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Importance of Nanotechnology in Agriculture: A Review

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ABSTRACT: Nanotechnology is essential in the advancement of agriculture and farming products. Nanotechnology has the great capacity to enhance sustainable agriculture and, as a result, global food security Nanotechnology also aids in the improvement of crop output in agriculture by reducing input losses and ensuring efficient nutrient and water management. The primary substantial achievements of nanotechnology in agriculture are the innovation of Nano-based fertilizers and pesticides for enhanced crop production. The bulky use of fertilizers keeps agricultural productivity high. However, it has been elucidated this would have a serious environmental impact as well as a life-threatening effect on humans. This usually requires the need to modernize agricultural practices with safe and effective technologies that focus on increased agricultural production while causing less harm to the environment and humans. These include the advancement of nano-formulations of agrochemicals for increased crop yield and protection, as well as the research of the potential of nanoparticles as an effective alternative to agrochemicals. Another breakthrough in nanotechnology for agricultural production improvement is the development of cultivars resistant to various insects through DNA transfer method in plants or nanoparticle-mediated gene transfer respectively. The advantages of using nanoparticles in agricultural fields include reduction pollution, rapid disease diagnosis, a simple preparation process, reduced side effects, and cost-effectiveness. The green synthesis of nanoparticles using plant extracts has piqued the interest of many researchers because it is reproducible, biodegradable, and highly effective against a wide range of plant pathogenic microbes.

Keywords: Nanotechnology, sustainable agriculture, Nano-based fertilizers, nanoparticle-mediated gene transfer, and green synthesis.

INTRODUCTION

Agriculture and farming systems are becoming more concerned in recent years with sustainable production and the development of new disease-resistant crop plant varieties. Though the first green revolution sought to introduce high-yielding rice and wheat varieties, the rest of the world awaits the second green revolution as current agricultural sectors face new challenges. Scientists have developed a variety of new agricultural innovation technologies and strategies over the last several years. Many traditional methods for growing disease-resistant crops are accessible, but these methods will not always fulfill the actual need; as a result, scientists are looking for new and more convenient technologies to solve current agriculture-related issues. Agriculture plays a significant role in developing countries, with more than 60% of the population depending on agriculture for a livelihood. Department of Agriculture Scientists are reportedly facing numerous challenges, including decreased crop yield, decreased organic content in the soil, decreased nutrient utilization quality, multi-nutritional deficiencies, extreme weather events, declining arable land, and water availability, and labor shortage, in addition to people quitting farming. To solve these problems, we must explore novel technologies such as 'Nanotechnology,' as well as ensure sustainable agricultural growth. The agricultural industry has the potential to be helped transform by nanotechnology (Subramanian *et al.*, 2011; Dehkordi & Keivani 2017). In this regard, nanoparticles have appeared as a dependable solution for farmers. It's a novel agricultural research method that focuses on diagnosing plant diseases, increasing productivity, and developing disease-resistant types. Nanotechnology is gaining popularity due to its multidimensional applications in a variety of fields, which include plant pathology (Mazzaglia *et al.,* 2017). In Greek, the term 'Nano' is defined as 'dwarf.' Nanotechnology was originally discussed in 1959 in a talk given by Nobel Laureate Physicist Albert Einstein, titled "At the bottom, there's plenty of room." Richard Feynman proposed that a set of standard-sized robot arms construct a one-tenth-size clone of themselves, then use that new set of arms to construct an even smaller set, and so on until the molecular scale is reached. We could program millions or billions of such molecular-scale arms to work together to create macro-scale products built from individual molecules - a "bottom-up manufacturing" technique, as opposed to the traditional "top-down manufacturing" technique of cutting away material until you have a finished component or product. K. Eric Drexler coined the term nanotechnology in 1986. In general, the term nanomaterial refers to things that are measured in the one to hundred nanometers (nm) range (Rai *et al.,* 2012). Nanoparticles with sizes ranging from 1 to 100 nm have been found to perform a variety of biological functions. Because of its unique physicochemical properties such as small size and large surface area to volume ratio, high reactivity, changed molecular interactions, and so on, it is more efficient than its molecular and macro-scale counterparts (Wang *et al.,* 2016). The smallest creatures are called Nano organisms. The knowledge gathered from many applications could be put to use to transform food and farm technology. Nanotechnology is used in agriculture in the very same way it is used in other industries (Vijayalakshmi *et al.,* 2015). From microbes to humans, all organisms are propelled by highly evolved molecular and cellular machines that operate at the Nanoscale. For millions of years, nature has been performing 'Nanotechnological feats' Biological systems combine wet chemistry and electrochemistry in a single living system by arranging atoms and molecules. The more we learn about these naturally occurring Nanomachines, the closer we will be to creating new ones with different functions. This Nano-scale convergence of technology and biology is known as 'Nanobiotechnology' (Prasanna *et al.,* 2007). Nanotechnology is the future of advanced development (Tile *et al.,* 2016). Nanotechnology can be applied in a variety of fields, including biology, physics, chemistry, electronics, medicine, energy, material science, soil science, the environment, and health care. The Nano food market expanded quickly in the first decade of the 21st century. The use of nanotechnology in agriculture plays an important role because it tends to increase food value, minimizes agricultural inputs, helps to improve nutrient content, and expanded shelf life. Modern technologies, such as bio and nanotechnologies, can help farmers increase production and improve the quality of the food they produce. Many people believe that modern technologies will meet expanding global food demands while also providing a slew of environmental, health, and economic benefits (Wheeler *et al.,* 2008).

Major Challenges of Agriculture to be addressed by Nanotechnology:

1. Food security for an increasing population
2. In cultivable areas, productivity is low.
3. Less efficient agricultural inputs
4. Unsustainably managed farms
5. Vast uncultivated areas
6. Decrease in cultivable land
7. Product wastage
8. Short shelf-life/perishability
9. After-harvest losses (processing, packaging)
10. Diseases and climate change vulnerabilities as a result of global warming.

Current Status of Nanotechnology in Agriculture: Nanotechnology is a revolutionary technique in agriculture because of its capacity to deliver nutrients and pesticides in the right amounts, resulting in higher crop yields or nutritional qualities. Particle farming, wherein plants are cultivated in specific soils to produce nanoparticles for industrial use, is one of the most prevalent uses of nanotechnology in agriculture. Cultivating plants in gold-rich soil was used in a study to extract gold nanoparticles, and the plant tissues collected nanoparticles of gold, which were assimilated through the roots of the plants. After the plants were harvested, the nano particles of gold were mechanically separated (Kalaugher *et al.,* 2002). Studies on the effect of nanoparticles on plant growth and development have also been carried out. Some research reported a favorable effect, while others found a negative effect when nanoparticles were sprayed to plants. The size, concentration, and physical and chemical properties of the nanoparticles used, as well as their composition, influenced the plants' reaction (Siddiqui *et al.,* 2015). The use of calcium carbonate nanoparticles aided in the production of macro and micro aggregates in soil (Liu *et al.,* 2012). Nanotechnology can also be used to improve plant genetic material by delivering drug molecules and genes to precise locations at the cellular level in animals and plants (Kuzma *et al.,* 2007). Conventional fertilizers have been replaced with Nano fertilizers as a result of the usage of nanotechnology. Nano fertilizers tend to improve soil fertility, hence assisting in the elimination of eutrophication and groundwater contamination (Bhalla *et al.,* 2010; DeRosa *et al.,* 2010). The research was conducted on Nanohybrid Antifungals for Plant Disease Control, and the findings revealed that due to widespread diseases of fungal diseases and post-harvest diseases, creating sustainability principles and tools that do not depend on existing agricultural practices is critical. Nano-based technologies in agriculture have a lot of potential, development of powerful formulations that ensure optimal distribution of Agro - nutrients, pesticides/insecticides, chemicals, and even plant growth regulators for increased usage efficiency (Alghuthaymi *et al.,* 2021). After biotechnology, nanotechnology is the sixth revolutionary technology of the century. It showed a strong variety of applications in biology, agriculture chemistry, pharmaceutics, materials science, electronics, and physics. The socio-economic elements of preserving a good atmosphere for sustainable development are influenced by Ecological Nanoscience goods and processes. Nanotechnology is a broad and interdisciplinary field of research and development activities that are growing exponentially worldwide. Nanotechnology will provide the capacity to create affordable products with dramatically improved performance (Yadav, 2021).

Nanotechnological Developments in India: With over one billion people, a diverse socioeconomic base, and a vast landscape, India has enormous potential for any technological intervention, including nanotechnology. India has been slow to adopt and even slower to experiment with new technologies. This has occurred primarily because individuals, organizations, and governments have a low risk-taking capacity. Furthermore, due to a lack of communication with the rest of the world, confidence in the innovations has been low. Nanotechnology in India is a government-led initiative. Industry participation is a relatively new phenomenon. With a few exceptions, most nanotechnology research and development are carried out at publicly funded universities and research institutes (Bhagat *et al.*, 2015).

Nanotechnology for Detecting Plant Diseases: The need to diagnose plant disease at an early stage in terms of protecting tonnes of food from a potential outbreak has compelled nanotechnologists to seek a nano solution for protecting agriculture from bacteria, fungus, and viral agents. A detection method that takes less time and can provide results in a matter of hours, is simple, portable, and accurate, and does not require any complex and difficult technique to operate so that even a beginner's farmer can use the versatile system. It would be incredibly beneficial if autonomous Nano sensors linked to a GPS for real-time monitoring might be distributed throughout the field to monitor soil characteristics and crops.

Nanosensors: Nanotechnology, in the form of Nano sensors, can be used in agricultural production to monitor crop growth and pest control by detecting animal or plant diseases early. These Nano sensors have the potential to improve production and food safety. The sensors serve as external monitoring systems and are not consumed with the food. Nanomaterials can also be initiated into or on food. The effectiveness of pesticides can be improved by incorporating very small amounts in hollow capsules with nanometer diameters that can be designed to open only when stimulated by the presence of the pest to be controlled. Nano-sensors are capable of detecting contaminants, pests, nutrient content, and plant stress caused by drought, temperature, or pressure. The developed biosensor system is an effective tool for monitoring organophosphate pesticides and nerve agents on a real-time basis. Bioanalytical Nano sensors are used in agriculture and food systems to identify and quantify minute quantities of contaminants including viruses, bacteria, toxins, bio-hazardous substances, and so on. A large number of these toxins are still reviewed using conventional methods; however, biosensor methods are being developed as screening methods for use in field analysis (Tothill *et al.*, 2011).

Nano-Particles Control Plant Diseases: Carbon nanoparticles, silver nanoparticles, silica nanoparticles, and aluminosilicate nanoparticles are some of the nanoparticles that have entered the arena of plant disease control. Pesticides enclosed within nanoparticles are being developed with timed-release or release linked to an external stimulus. Herbicide could be applied only when needed when combined with a smart delivery system, leading to increased crop production and less injury to agricultural workers. Leading chemical companies are now having advanced Nano pesticides and Nano herbicides. One such effort involves the use of Alumino-Silicate nanotubes usually contain active ingredients. Encapsulation of pesticides, Pesticides with Nano-scale active ingredients are already on the market, and many of the world's leading agrochemical industries are conducting studies to find new Nano-scale pesticide formulations.

Nano Fertilizers, Nano Pesticides, and Nano Insecticides: Nanotechnology is a beneficial advancement that can also be used as a fertilizer alternative. Using Nano fertilizers instead of traditional fertilizer applications will provide a new technique to release nutrients into the soil gradually and in a regulated manner, avoiding eutrophication and polluting of water resources. A large surface area to volume ratio allows for better and more effective nanoparticle engagement with target areas. Nano-fertilizers have the potential to meet plant nutrition needs while also ensuring crop production systems' sustainability, all without affecting crop yield (Kumar *et al.*, 2021). NFs have the potential to improve overall crop production and promote sustainable agriculture by boosting the nutrient utilization efficiency (NUE) of field and greenhouse crops. When used alone or in combination with synthetic or organic fertilizers, NFs can release nutrients at a gradual and constant rate (Seleiman *et al.*, 2021). Recent studies on Nano fertilizers towards sustainable agriculture and the environment focuses on the design, contribution, and interaction of Nano-enabled fertilizers with edible plants based. Because current agricultural practices rely heavily on chemical fertilizers, precise nutrient management of crops and soil fertility will be a major challenge worldwide in the coming decades. The use of conventional fertilizers results in low crop nutrient efficiency, negative environmental impacts, and high water body loss. Nano-biotechnology is emerging as a promising alternative technique with the potential to transform agricultural systems by delivering nutrients to crops in a controlled release manner. Engineering nanoparticle-based Nano fertilizers improve crop nutrition management by increasing abiotic stress tolerance and increasing agricultural productivity (Al-Mamun *et al.*, 2021). In recent years, the agricultural system has been plagued by various insect and pest invasions, which have reduced crop output and resulted in significant financial losses for farmers. Because of their toxicity, traditional pesticides and insecticides have several negative effects on the environment and agriculture. Because of their low transfer capacity, most pesticides and insecticides are unable to prevent insect assaults. Chemical pesticides also raise the cost of agricultural yield, produce toxic byproducts, and impair soil biodiversity, all of which are hazardous to plants and soil-dwelling microbes. To address this problem, agricultural research is concentrating on developing a novel plant protection formulation with fewer side effects and more activity. Tinosporacordifolia Ag nanoparticles, for example, displayed potential insecticidal action against Culex quinquefasciatus and Anopheles sub pictus larvae (Kah *et al.,* 2013). The use of Nano pesticides increased crop productivity by enhancing the pesticides' transport potential. The use of Nanocapsules containing the pyrethroid bifenthrin enhanced the transport capacity of various biofertilizers including Ca^{2+} and Mg^{2+} cations (Petosa *et al.,* 2017). Furthermore, using Nano pesticides and Nano insecticides minimizes the chemical dose and produces better results. Azadirachta indica, Ocimum spp., Citrus lemon leaf extracts, Acacia gum, and Punica granatum are all recognized to have insecticidal and pesticide properties (Ghidan *et al.,* 2017).

Nanoparticles: as Molecular Approach: The combination of biotechnology and nanotechnology results in the development of a new tool for gene transfer and drug delivery. Researchers have successfully used Nanofibers, Nano capsules, and nanoparticles to manipulate gene expression (Agrawal *et al.,* 2014). During the transfer of genetic material, the conventional gene transfer method using bacteriophages faces several challenges. The use of nanotechnology to transfer genes is more convenient than using viral vectors to transport genomes. Besides this, it has been used in many plant species to replace the existing genome (Torney *et al.,* 2007). In addition to ethylene glycol, DNA-coated Ag nanoparticles have been used to successfully transfer plasmatic DNA into the isolated protoplast of the petunia plant (Rad *et al.,* 2013). The CRISPR/Cas9 system is a revolutionary invention in molecular biology that will forever change biotechnological procedures. CRISPR/Cas9 is an RNA-mediated genome editing system made up of 2 parts: a short stretch of repeated sequence and the Cas9 protein. The nanotechnology transfer of CRISPR/Cas9 single guide RNA (sg-RNA) attendants in a new era of plant disease management (Miller *et al.,* 2017)The use of nanoparticles in the delivery of the CRISPR/Cas9 increases significantly its specificity and efficiency for target genome editing (Mout *et al.,* 2017). Chitosan is a natural biopolymer with a wide range of bioactivities, including antimicrobial properties against a range of pathogens microbes. Chitosan nanoparticles are strong candidates for drug delivery and genome transfer because their transfection efficiency can be modified with various chemical agents such as polyethylene glycol (PEG). One additional benefit of using chitosan nanoparticles is their ability to rapidly bind to RNA and cross the plasma membrane, making it a great gene transfer vehicle. Chitosan nanoparticles can transfer siRNA, improving disease tolerance in crop plants against a range of different pests and pathogens (Zhang *et al.,* 2010; Gaur *et al.,* 2020). In maize, MSNs are used to transmit Cre recombinase, which is accurately recombined in the chromosomal DNA by lox P (Martin-Ortigosa *et al.,* 2013). Carbon nanotubes were recently used for si-RNA mediated gene silencing in Triticum aestivum, Nicotiana benthamiana, Gossypium hirsutum, and Erucasativa. In Nicotiana benthamiana, si-RNA mediated gene silencing has occurred in 95% of the situations (Demirer *et al.,* 2018).

Nanotechnology in Agriculture. Natural processes will be recreated in increasing scientific sophistication for the successful implementation of nanotechnology applications in agriculture (Rani *et al.,* 2020). To manage the nutrient application with nanomaterial's, two important parameters must be considered: the ions that are intended to be supplied must be present in plant-available forms in the soil system, and while nutrient transport in soil-plant systems is based on ion exchange, solubility-precipitation, and adsorption-desorption, nanomaterial's application must contribute to processes that make nutrients available to plants in a timely and efficient manner. Because clay minerals control these reactions, they could be utilized as receptacles. In hydrogel form, nanomaterials carrying plant nutrients can be employed in the early detection of plant disease and pathogens, food processing, packaging, and agricultural and food system security monitoring. The use of Nano-fertilizers instead of conventional fertilizers may eliminate eutrophication and contamination of drinking water (Bhalla and Mukhopadhyay, 2010; Mukhopadhyay and Sharma, 2013). As the global demand for food, energy, and water continues to rise, it becomes a major concern, and the interdependence of the three components becomes more complex (Cai *et al.,* 2018).

Big challenges of the field of agriculture that are to be addressed under the nanotechnology discussion forum:

1. Cultivable area output and yield are lower
2. Food security problems for growing populations
3. Less agricultural input efficacy
4. Unsustainable farming managements
5. Vast uncultivated lands
6. Reduction of cultivable areas
7. Depletion of products
8. Low shelf life
9. Post-harvest losses
10. Global warming effects.

Nanoscale nutrients (metals, metal oxides, carbon) are used to decrease crop disease by requiring less input and producing less waste than conventional products, resulting in improved plant development and output. By directing this increased yield, pathogen development is reduced while the nutritional value of the nanoparticles is increased for the key micronutrients required for host defense (Kumar *et al.,* 2021). Plant-microbe-engineered nanoparticles (PM-ENPS) are more efficient, less hazardous, and less expensive than physically and chemically manufactured nanoparticles in bio-nanotechnology. Because of electrostatic interaction with microorganism cell membranes and electrostatic interaction build-up inside the cell cytoplasm, plant-microbe-engineered nanoparticles have high antimicrobial activity (Dhiman *et al.,* 2021).

Role of Nanotechnology in Agriculture: Plant trait enhancement to ecological infection and stress; field-sensing devices that monitor plant conditions and environmental stress; pesticide delivery systems that enable for the targeted delivery of pesticides, fertilizers, and herbicides; increased production rate and crop yield; increased resource efficiency; and waste reduction are just a few of the applications of nanotechnology in agriculture (Marchiol *et al.,* 2018). Agrochemicals can now be encapsulated or incorporated into a matrix of polymers, metals, carbon-based materials, micelles, liposomes, and other substances known as agro Nano chemicals. Nanotechnology also enabled the controlled release of active ingredients and site-specific delivery, demonstrating its potential to be a game-changer in the advancement of integrated pest and disease management (Maluin *et al.,* 2020). To create powerful antifungal drugs, three chitosan-based agro nano fungicides systems were synthesized: chitosan-hexaconazole nanoparticles (CHEN), chitosan-dazomet nanoparticles (CDEN), and chitosan-hexaconazole-dazomet nanoparticles (CHDEN). Pure fungicides were fully released in 4 hours, whereas all systems demonstrated a regulated release with a release duration of up to 130 hours. In vitro and in vivo studies have shown that incorporating fungicides into the chitosan matrix significantly reduced and suppressed the basal stem rot disease in oil palm, with four times lower half-maximal effective concentration (EC_{50}) and up to 75 percent disease reduction. Furthermore, phytotoxicity, cytotoxicity, and genotoxicity experiments on chitosan-based agro nano fungicides indicated the superiority of the chitosan nanoparticles, which operate as a protective wall to mask the fungicide's damaging effect on oil palm seedlings, cells, and DNA (Maluin *et al.,* 2020). The use of SiO_2 and ZnO nanoparticles, for example, enhances amino acid and free proline accumulation. They can increase nutrient and water absorption as well. The usage of these nanoparticles boosts the activity of antioxidant enzymes such as superoxide oxidase, catalase, and peroxidase, as well as nitrate reductase, allowing plants to withstand abiotic stress (Siddiqui *et al.,* 2014; Sun *et al.,* 2020). Contaminants such as food allergies, mycotoxins, and pesticide residue have been assessed utilizing magnetic nanoparticles integrated immunoassays in food safety applications (Khan *et al.,* 2019). In pesticide detection, several enzyme-based biosensors have been utilized in conjunction with various nanomaterials. Nanomaterial's biosensors improve analytic responsiveness, sensitivity, and selectivity. Some of the most commonly employed enzymes in pesticide detection biosensors are acetylcholinesterase, organophosphate hydrolase, and lactase. In the presence of pesticides, which operate as enzyme inhibitors, the basic mechanism underpinning pesticide detection utilizes enzyme-based biosensors to lower the catalytic activity of these enzymes (Rawtani *et al.,* 2018).

CONCLUSION

Nanotechnology in agriculture had already forever changed agricultural methods over the last few decades. Some of the benefits of using nanoparticles in agricultural fields encompass rapid disease detection, disease diagnosis, nutrient enrichment, disease suppression, real-time monitoring of cultivated fields, and waste reduction. The primary objectives of sustainable agriculture are to reduce environmental pollutants and increase crop yield. Engineered nanoparticles and biosensors collaborated to create a new tool for rapid pathogen detection. The use of green prepared particles reduces the chance of environmental pollution while improving the efficiency of bioactivity.

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Conflict of Interest. None.

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