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Nanotechnology for Crop Protection

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Diksha Sinha[1]
[1]Department of Plant Pathology, CSK HPKV, Palampur (HP), India.

Nanotechnology is an emerging tool for enhancing crop production and assuring crop protection. Nanoparticles act as spreaders as well as unique carriers of agrochemicals like fertilizers and pesticides; thus facilitate the site-targeted controlled delivery of nutrients and improve the efficiency of inputs. Innovative utilization of nanotechnology in agriculture may help to meet the rising demand for food and environmental sustainability.

Introduction

The term 'nanotechnology' was first coined by Norio Taniguichi, a professor at Tokyo University of Science, in 1974. Nanoparticles (NPs) are organic, inorganic or hybrid materials with at least one of their dimensions ranging from 1 to 100 nm (at the nanoscale). NPs that exist in the natural world can be produced from the processes of photochemical reactions, volcanic eruptions, forest fires, simple erosion, plants and animals or even by the microorganisms.

A number of plant species and microorganisms including bacteria, algae and fungi are being currently used as efficient biological sources for NP synthesis. For example, *Medicago sativa* and *Sesbania* sp. are used to formulate gold nanoparticles. Likewise, silver, nickel, cobalt, zinc and copper NPs can be synthesized inside *Brassica juncea* and *Medicago sativa*. Diatoms, such as *Pseudomonas stuzeri*, *Clostridium thermoaceticum* and *Klebsiella aerogens* are used to synthesize silicon, gold, zinc sulphide and cadmium sulphide NPs. Also, fungi, mainly *Verticillium* sp., *Aspergillus flavus*, *Aspergillus fumigatus* and *Fusarium oxysporum* are competent for the NPs biosynthesis.

Applications of Nanotechnology in Agriculture

Numerous researches carried out over the last two decades, emphasizes on the varied applications of nanotechnology in agriculture sectors. Chemical application is pivotal in plant protection; however, their excessive usages irreversibly alter the chemical ecology of soil. Sustainable agriculture for environment protection and biodiversity conservation entails a minimum use of agrochemicals. Notably, nanoparticles enhance the efficiency of agricultural inputs to facilitate site-targeted controlled delivery of nutrients, thereby ensuring the minimal use of agrochemicals.

NP-Enabled Delivery Systems

Conventionally, agrochemicals are generally applied to crops by spraying or by broadcasting. Also, substantial losses occur due to leaching of chemicals, degradation by photolysis, hydrolysis and microbial degradation. Consequently, very small number of agrochemicals reach the target sites of crops. The nanotechnology-based slow or controlled release fertilizers, pesticides and herbicides release measured number of agrochemicals over a period of time and help obtain the full biological competency with minimum loss and harmful effects. NPs offer the advantages of effective delivery of agrochemical due to their large surface area, easy attachment and fast mass transfer. These particles are incorporated into the agrochemicals through capsulation, absorption, surface ionic or weak bond attachments and entrapment into the nano-matrix of active ingredients. Nanomaterials improve the stability of agrochemicals and protect them from degradation and subsequent release into the environment.

Besides agrochemicals, nano-biotechnology implicates nanoparticles, nanocapsules, and nanofibres for molecular delivery system to carry foreign DNA and chemicals for target gene modification. In genetic engineering, silicon dioxide NPs are used to deliver DNA fragments to the target species, without any undesirable side effects. In addition, NP-assisted delivery system is also used to develop insect resistant novel crop varieties. For examples, DNA-coated NPs are used as bullets in gene-gun technology for bombardment of cells or tissues to transfer the desired genes to the target plants. Contemporary advancement in NPs-based specific delivery of CRISPR/Cas9 sgRNA is also a notable achievement.

Nanomaterials in Plant Protection

Nanoparticles can be used for multiple plant protection purposes, such as pathogen detection (nanodiagnostics), pest control, weed control, pesticide formulation, induced resistance, etc. Application of different NPs like ZnO, AgNPs TiO2 and SiO2 have been found to effectively improve seed germination, increase biomass accumulation and water absorption potential of seeds, enhance net photosynthesis, grain yield, improve growth and tolerance to heat stress in various crops like *Hordeum vulgare*, *Glycine max*, *Zea mays, Coffea arabica*, *Triticum aestivum, Nicotiana tabacum* and *Oryza sativa.* These could also stimulate root nodulation and improve soil bacterial diversity in legumes like *Vigna sinensis*. Seed priming, foliar spray, mixing with growth substrate and pot soils and hydroponics are the most common modes of application of NPs to plants.

Metal oxide nanomaterials, such as CuO, ZnO, and MgO can effectively control many plant diseases caused by *Botrytis cinerea*, *Alternaria alternata*, *Monilinia fructicola*, *Colletotrichum gloeosporioides*, *Fusarium solani*, *Phytophthora infestans* and *Ralstonia solanacearum* in different plant species. ZnO nanoparticles have been shown to provide effective growth control of *Fusarium graminearum*, *Penicillium expansum*, *Alternaria alternata*, *F. oxysporum*, *Rhizopus stolonifer* and *A. flavus* as well as pathogenic bacteria *Pseudomonas aeruginosa*. Nano-Cu application was found to be effective against *Phytophthora infestans*. Si and TiO_2 are promising to suppress crop diseases directly, through inhibition of conidiation and antimicrobial activity.

Nanoparticles	Crop Species	Responses
ZnO, CuO and Ag NPs	*Prunus domestica*	Suppressed grey mold (B. cinerea)
Al2O3 NPs	*Solanum lycopersicum*	controlled Fusarium root rot in tomato
Ag NPs	*Vigna unguiculata*	in vitro growth inhibition of *Xanthomonas axonopodis* pv. *malvacearum* and *Xanthomonas campestris* pv. *campestris*
CuO	*Solanum lycopersicum*	controlled late blight *(Phytophthora infestans)*
MgO	*Solanum lycopersicum*	controlled bacterial wilt of tomato *(Ralstonia solanacearum).*

Development of nanocomposites of pesticides has further increased their efficacy and shelf life besides reducing the required dosage. The underlying mechanisms are largely explained by the increased enzymatic activity. For example, nanomaterials like nano-SiO_2 or nano-ZnO application increases the accumulation of free proline and amino acids, nutrients and water uptake, along with antioxidant enzyme activity of superoxide dismutase, catalase, peroxidase, nitrate reductase and glutathione reductase that improve plant tolerance to stress. In addition, nanomaterials could also regulate stress gene expression. Such NPs-induced responses are directly involved in plant protection against stresses.

Nano-formulation or encapsulation of pesticides is an emerging plant protection sector. These ensure the presence of active ingredients in minimum effective concentration at the target sites and reduce the total amount of pesticides required for pest and disease control; thus, reducing the expenses in crop production besides preventing environmental depletion.

Nanoformulation of pesticides contains a very tiny number of particles that act as active ingredients of pesticides. The nanoencapsulation of pesticides is the coating of active ingredients of pesticides with another material of various sizes at nano-range. These facilitate the controlled and effective release of active ingredients in root zones or inside plants.

The increased potential of dispersion and wettability of nanoformulations reduce organic solvent runoff and unwanted pesticidal movement. NPs in pesticide formulation show increased stiffness, permeability, thermal stability, solubility, crystallinity and also biodegradability that is essential for sustainable agro-environmental system. Thus, the nanomaterials in pesticides, fungicides and herbicides have a tremendous scope in sustainable agricultural development.

Nanomaterials as Nanosensors

Nanosensors are useful for the observation of environmental stress and enhancing the combating potentials of plants against diseases. The development of nanosensors to measure and monitor crop growth and soil conditions, nutrient deficiency, toxicity, diseases, and the entry of agrochemicals to the environment help to assure soil and plant health.

Nanosensors enable rapid and accurate detection of insects or pathogens for timely application of pesticides or fertilizers. For instance, a wireless nanosensor has been developed for detecting the insect attack based on emitted volatile organics. Nano-gold based immunosensor is effective to detect karnal bunt disease in wheat plants. Such nanosensors provide an easy and low-cost effective technology for the detection of specific pests.

Indeed, the assistance of nanotechnology in plant protection has exponentially increased, which may assure increased crop yield and sustainable agro-ecosystem.

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