NANOTECHNOLOGY IN AGRICULTURE

Abstract

Nanoparticles are not a recent occurrence in nature; they can be found in nature in the form of minerals, clays, bacterial byproducts etc. Apart from various perspectives of nanotechnology, it plays a crucial role in agriculture. Conventionally, chemical fertilizers, herbicides, pesticides etc. are heavily applied in agriculture to sustain production, which have major adverse effects on the environment including human health. Again, as a result of pest infestation, microbial attacks, natural catastrophes, low-quality soil, and unavailability of nutrients, a third or so of crops are cultivated traditionally which suffer harmful effect. Abiotic stresses like stress caused by salinity and drought, and flood stress are major concerned issues including critical issues like the increasing continuous food demands due to expanding global population. All of these issues cannot be mitigated by using the conventional procedures. Consequently, there is a pressing need to look for better options. Nanotechnology's use in this context has the potential to revolutionise agriculture's transition to sustainable practises. Using a range of nanoparticle-based approaches, including nano-sized pesticides, herbicides, fungicides, fertilisers, sensors, etc., it has been thoroughly studied how to preserve plant health and soil. Although nanoparticles have been effectively applied to plants as fertilizers or to promote plant development, little is understood about the mechanism by which nanoparticles migrate across the cell walls. This chapter summarises current efforts to implement cutting-edge nanotechnology in agriculture in diverse directions including socio-economic issue, challenges, which may make it easier to meet the rising need for sustainable food production.

Keywords: *Nanotechnology, Nanoparticles, Agriculture, Nano pesticide, Nano fertilizer, Nano herbicide*

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I. INTRODUCTION

The myriad applications of nanotechnology in various sectors have garnered a lot of attention in diverse fields like medicine, pharmaceuticals, catalysis, agriculture, energy, and materials in recent years. Nanoparticles have the size in the range from 1 to 100 nm. Scientists have made substantial efforts to create nanoparticles utilising various methods, including physical, chemical, and biological ones. Additionally, plant extract-based green methods for creating nanoparticles offer many benefits, including being rapid, simple, and safe for the environment [1]. The potential for improving fertilization, plant growth regulators, and insecticides in agriculture could be increased by using nanomaterials produced using sustainable ways. The emergence of a new class of agrochemicals with the goal of lowering adverse environmental effects while preserving crop yields is made possible by the rapid transformation of agriculture and agricultural production brought about by nanotechnology [2]. Nanomaterials in agriculture constitute one of the most cutting-edge methods for protecting crops due to their potential use as nanopesticides or as nanocarriers or as nonherbicides for active substances. In addition, the possibility of creating highly advanced nanometric materials out of agricultural and industrial wastes allows for the combination of nanotechnology and the circular economy idea [3]. The biggest worldwide worry facing humanity is how to ensure food security for the rapidly growing global population. Chemical fertilizers and insecticides are widely used in agriculture to sustain production. However, it has been observed that a major negative influence on the environment and poses threat to human life exists [4]. This necessitates the need to modernise agricultural methods with the safest and most efficient technology that concentrate on increased agricultural output with little negative impact on the environment or people. Nanoparticles serve as an effective pesticide substitute and are used to create new agrochemicals that improve crop protection and productivity. [5].

In this chapter, we talk about the various perspectives and significance of applying nanotechnology in agriculture and also discusses how various nanoparticles are applied in agricultural fields to increase production including socio-economic effects and various challenges faced by scientific community (Figure: 1).
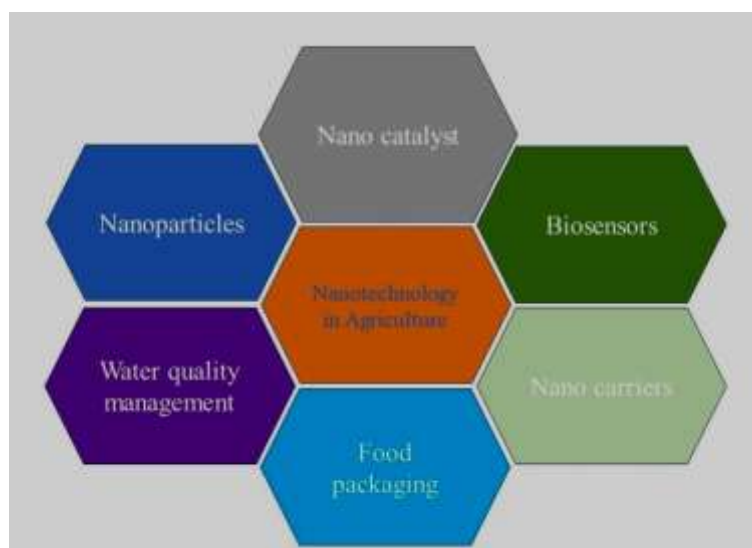
**Figure 1:** Nanotechnology in Agriculture

II. FUNDAMENTALS OF NANOTECHNOLOGY

Nanomaterials are characterised as synthetic or natural substances with a typical size between 1 and 100 nm. Nanotechnology is an interdisciplinary branch of research that combines the fields of chemistry, engineering, physics, and materials science etc. It is a branch of science whose major goal is to create nanoscaled materials with precise shapes, sizes, morphological characteristics and various industrial methods of synthesis [6]. Materials can display peculiar physical, chemical, and biological traits at the nanoscale. These features could be fundamentally dissimilar from those of individual atoms and molecules as well as bulk materials. These materials have exceptional functional, magnetic, optical, electrical, and mechanical properties [7]. The bulk properties of materials usually alter significantly when nano components are added. The strength of composite materials made from nanoscale ceramic or metal particles can unexpectedly exceed that predicted by existing materials science models. [8]. Nanoparticles have a significantly larger surface area than the same mass of material produced in a larger form. As a result, the material's strength or electrical properties could change, and its chemical reactivity could be increased (in some cases, materials that are inert in their larger form turn reactive when formed in their nanoscale form) [9]. Particularly at the lower end of the nanoscale, quantum phenomena may begin to dominate the behaviour of matter, influencing how materials behave optically, electrically, and magnetically [10]. Researchers from all over the world have been looking at various synthesis routes for nanomaterials, including physical, chemical, and biological techniques. There are significant worries over the release of dangerous toxic byproducts that typically accompany the synthesis process, despite the considerable control that can be exerted over the size and structure of nanomaterials through chemical and physical synthesis approaches [11]. Nanoparticles are used in a wide variety of fields such as nano cables, nano transformer, nano insulators, nano based rectifiers, nano powders [12], nano engineering materials, nano sic arrestors [13], nano ZnO arrestors, nano capacitor-based microphones, utilising nanotechnology in receivers, nano alloys, nano electrets, nano thermo-electric materials nano nuclear engineering, nano medicines etc [14].

III. APPLICATION OF NANOTECHNOLOGY IN AGRICULTURE

There are a large number of applications of nanotechnology in different fields. Here, we will focus on agriculture. Agriculture-related uses of nanotechnology are intended to boost output and safeguard crops while reducing any possible negative effects on the environment. In agriculture, "smart" delivery systems made of nanomaterials can precisely release nutrients or medications, improving plant health and yield [15]. For instance, nano sensors are used to track soil quality and spot pests or illnesses, enabling prompt and targeted treatment. Polymeric nanoparticles are employed to deliver agrochemicals slowly and precisely in the agriculture sector [16]. Greater biocompatibility and reduced impact on organisms not intended to be harmed are two advantages of polymeric nanoparticles. Some of the polymeric nanoparticles are employed in agriculture, include polyethylene glycol, poly(epsilon-caprolactone) etc [17]. Silver nanoparticles have been discovered to encourage plant development [18]. Graphene, graphene oxide, carbon dots, and fullerenes are just a few examples of the carbon nanoparticles that are used for enhanced seed germination. [19]. Other nanoparticles those are utilised in agriculture include magnetic copper oxide, and zinc oxide nanoparticles etc [20]. In case of crop productivity, researchers able to greatly rise crop production by using nano pesticides and nano herbicides for weed and pest management including nano fertilizers. The formulations for nano herbicides use a variety of nanoparticles

includes inorganic and polymeric nanoparticles. Additionally, nano-encapsulation of fertilizers and pesticides increases the effectiveness of managing nutrients and pests by lowering the overall amount of these chemicals required and limits their discharge into neighbouring ecosystems [21]. For instance, the pesticide atrazine is enclosed in poly (epsiloncaprolactone) nanoparticles. This nano capsule demonstrated effective control of the targeted species, a low level of genotoxicity, and the ability to considerably limit atrazine mobility in soil [22]. Each year, microbiological (virus, fungus, and bacteria) illnesses cause significant losses in the agriculture sector. To stop microbial invasions, certain antibacterial nanoparticles are used. Some of the common pathogenic fungi that cause infections are Colletotrichum gloeosporioides, Fusarium oxysporum, Fusarium solani, and Dematophora necatrix. [23, 24]. Many nanoparticles, including copper and nickel ferrite nanoparticles, have potent antifungal properties and are utilised to manage illness [25]. Nanoparticles of chitosan, zinc oxide, and silica are helpful in the treatment of viral infections, such as the mosaic virus for tobacco, potatoes, and lucerne [26]. Hence, we could tell that nanotechnology has greatly influenced the agricultural field in diverse ways (Figure: 2).
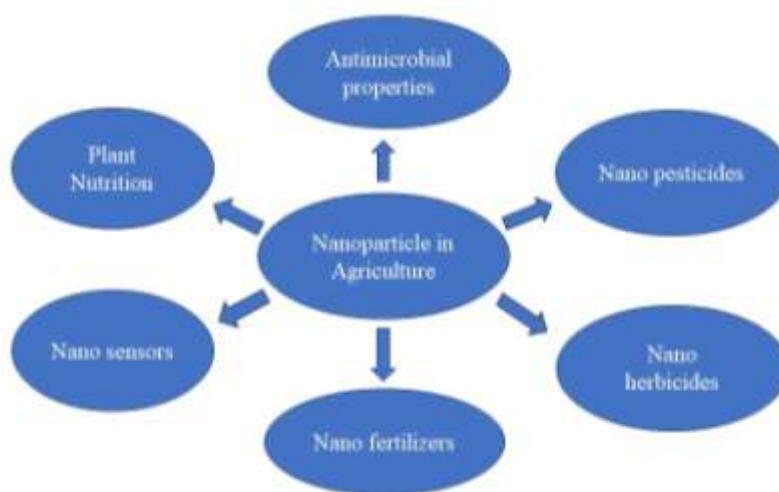
Figure 2: Applications of Nanoparticles in agriculture

IV. INTERACTION OF NANOPARTICLE WITH PLANT

Agriculture is able to gain from the creation of more effective and less harmful agricultural chemicals (nanoformulations), devices that detect biotic or abiotic stresses before they have a negative impact on production (nanosensors), or using novel genetic manipulation approaches that increase the efficiency of plant breeding schemes (nanotechnologies) [27]. Plant uptake of nanoparticles is influenced by various aspects, including the nature of the nanoparticle itself, as well as plant physiology and the interaction of the nanomaterials with the environment. The characteristics of a nanoparticle will have a huge impact on how it acts and, consequently, whether a plant can absorb it [28]. Nanoparticles can change in terms of their characteristics for being digested by plants as a result of interactions with other environmental elements. Once inside the plant, nanoparticles can travel across tissues using one of two methods: *through the apoplast and the symplast* [29]. While symplastic transport involves the movement of water and substances between adjacent cells' cytoplasms via specialised structures known as plasmodesmata and sieve plates, apoplastic transport occurs outside the plasma membrane via extracellular spaces,

adjacent cell walls, and xylem vessels. [30]. The apoplastic channel is crucial for radial movement inside plant tissues and enables nanoparticles to gain access to the vascular tissues and root central cylinder for continued ascent of the aerial portion. Tracing the transpiration stream, nanoparticles can migrate through the xylem and towards the aerial region after entering the central cylinder. The movement of nanomaterials throughout plants are really important since it can provide clues as to which parts of the plant they can enter and potential final destinations and accumulation sites [31]. In addition to the varieties of plants, the properties and nature of the nanomaterials will significantly alter how they are conveyed and accumulated in plant tissues. Nanomaterials must be internalised by the plant cell and pass the plasma membrane in order to move via the symplastic pathway. Despite the fact that plant cells and animal cells each have a different level of understanding of these mechanisms, nanoparticles can accomplish this in a number of different ways [32, 33].

1. **Endocytosis:** The nanoparticles enter the cell through invagination of the plasma membrane, causing the development of a vesicle that can travel to different cell compartments [34].

2. **Pore formation:** Plasma membrane disruption is possible with several nanomaterials, causing pores to form which enable them to enter the cell and get to the cytoplasm without being enclosed in any organelle [35].

3. **Carrier proteins:** Proteins in the area can bind to nanoparticles, including cell membrane proteins, which may serve as carriers for internalisation and uptake inside the cell [32, 36].

4. **Plasmodesmata:** Nanomaterials can also infiltrate cells through plasmodesmata, which are specialised structures for transporting materials between cells. Of course, the nanoparticles must already be in the symplast, yet this method is critical in plants for translocation across the phloem [37].

5. **Ion channels:** These have been suggested as probable entry points for nanoparticles into cells. However, the size of these channels is about 1 nm, making it exceedingly unlikely that nanoparticles will be able to traverse them successfully without significant alterations [32, 33].

V. DETECTION OF PLANT DISEASES

Nanomaterials are important in a range of fields, including life science, electronics, and chemical engineering, because to their distinctive and adaptable physicochemical features. Due to the necessity to create efficient miniaturised strategies for improving seed germination, development, and plant protection against abiotic and biotic stresses, nanotechnology has recently attracted interest in plant research. In order to effectively control and manage illnesses and reduce crop loss, early and effective disease detection is critical [38-40]. The most popular nanoparticles often used for molecular detection are gold nanoparticles, magnetic nanoparticles, and quantum dots. Gold nanoparticles are commonly utilised in quick immunological testing due to their specific physiochemical properties, such as small size, surface effect, and catalytic effect. They have a significant application value in DNA identification and detection and can also interact with nucleic acids via an Au-S covalent connection. In order to protect crops against pandemic diseases, the cutting-edge

discipline to diagnose, treat, and prevent plant diseases and their pathogens early on, nano-phytopathology uses nanotechnology. [41, 42]. The modern plant pathologist works to put his study of nano phytopathology to use in developing and/or evaluating eco-friendly diagnostic tools as well as understanding the governing variables of plant diseases. To monitor or comprehend pathogen population genetics, plant-microbe interactions, and gene transfer between pathogens and even the host, modern nano molecular techniques are applied. In addition, nanoparticles such nanosized silica-silver have lately been used to develop antibacterial and antifungal medications. [43]. Additionally, nanomaterials can be used for mycotoxin detoxication, plant resistance enhancement, disease prediction, and nano-molecular diagnostics of plant pathogens. When looking for proteins or nucleic acids, the bio-barcode assay is highly sensitive. Magnetic gold nanoparticles (AuMNPs) tailored with oligo nucleotides are used in DNA bio-bar coded testing to amplify the signal and quickly separate a target protein from the sample. The considerable signal amplification is made possible by the high b-DNA-to-recognition agent ratio. It is particularly hopeful since, under ideal circumstances, it permits the quick detection of a variety of protein targets at low concentrations and nucleic acids at high-zeptomolar quantities. [44-46]. The bio-barcode assay is a novel idea that offers a potential substitution for the PCR (Polymerase chain reaction) method. Currently, research is concentrated on the use of nanotechnology for quicker, less expensive, and more precise methods of diagnosing plant diseases. In the coming years, this technology will have a significant impact on Indian agriculture. Utilising technology responsibly will create chances for the creation of novel materials and techniques that will improve our capacity to create analytical systems that are quicker, more dependable, and more sensitive [47, 48].

VI. FOOD SECURITY AND THE USE OF NANOTECHNOLOGY

Around the world, people are very concerned about issues related to food security and safety. With the use of nanotechnology, there will be fantastic chances to increase agricultural output and improve food safety [49]. In order to improve food security, nanotechnology must be relevant to every link in the food chain, from farm to fork. Inputs for framing, the framing production system, postharvest management, processing, markets, and eventually consumers are the components. [50]. Nanotechnology enables us to lower overhead costs, increase output value, boost rural incomes, and improve the standard of the natural resource base of the agricultural production system. [51].

1. **Food Production:** Food security depends on there being enough food available. Applying nanotechnology at the frame level can improve food output. The notion of precision farming, in which productivity can be optimised while giving inputs and conditions only at precisely the right levels necessary, can be expanded by nanotechnology-based biosensors placed in agricultural fields and in plants to monitor soil conditions, growth, and disease factors. [52, 53].

2. **Food Safety:** To ensure food safety, all food products must be shielded against contamination during processing, handling, and distribution by chemicals, biological agents, physical hazards, and radiation. Nanosensors made using nanotechnology allow for quick testing of raw and processed food products in the plant and during transportation. [54, 55].

The food processing business uses nanoparticles to increase the stability of the food and preservation of food colour. Silicate nanoparticles can limit moisture loss and oxygen flow in packaging containers. This guarantees that the food stays fresh for a longer period of time. Numerous nanoparticles have the ability to selectively bind to infections, which can then be completely eliminated. The growth of biofilms can be prevented by using nanoparticles [56]. An impenetrable barrier is created by biofilms, which are collections of closely spaced bacterial cells adhered to a variety of surfaces. These biofilms cause issues such buildup, biofouling, and biocorrosion in the food processing sectors. Against several Gram-positive bacteria, glycerol monolaurate has antibacterial properties. Three separate strains of MRSA (Methicillin-resistant Staphylococcus aureus) and S. aureus are prevented from forming biofilms using this technique. Essential oils are an example of an organic compound that has antibacterial properties but is also quite susceptible to extreme physical conditions. But inorganic nanoparticles exhibit potent antibacterial activity at low concentrations and are more durable under harsh environments. As a result, manufacturers have recently expressed a strong interest in employing these nanoparticles in food packaging that is antibacterial [57-59]. Extreme environmental conditions frequently lead to the degradation and eventual inactivation of bioactive substances found in food. Because these bioactive components can lengthen the shelf life of food goods by slowing down or halting the process of degradation until the product reaches the target site, nanoencapsulation of these bioactive ingredients is crucial. For instance, curcumin, a therapeutic component from Curcuma longa (turmeric), becomes stable at different ionic strengths when it is encapsulated [60, 61].

VII. SOCIO ECONOMIC ISSUES OF AGRICULTURAL NANOTECHNOLOGY

A chemical, industrial, and corporate agri-food system is becoming entrenched by the use of nanotechnology in high-tech farming methods. While embracing new technology is important, it is also our responsibility to monitor how these materials are being used in various fields. In a socioeconomic setting where various experiments are continually being conducted, food is a crucial component. Without a solid foundation in science and technology, sustainable economic progress would never be feasible [63-66]. Because of its robust communication channels with other industries, the nanotechnology industry is playing a significant role in economic development. The nanotechnology sector is thought to be at the centre of the coming unstoppable technological revolution, and it significantly contributes to the expansion of the world economy [67, 68]. Scientists, researchers, investors, and legislators worldwide are aware of nanotechnology's tremendous power because it has several applications in all industries. In the current global economy, highly developed nations are engaged in parallel and complementary nanotechnology competition with one another. Nanotechnologies will promote a new wave of industrial expansion that will increase existing resource and energy consumption, as measured by economic growth, better health and longevity, environmental protection, increased security, and improved human capabilities [69-72]. Our above discussion enables us to comprehend that whatever nanoparticles we use in the agriculture sector will originate from an agricultural field and travel from there to a main producer and customer. Thus, it will disrupt the ecological system as a whole, which could affect environmentally friendly practises. This knowledge will assist us in thinking about future social and environmental sustainability in addition to food quality preservation.

VIII. THE CHALLENGES OF NANOTECHNOLOGY IN FOOD AND AGRICULTURE SYSTEM

There are a lot of challenges of nanotechnology in food and agricultural systems. Achieving the necessary scale and quality for the production of nanomaterials is the one most challenging part in agricultural nanotechnology [73, 74]. The provision of nanomaterials in a manner that would enable integration into the processes (such as the appropriate particle size, surface chemistry, compatibility, etc.) depends on a number of factors, which is also a difficult component. Due of their varied characteristics and behaviours, the hazards carried out by nanomaterials to human health and the environment are difficult to evaluate [75]. Even nanoparticles with the same chemical content but various sizes or shapes may demonstrate dramatically diverse toxicity because the size, shape, and charge of these materials alter their kinetic (absorption, distribution, metabolism, and excretion) and hazardous qualities. [76]. The usage and disposal of nano goods and materials in food and agriculture must take environmental health and safety considerations into consideration strictly. Another difficulty with nanotechnology, as with many other technologies, is the distance between fundamental research and implementation [77]. In addition, significant risks are associated with using nanotechnology in agriculture. There is no way to know for sure if these nanotechnologies are harmful or fully safe for health. [78]. Prior to making any choices, it's crucial to consider the dangers associated with farmers' prolonged exposure to nanomaterials, their illogical life cycles, interactions with the biotic or abiotic environment, and any potential increased bioaccumulation consequences. [79, 80].

IX. CONCLUSION AND FUTURE PROSPECTS

The application of nanotechnology could enable quick advancements in agricultural research that would produce enormous quantities of seeds and fruits without regard to the time of year. India will face significant challenges in the future, particularly as a result of both global population growth and climate change. The use of nanotechnology in agriculture enhances soil health and agricultural practises. Actually, using nanoscale transporters and chemicals can increase the effectiveness of fertilizers and pesticides, reducing the amount that needs to be sprayed while preserving production. Increased input effectiveness, balanced crop nutrition, and weed-controlling nano-herbicides, nano-insecticide, smart delivery systems, nano-devices for identity preservation, the nano-food industry, environmental safety and sustainable farming, among others, are all possible under the influence of nanotechnology. The agricultural industry will be assisted in its fight against viruses, spores, and other crop pathogens. The efficiency of insecticides and herbicides will be improved by nanostructured catalysts, enabling the use of measured doses when needed. Utilising nanoscale technologies, agricultural systems may become intelligent in the future in order to combat hazards and environmental effects on human health, including plants.

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