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Nanotechnology in Agricultural Applications- A Review

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Abstract

Nanotechnology can help increase agriculture production sustainably by making better use of agricultural products and decreasing by-products harmful to the ecosystem or human health. The use of nanotechnology raises expectations for increasing farming output by tackling issues that cannot be handled in a traditional way. Through processes such as targeted delivery, slow/controlled release, and conditional release, nanostructured formulations could more exactly release their active components in reaction to environmental cues and biological demands. According to studies, the use of nano fertilizers increases nutrient use efficiency, reduces soil toxicity, minimizes the possible negative impacts of overdosing, and lowers the frequency of application. This review provides a comprehensive overview of significant applications in agriculture and food production including nanotechnology in seed science, weed control, nutrition, pesticides, and disease control among others. Additionally, future applications and possible risks are also discussed.

Keywords: *Nano technology, Nutrition, Pesticides, Seed Science, Weed Control*

1.0 Introduction

Nano technology offers the potential to raise food supply stability for consumer and producer security, increase the effectiveness and standard of cultivation and food storage, and introduce new usefulness (value-added items) for food, fiber, and agricultural commodities. New research areas and applications made possible by nano technology include DNA chips, protein identification and modification, inventive films based on nucleic acid engineering, and smart DNA transport employing gold nanoparticles. Specific chemicals, structures, or microbes can be recognized using magnetic nanoparticles that have been linked to the relevant antibody. Nano technology has the potential to revolutionize a wide range of disciplines, including water resources, energy transmission, safety and security, biology, agriculture, and environmental engineering. By resolving previously unsolved problems that were previously unsolved and working with the tiniest elements conceivable, nano technology is increasing hopes for an improvement in agricultural output[1]. Previous studies show that employing Nano fertilizers improves nutrient usage efficiency, lowers soil toxicity, reduces the possibility of adverse effects from overdosing, and lowers the frequency of application. Because of this, nano technology has significant potential to foster sustainable agriculture, especially in underdeveloped countries[2]. In agricultural production, the main rationale for using fertilizer is to offer full-fledged macro and micronutrients in the soil which typically lacks. Fertilizer accounts for 35-40 % of crop yield, but some fertilizer directly impacts plant development. To surmount all these disadvantages

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more intelligently, nano technology could be one of the possibilities. Because fertilizer is the primary worry, developing Nano-based Fertilizers would be a novel technological advancement in this area. Fertilizers are applied in a variety of ways, including soil, leaves, and even marine settings; these inorganic fertilizers are provided in equal amounts of three primary components: Nitrogen, phosphorous, and potassium[3]. Nano nutrients improve Nutrient Use Efficiency (NUE) by three times and provide stress tolerance. Regardless of the product, nano technology increases BioSource use and eco-friendliness, increases carbon absorption, and enhances soil aggregation. These Nano fertilizers will have a gradual and focused effective release because they comprise nutrients and growth promoters enclosed in Nano-scale polymers. Nano technology is the study of elements at the nanoscale level, with an emphasis on physical, catalytic, magnetic, and visual characteristics[4]. Nano technology is an advantageous component of cognitive research that has the potential to revolutionize agriculture and associated fields. It may prove to be a useful instrument for a complete understanding of many biological and physiological processes, including cellular processes, trait control, and the creation of genotypes resistant to biotic and abiotic factors to boost agricultural output[5]. There are no such areas left untouched by nano technology in this contemporary age of science and technology.

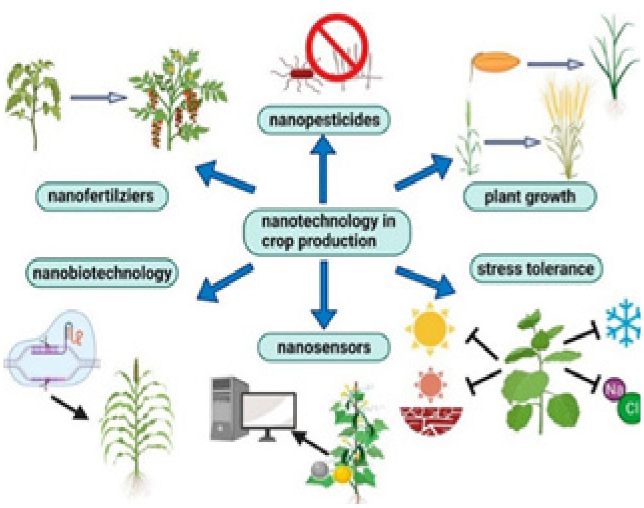

Figure 1. Applications of nano technology in agriculture[8] (By Haris M *et al.,* A new frontier of nano-farming in agricultural and food production and its development – Nano Technology *Sci Total Environ.* 857, 159639, 2023).

Farming is no different. This technology has numerous uses in agriculture and food, telecommunications, the food business, cosmetics, and other fields. We can learn about the biochemistry of various crops using nanobiotechnology, which will ultimately help us improve the production and nutritious worth of those products through breeding[6]. Nano technology is needed in agriculture to enhance crops, identify plant diseases, and track plant health and soil purity. These will eventually add to enhanced plant performance, which is the primary emphasis of every breeding programme[7] (Figure 1).

2.0 Properties of Nanomaterials

Nanomaterials are notable for their ability to alter and regulate the physical, chemical, mechanical, and biological characteristics that work at this scale, such as enhanced conductivity, optical properties, and reactivity[9]. The higher relative surface area and quantum effects are the two main reasons why the characteristics of nanomaterials vary considerably from those of other materials. Surface roughness, solubility-release of hazardous chemicals, hydrophobic nature, morphology-aspect ratio/size, contamination or deposition of surface organisms during synthesis or history. The key characteristics of nanoparticles include Reactive Oxygen Species (ROS) O_2 and H_2O, the ability to generate ROS, shape and content, competitive binding sites with receptors, and dispersion and aggregation[10].

3.0 Applications of Nano Technology

3.1 Agriculture and Food Production Applications of Nano Technology

It is possible to enhance the effectiveness and quality of crop cultivation and food storage, raise the safety of food supplies to protect consumers and producers, and introduce new functionality by introducing the protection of consumers and producers, and introduce new functionality through the introduction of value-added products for food, fibre, and agricultural commodities. Nano technology will open up new study areas and applications, such as DNA chips, protein identification, and alteration, inventive films based on nucleic acid engineering, and intelligent DNA delivery utilizing gold nanoparticles. When nano-

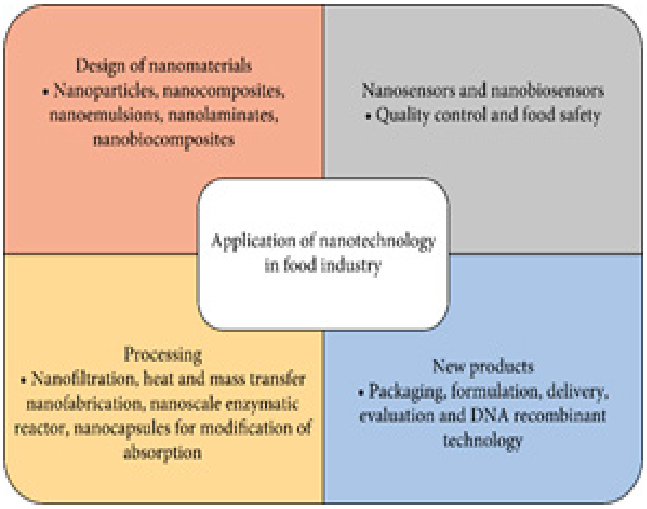

Figure 2. Applications of nano technology in food insdustry[11] (Ahmed HM *et al.,* Applications of nanomaterials in agrifood and pharmaceutical industry. J Nanomater. 2021, 1472096,2021).

particles are used as tags or indicators, biological assays detecting the existence or activity of particular substances become faster, more accurate, and more adaptable. Specific compounds, structures, or microbes are labeled using magnetic nanoparticles attached to the appropriate antibodies (Figure 2).

3.2 Nano Technology for Crop Biotechnology

Using nano technology for crop engineering Herbicides can be more effectively absorbed by tissues and cuticles with the help of nanocapsules, enabling a steady and progressive release of the active ingredients. This may serve as "magic bullets," delivering herbicides and chemical sources that specifically target certain plant parts to release their material[12,13]. DNA and chemicals were delivered to the individual plant cellular tissues by researchers using a 3nm meso porous silica nanoparticle. Meso porous silica nanoparticles with chemical coatings act as carriers for genes introduced into plants; they encourage the plant's cells to embrace particles through the cell walls, wherein the genes are precisely and deliberately inserted and activated without having any adverse effects. Initially, this method was used to successfully implant DNA in tobacco and maize seedlings.

3.3 Seed Science Nano Technology

The fate of any crop's production is largely determined by the input of its seed. Traditionally, seeds are tested for germination before being given to farmers to plant. Even though the germination rate of seeds observed in the laboratory ranges from 80 to 90 %, it hardly ever happens in the field due to insufficient or a lack of sufficient moisture under a rain-fed systems. It makes sense to develop technology for rainfed in Indian Agriculture, as the net area exceeds 60%, which is planted under this method. The germination of rainfed crops is now being improved by a team of researchers using carbon nanotubes and metal oxide nanoparticles. Carbon nanotubes have been used to refine tomato seed germination by moisture penetration, according to Khodakovskaya *et al.,*[14] at the University of Arkansas in the United States. Data from their study has shown how Carbon Nanotubes (CNTs) function as new holes allowing water to permeate by penetrating the seed coating and acting as a path to route water from the substrate into the seeds. Germination that is facilitated by these mechanisms can be used in a rainfed agricultural system. A seed is a self-replicating living organism that can endure inhospitable conditions on its own. The entire potential of the seeds can be realised through the use of nano technology. It takes a lot of work to produce seeds, particularly for products that are wind-pollinated. By determining the pollen loads that may cause contamination, the integrity of the genetic material can be ensured with confidence. Wind humidity, wind speeds, temperature, and agricultural pollen production all have an impact on pollen dispersion. It is possible to identify potential contamination and then reduce pollution by using bionanosensors created to find tainted pollen. To stop the pollen from genetically modified crops from infecting outdoor crops, an identical method might be utilized. Seedlings are being given new genomes that are then sold and circulated. Sold seeds may be tracked using nanobarcodes, which are machine readable, strong, and sub-micron sized taggants[15]. Disease spreads through seeds, and bacteria frequently destroy saved seeds. Using elemental forms of Zn, Mn, Pt, Au, and Ag in nanoscale seed coatings will not only safeguard seedlings but also use much less material. In order to distinguish between seedlings that are viable and those that are infectious, Su and Li[16] created a method known as Quantum Dots (QDs) as a flourescence marker

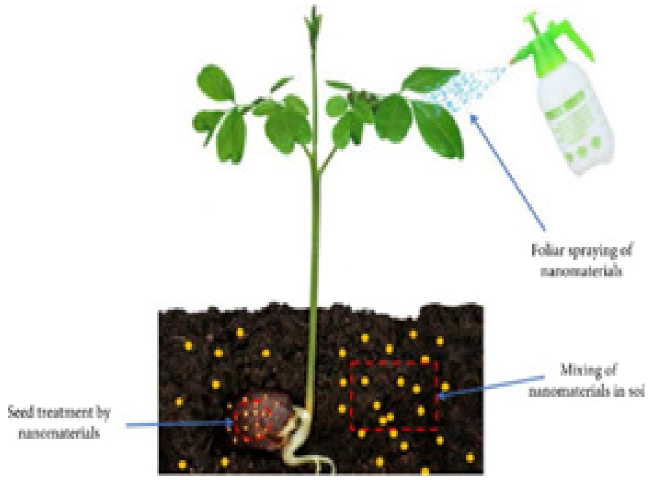

Figure 3. Nano technology in seed science[18] (By Vijayakumar MD *et al.* Evolution and recent scenario of nano technology in agriculture and food industries. J Nanomater. 2022, 1280411).

in combination with immuno-magnetic separation for *E coli* 0157:H7. The use of pesticides and herbicides has been transformed by technologies like encapsulation and regulated release techniques, according to Natarajan and Sivasubramanian[17]. Smart seeds are seeds that have been nano-encapsulated with a particular bacterium species. As a result, it will guarantee proper field stand, lower the seed rate, and increase agricultural production. A smart seed that can be spread over a mountain region for reforestation can be designed to sprout when sufficient moisture is present. Aerial dispersal of seeds coated in nanomembranes which detect the availability of water and only permit ingesting when the moment is perfect for germination. Detecting moisture levels while storing and taking the appropriate steps to reduce harm (Figure 3).

3.3.1 Nanoscience for Weed Control

In the Agrarian producing system, weeds are a threat. Weeds may endanger the entire crop in the sensitive agro-ecosystems because two thirds of Indian agriculture is rainfed farming, which uses very little herbicide. Market-available herbicides are made to prevent or eliminate the developing above-ground portion of weed vegetation. None of the pesticides prevent the growth of rhizomes or tubers, which are active belowground plant sections that serve as a seed for new plants the following season. Agriculture results on weed-infested and weed-seed-producing soils are likely to be lower than on weed-controlled soils. The use of nano technology to increase herbicide effectiveness could lead to increased crop output and less harm to farm employees who must manually clear weeds if herbicides are not used. Encapsulated nano-herbicides are important for designing and manufacturing a nano-herbicide that is shielded from the environment and only works during a period of rainwater that accurately mimics the rainfed system.

The creation of a target-specific herbicide molecule enclosed in a nanoparticle is directed at a particular receptor in the roots of the target weeds; this receptor allows the herbicide to enter the system and be transported to regions that block the glycosylation of food reserves in the root system. This will cause the particular grass plant to run out of sustenance and die[19]. There are presently available adjuvants for applying herbicides that say they contain nanoparticles. When used with a "nano technology-derived surfactant," one nano surfactant produced from soybean micelles promises to render glyphosate-resistant crops susceptible to the herbicide. (Bio-Based, 2010).

3.3.2 Nano-Fertilizers for Balanced Crop Nutrition

N, P, and K fertilizer consumption rates have remained constant over the previous three decades at 30%-35%, 18%-20%, and 35%-40%, respectively. Accordingly, a large portion of added nutrients either stay in the soil or make it to the aquatic system, where they cause eutrophication. It is essential to develop a nano-based fertilizer combination with a variety of functionalities in order to solve problems including inefficient fertilizer use, uneven fertilization, multinutrient deficits, and the loss of organic matter. Although nano fertilizer technology is rather new, there hasn't been much coverage of it in the media. However, certain research and patents unmistakably show that there are several potential uses for the creation of nano-fertilizers. The foliar application of nanoparticles as fertiliser has resulted in a substantial rise in production. Presently, research is being conducted to create nano-composites that will give all of the necessary important nutrients in an appropriate amount via a smart distribution system[20–23]. Preliminary findings indicate that nano technology may be used to accomplish regulated reproduction. Indeed, the metabolic assimilation of metals, such as soil-borne and foliar applications of micronutrients in the nano formulations, within plant biomass must be determined. In addition, it is important to carefully evaluate the nano-composites that are being investigated to give all nutrients in the right amounts using "Smart" delivery methods. Due to the loss of 50-70 % of the nitrogen given by traditional fertilizers, nitrogen utilisation efficacy is currently inadequate. Advanced nutrient delivery methods that take advantage of plant porous nanoscale components could decrease nitrogen loss by boosting plant uptake. Fertilizers embedded in nanoparticles will improve nutrient absorption. The next generation of nano fertilizers will either release nutrients at a specified period or in response to an environmental event. The protective covering and sealing of nano and sub-nano-composites nano-composites, according to Liu *et al.*,[24] can regulate how rapidly nutrients are released from the fertilizer container. A unique nanocomposite of N, P, K, micronutrients, mannose, and amino acids, according to Jinghua[25], improves the absorption and utilization of vital nutrients by cereal products. The primary possible application of the technology, according to Adhikari *et al.*,[26] is nano fertilisers for optimal water utilisation and delayed release of fertilisers in plants. One of these novel facilities is the encapsulation of fertilisers within a nanoparticle, this involves three stages. According to Rai *et al.*, the nourishment can be disseminated as nanoscale particles or emulsions, covered with a thin polymer coating, or encapsulated within nanoporous materials[27]. Additionally, nano technology will be combined with fertiliser N and P release to synchronise with crop uptake. This will prevent unintended nutrient losses to soil, water, and air through direct internalisation by crops and prevent nutrient interaction with soil, microorganisms, water, and air[28].

3.3.3 Nano-Pesticide

The continued use of pesticides during the early stages of agricultural development aids in reducing the bug population below the point at which it becomes unprofitable and in maintaining effective control for a prolonged period of time. As a result, one of the most economical and adaptable methods of managing bug pests continues to be the usage of residues on the surface that was applied. A nano technology technique called "nano-encapsulation" by protecting the active ingredient, it is possible to improve the insecticidal value from the environment and encouraging perseverance. Nano-encapsulation involves sealing tiny amounts of the active components inside a sac or casing with a thin wall (Protective coating). Insecticide encapsulation has been the subject of several recent study articles. Insecticides, fungicides, or nematicides can be nano-encapsulated to create formulations that effectively manage bugs without leaving residues in the soil. To increase the formulation's effectiveness, safeguard the active component from the environment, and encourage persistence, a nano technology technique known as "controlled release of the active ingredient" can be applied. This may significantly reduce the amount of pesticide input and the associated environmental risks. Because the amount of product needed to achieve an effective result is at least 10-15 times lower than that applied with conventional formulations, nano pesticides must decrease the rate of application. As a result, a much smaller amount may be needed to achieve an improved and extended administration. With the help of nano technology, chemical and biological insecticides could be delivered effectively using nanosized formulations or agrochemicals based on nanomaterials formulations. Nanomaterial-based formulations have better efficacy than commonly used pesticides and their formulations because they have more surface area, are more soluble, cause systemic activity because of fewer particles and greater mobility, and are less toxic because organic solvents aren't present[29]. In the field, the use of nanoparticles for pesticide and biopesticide distribution faces several challenges, including numerous environmental disturbances, vast regions of spray coverage, and ultimately cost-effectiveness. For ease of application, the pesticide is typically sprayed across the entire piece of product, requiring a high volume, low-value preparation. On the other hand, low-volume, high-value applications are predicted for formulations based on nanomaterials. Such regulated nanoparticulate delivery systems would demand a specific distribution plan based on understanding the life cycle and behaviour of the virus or pest.

3.4 Nano Technology in Agricultural Waste Recycling

Nanoparticles is used in agriculture to reduce waste, especially in the cotton business. Some of the cellulose or fibres used to make cotton into fabric or clothing are abandoned as trash or used to make low-value goods like cotton batting, cotton pellets, and yarns. Scientists have created 100 nanometre-diameter fibers that can be used as fertiliser or herbicide absorbents using freshly developed solvents and a process called electro spinning.

3.5 Nano Technology in Organic Farming

Increasing output (i.e., food harvests) with minimal organic fertilizers and pesticides through environmental tracking and focused action has long been an aim of organic farming. Computers, GPS, and remote sensing equipment are used in organic farming to assess highly localised environmental conditions, deciding whether crops are developing as efficiently as possible or exactly finding the type and position of issues. It is possible to fine-tune seeding, fertilizer, chemical, and water use to reduce production costs and possibly increase output, all of which are advantageous to the farmer. Centralized data can be used to determine soil conditions and plant growth. Additionally, precision farming can help minimise environmental pollution by reducing agrarian debris.

3.5.1 Nanoparticles and Vegetation Disease Control

Carbon, silver, silica, and alumino-silicate nanoparticles are among the nanoparticles that have joined the field of plant disease management. In such a case, nano technology has astounded the scientific community because the substance exhibits distinct properties at the nano-level. Emplyoying nano-sized silver particles as antimicrobial agents is becoming more prevalent as technology improves and makes their manufacturing more cost-effective. Because silver inhibits microorganisms in a variety of ways, it can be applied to manage different plant pathogens in a better manner than widely available fungicides. Many biochemical processes in microbes are known to be affected by silver, including alterations in routine activities and plasma membranes[30]. The silver nanoparticles also inhibit the translation of proteins involved in ATP generation[31]. In a summary, the exact process of biomolecule inhibition is unknown.

3.6 Nano Technology in Water Management

Surface water, groundwater, and wastewater contaminated by hazardous metal ions, organic and inorganic solutes, and microorganisms are treated, nano technology provides the possibility of innovative nanomaterial. Many nanomaterials are being researched and developed for application in water purification because of their special activity towards resistant pollutants. Pathogens in water need to be quickly and accurately identified toto ensure public health. Conventional laboratory testing, however, takes a lot of time. Enzyme-based, immunological, or genetic assays are being developed as faster alternatives. The employment of nano biocides and nanofiber membranes, which seem to be promisingly successful, might enhance water filtering. Biofilms are bacterial mats coated in naturally occurring polymers that contaminate potable water and are difficult to remove using antimicrobials or other chemicals. They can only be manually sanitised which takes time and requires a lot of work. the creation of an enzyme treatment to remove these biofilms.

4.0 Conclusion

Across the whole range of food technology, from agriculture to food processing, packaging, and dietary supplements, nano technology applications are currently being investigated, evaluated, and in some cases, already deployed. They have special chemical, physical, and mechanical characteristics. Agricultural waste products have gained popularity recently as sources of renewable raw resources. One of the finest instances of evolution taking place on an ecological time scale is insecticide resistance. Because it helps us understand how evolutionary processes work in real time, the study of pesticide resistance is crucial. For agricultural and public health, the emergence of pesticide resistance in pest insects has become a growing issue. Typical agricultural practises involve the routine administration of a wide range of active substances at different doses and frequency.

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