than its own weight (Vundavalli, 2015; Makama, 2016). Hydrogels are bio-degradeable and are capable to reduce the amount of contaminants (Magalhaes *et al*., 2013; Montesano *et al*., 2015; Montesano and Serio, 2016; Demetri, 2016). In crop production drought is considered as a greater environmental risk. Therefore, this nanotechnology is highly useful especially in dry areas (Jaleel *et al*., 2009).

1.10 Crop biotechnology

Mesoporus silica nanoparticles with 3nm are used for the delivery of chemicals and DNA into isolated plant cells. Theses chemically coated nanoparticles act as containers for the gene delivery into the plants and also stimulate plants by their cell wall to obtain particles. By this in controlled ways genes are inserted which are activated without any toxic effects. Using this technique DNA incorporation has been established first time successfully in corn and tobacco plants (Torney *et al*., 2007).

1.11 Pollution reduction

Nanotechnology is also applicable in agriculture to reduce the pollution resulted from fertilizers and plant protections products and is also used to remediate the soil that is polluted with heavy metals and making them productive again. Cadmium (Cd) and lead (Pb) from polluted soil that can be eliminated by application of zero valent iron nanoparticles. (Kern *et al*., 2009; Kah *et al*., 2013; Kah and Hofmann, 2014; Rabbani, 2016; Kah, 2016). Due to uncontrolled application of agrochemicals up to 90% are subjected to run-off indirectly. The efficiency of agrochemicals can be increased by using smart delivery system, which ultimately reduces the pollution, subsequently health and environmental risks (Pimentel and Burgess, 2014; Kah, 2015; Kah and Hofmann, 2015; Dasgupta *et al*., 2016; Saharan and Pal, 2016; Hasegawa *et al*., 2016).

Conclusion and Recommendations

Nanotechnology applications have the capability to transform the agriculture scenario by increasing production with enhanced management and minimum use of inputs. Insect pests, diseases of crops and weeds can be managed efficiently by the development of nanopesticides, nanofungicides and nanoherbicides as crop protection measures, similarly efficiency of nutrients can be increased by using nanofertlizers. Furthermore, removal of soil and water contamination, pollution reduction can also possible through nanotechnology. For the betterment of human beings nanotechnology will serve as a powerful toll in agricultural technology.

Novelty Statement

Nanotechnology is novel approach to manage insect pests, diseases, weeds and improving the yields of crops by the application of nanopesticides, nanofungicides, nanoherbicides and nanofertilizers.

Author's Contribution

MJ wrote the manuscript. UNU planned the study. WSK, SS, MAQ and MAK critically reviewed the manuscript.

Conflict of interest

The authors have declared no conflict of interest.

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