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An Overview of Nanotechnology in Agriculture to Ensure Food Security and Sustainable Agriculture

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Abstract

Applications of nanotechnology can be found all over the world, and their number is quickly growing. According to a number of studies, the small size, high surface area, and catalytic nature of nanoparticle0s and nanostructures all contribute to arise in a variety of characteristics. The application of nanotechnology in agriculture ensures the safety of food supplies. An improvement in agricultural output can be achieved by microbial, insect, and weed management that is safe, secure, and inexpensive. Processing, stability, sensing, shelf-life, loss reduction, and food safety are all improved as a result of this. The post-harvest stability, safety and packaging are all improved thanks to nanotechnology. Food processing nanoparticles made of Ag, Zn, TiO_2, ZnO, SiO_2 and MgO have been shown to enter cells and cause damage to humans, animals, and plants.

Keywords: Agriculture, Fertilizers, Food security, Nanoparticles

Introduction

Due to its microscopic scale, nanotechnology allows for the observation and research of an important agricultural control mechanism. Numerous advantages, such as decreased agricultural inputs and increased uptake of nanoscale nutrients from the soil, pave the way for the widespread adoption of nanotechnology in the food production sector. Natural hazards, sustenance, sustainability, and quality of life are all intertwined with food production and agriculture. Nanomaterials are being developed in the hopes that they will increase agricultural productivity while decreasing the need for toxic herbicides through better insect and nutrient control. Innovative nano-tools for controlling and enhancing quick disease diagnosis have the potential to revolutionize the food and agriculture sector thanks to nanotechnology. Most notably, nanotechnology is being used in agriculture in the form of nano-fertilizers and nano-pesticides to test new products and increase productivity without cleaning up rivers, soils, pest-insect defense, and bacterial diseases. Concerns about climate change, food security, and sustainability have prompted scientists to investigate how nanotechnology can be used to improve agriculture. The sustained health of agricultural plants could be ensured by the use of nanotechnology-based soil quality sensors. Soil can better absorb nano-nutrients and food is safer to eat thanks to advancements in nanotechnology. Agriculture, food production, and the availability of natural resources all pose risks to human wellbeing. Nanomaterials improve crop yield while decreasing the need for chemical fertilizers and pesticides. Increased nutrient uptake and easier disease diagnostics are only two of the many benefits that plants experience through the application of nanotechnology.

This article focuses on how to use nanotechnology to improve the soil quality by creating nano-fertilizers, nano-pesticides, nano-biosensors, and other nano-enabled technologies and also look into the latest innovations in crop protection and agricultural practice using nanotechnology. Seeding at the nanoscale boosted the strength of materials, enhanced their optical qualities, altered their antibacterial potential, and exposed their amazing superconductive nature. Nanoscale objects can take many different forms, including nanotubes, nanoparticles, nanofibers, fullerenes,

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nanosheets, and nanowhiskers (Cushen *et al.*, 2012). Nanomaterials are defined by the US Food and Drug Administration (USFDA) as the "particles, in an unbound state or in the form of aggregate or agglomerate, where 50% or more of the particles in the number and size distribution, one or more than one dimension lies in the range of 1-100 nm". Nanotechnology has the potential to improve crop yields and reduce pesticide use by enabling the use of novel agrochemical agents and delivery systems. The use of nanoformulations of agrochemicals in the application of pesticides and fertilizers to improve crops; the use of nanosensors in crop protection for the detection of diseases and agrochemical residues; the use of nanodevices for plant genetic engineering; the diagnosis of plant diseases; the enhancement of animal health, breeding, and production; and the microbial harvesting of food, have increased the agricultural output with less usage of scarce resources like land and water with the help of precision farming techniques.

Application of Nanomaterials in Agriculture

Nanopesticides

Nanoparticles alter the persistence, mobility, and toxicity of pollutants in the soil. The fate and efficiency of nanomaterials are reliant on their interactions with soil. Nanoparticle soil remediation is primarily conducted in the laboratory. Growing "miracle seeds" using artificial aids like water, fertilizer, and pesticides has been called into doubt on both the scientific and political fronts. The vast potential of nanotechnology in agriculture has been limited by a lack of public investment. Unlike industrial nanoproducts, agricultural production operates as an open system where energy and matter can be freely exchanged. The input material demands are typically massive, and the use of nanomaterials cannot be entirely regulated, requiring consideration of their impact on the geosphere (pedosphere), biosphere (chlorophyll), hydrosphere (hydrosphere), and atmosphere (atmosphere) in a coevolving manner. New evidence reveals that nanotechnology has the potential to increase food supply and security by enhancing the efficiency of agricultural inputs and reducing the negative effects of agriculture on the environment. Despite research, nanotechnology's potential in agriculture has not yet been realized. The use of nanotechnology in agriculture has been advanced through government funding.

Nanofertilizers

Nanotechnology agrochemical agents and delivery technologies have improved agricultural production and pesticide application. Crop improvement, crop protection, plant genetic engineering, plant disease diagnostics, animal health, breeding, poultry production, and postharvest management are just some of the ways that nanotechnology is used in agriculture. Precision farming increases output with less environmental impact. Plants produce more food when chemical fertilizers are used. Crops that thrived with added chemical fertilizer required more of it. Chemical fertilizers increase expenses of production and environmental damage due to nutrient leaching and volatilization. 50-70% of nitrogen is lost in conventional fertilizers. As a result, researchers are probing several strategies for ensuring that nutrient use is sustainable. Reducing nutrient runoff from vehicles, creating slow-release fertilizers, and increasing nutrient accessibility are all possible thanks to nanotechnology (Kah *et al.*, 2019).

Nanobiosensors

E-noses are advanced sensors and AI systems built on nanotechnology. They have been put to use in farms to track yields and spot signs of pests or pollution in the ground or water. While nanotechnology has made precision farming safer, there is cause for concern about the widespread use of food and agricultural products made with nanomaterials and, less likely, immobilized nano-sensors.

Nanomaterials for Soil Remediation

When two powerful remediation strategies (nano-bio) are combined, it represents a significant step forward in the process of cleaning up organically contaminated soils. Recalcitrant organic contaminants can be dechlorinated/dehalogenated by highly reactive NMs, clearing the way for subsequent bioremediation, which is crucial for successful remediation. Bokare *et al.* (2010) investigated the potential of combining a reductive process utilizing palladium (Pd)/Fe with a bioremediation strategy to clean up a triclosan (2,4,4′-trichloro-2′-hydroxydiphenyl ether, TCS) contaminated solution (5 g l^{-1}). Pd/nFe catalyzed the quick reductive dechlorination of triclosan in the absence of oxygen, with 2-phenoxyphenol being the only by-product. Then, 2-phenoxyphenol was completely oxidized with the help of laccase enzyme isolated from *Trametes versicolor* and syringaldehyde, a natural redox mediator.

Effect of Nanomaterials on Soil Microbes

Soil quality can be gauged by looking at how microorganisms influence SOM dynamics and nitrogen cycling. The composition, diversity, and activity of soil microbes are all affected by NMs. Soil microorganisms are impacted by NMs because they increase the bioavailability of harmful chemicals. Exposure to nanoparticles may be harmful to soil microbes. When NM levels rise above a certain threshold, they can inhibit the growth of many soil microorganisms. This has major repercussions for the composition of microbial communities and their biomass. It has been proposed that biogenic NMs be employed to reduce soil nanotoxicity. Mishra *et al.* (2020) found that these NMs were less toxic to soil microorganisms than their chemically generated counterparts.

Nanomaterials in Plants

Nanoscale metal particles activate plant's antioxidant and ROS defense systems. Antioxidants are substances that prevent cell damage and slow the aging process (Singh and Lee, 2016). Superoxide dismutase converts superoxide anion into hydrogen peroxide, while catalase and guaiacol peroxidase neutralize reactive oxygen species and peroxy radicals, respectively. However, while ROS radicles produced by TiO_2 nanoparticles may cause photocytotoxicity, they may also activate the plant's antioxidant defense mechanism, which can then neutralize the free radicals. The globe is facing unprecedented problems due to climate change, land scarcity, population expansion, industrialization, low productivity, and post-harvest losses (Singh and Lee, 2016).

The Role of NM's in Ensuring Food Security

New agricultural, food, water, environmental, medical, energy, and electronic products are all within reach, thanks to nanotechnology. Nanotechnology is used in food technology both from the ground up and from the sky. Physically enforcing food and agriculture supplies from on above is possible. Most commercial nanomaterials are produced by reducing bulk precursors to nanoscale by "top-down" milling, nanolithography, or precision engineering.

Using nanomaterials expedites the breakdown of waste and harmful substances and increases the productivity of the microorganisms responsible for this process. Toxic substances, such as those found in agricultural chemicals, can be removed from soil and water through a process called bioremediation. Mycoremediation refers to the use of fungi and mushrooms, while phytoremediation refers to the use of plants; bioremediation refers to the use of helpful microbes; and so on.

Manufacturers have a responsibility to clearly label and package their goods because of how these characteristics affect the food distribution chain as a whole. Industry and academics face an ever-increasing challenge to develop intelligent gadgets that can provide actionable insights. Recent years have seen the introduction of "nanosensors" into several packaging components. Products and procedures to reduce oxidation have been developed by the food industry. The principle behind this is that a package's color change due to oxidation can reveal useful information about the food within. Milk and meat packaging have both benefited from this strategy.

Future Perspectives

NMs have been shown to be useful, and nanotechnology has been shown to be effective, in addressing a wide range of issues confronting the agricultural and food-processing sectors. Top-down procedures like grinding and ball milling are frequently used to prepare NMs. They are always made through chemical inference. Cutting-edge modern technologies facilitated the process of characterizing their physicochemical properties for potential applications. NMs' distinct physical and chemical features make them effective delivery methods for active compounds that require only a little amount to achieve their desired effect. Antimicrobial active components kill bacteria quickly and efficiently, seldom leading to resistance, and causing minimal harm to other organisms.

Conclusion

Nanofertilizers, nanopesticides, nanobiosensors, and environmental remediation are just a few of the ways that nanotechnology is used in farming. In agricultural and environmental sciences, questions remain about the ultimate destination and impact of nanoparticles. Collaboration amongst nanomaterials institutes is necessary if we're going to see nanoparticles that are effective, versatile, stable, cheap, and kind to the environment. This would wrap up the evaluation of the ecotoxicity, behavior, and fate of NMs. Some plant species might do better with NMs. Many plant species require extensive screening and optimization prior to commercial nanomaterial application. The efficiency of a nanomaterial is conditional on its stability and properties.

Nanofiltration, nanoscale enzyme-based reactors, nanoencapsulation for absorption and modification, heat and mass transmission, and nanofabrication are only some of the ways in which nanotechnology is used in the food sector. In the pharmaceutical industry, nanofiltration is an essential purification step for patient safety and for the effective removal of undesirable solutes. It is also used to purify water and dairy products by removing salt from lactose.

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