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Review Article

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Applications of Nanotechnology in Agriculture, with a Focus on Insect Pest Management

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Abstract

Agriculture has been by far the most successful revolution in human history. Because of improved health care, nutrition, and other factors the population of the twenty-first century exploded. Farmers began employing procedures (such as fertilizer, pesticide, herbicide, and so on) that enabled the yield to rise more quickly than with traditional farming practices in order to satisfy the needs of the increasing population. In the long term, this may have proven to be costly and destructive to the environment. This necessitated the urgent search for alternative solutions that are both environmentally benign and cost-effective. In this scenario, nanotechnology has proven to be the most viable option. The unique qualities of nanotechnology, such as its ultra-small size and enormous surface area, targeted distribution, high catalytic reactivity, gradual and controlled release of molecules of interest, and so on, allow for creative and environmentally friendly solutions to issues. Nano fertilizers, nano sensors, nano pesticides, nanomaterials, and other technologies improve farming efficiency. Precision agriculture was born with the introduction of the IoT (Internet of Things). Precision agriculture incorporates the Internet, satellite imagery, remote sensing, robotics, unmanned aerial vehicles global positioning system (GPS) multispectral imaging, and other technologies into agricultural techniques. However, more research and analysis into the use of nanomaterials in agriculture is required. Before applying to the fields, the risks must be analyzed.

Keywords

Nano technology, Nano pesticides, Nano fertilizers, Nano sensors, Nano materials

Introduction

Agriculture, which supplies and produces raw materials for the food products industries, has historically been the most dominant and stable business. The expanding global population increased nutrient mining, the need to boost overall food grain output, dwindling arable areas, a lack of water, degrading organic matter in the soil, climate change, and a variety of other factors, all need the employment of modern agricultural technologies such as Nanotechnology. Agriculture as well as other marketing facilities, can benefit from Nanotechnology in the manufacture, processing, storage, packaging, and delivery of products. In agriculture, nanomaterials are utilized to minimize pesticide usage, reduce nutrient losses during fertilization, and boost production through nutrient and pest control. Nonfertilizer and pesticides, as well as monitoring level of goods and nutrients to boost productivity without polluting soil and water, as well as protection against a number of biotic and abiotic issues, some of the key purpose of nanotechnology used in agriculture. In agricultural settings, nanotechnology might be used as sensors to monitor soil quality and assure crop health Precision farming techniques, increased plant nutrient absorption capacity, more efficient and targeted input utilization, and disease detection and management are all examples of how nanotechnology may impact agriculture and the food industry. Increase the nutrient utilization efficiency of applied fertilizers and restore soil fertility by releasing fixed nutrients with the use of nano clay and zeolites. To address perennial weed control difficulties and a decreasing weed seed pool, nano pesticides are being developed. Gas sensors and nano smart dust can measure pollution levels in the environment quickly and effectively. The use of polymer- based nanoparticles and the agglutination of green nanoparticles expands the scope of nanotechnology in agriculture. Metal-based nanoparticles also demonstrated promising results in seedling growth, plant development, and pest control at low concentrations. As a result, we compiled a list of metallic nanoparticles, metal oxide nanoparticles, polymer-based nanoparticles, green nanomaterials, nano formulation-based fertilizer, and pesticides' agricultural effects. Nanomaterials have also been proposed as detectors for soil nutrient detection, insect control, and food quality control. Agriculture has benefited and harmed because of nanotechnology, but more study is needed to understand the long-term impacts.

Nanotechnology and Nanoparticles

Nanotechnology is a recent research technique involving the use of equipment and materials that can use a substance's physical and chemical characteristics at the molecular level to examine the biological and material worlds at the nanometer scale and apply it to a variety of applications ranging from medicine to agriculture [1]. Nanotechnology is the study and use of extremely small things, such as materials that are approximately 100 nanometers in size. Nanotechnology incorporates solid state physics, chemical engineering, chemistry, biophysics, biochemistry, and materials science. Nanotechnology typically refers to the use of nanomaterials between 1 and 100 nm in size (Figure 1) A nanometer is one- billionth of a meter 10^9.Examples include nano emulsions, nanorods, quantum dots (QDs) carbon nanotubes, micro and nanoencapsulation, and other nanotechnologies.

Nanotechnology Application in Agriculture

Nanotechnology is a rapidly growing subject in medical, electronics, electrical engineering, solar energy, optics, and agriculture. Nanotechnology has also contributed many agri tools to agriculture, such as nano fertilizers, pesticides, and sensors, all of which have shown substantial outcomes for sustainable agricultural practices (Figure 2). Nano inputs lower the quantity of fertilizers and pesticides used while also delivering active agents to specific locations. As a result, non-targeted species are unaffected by these nanotools, ensuring environmental safety. Nano sensors also supply rapid and reliable information about soil conditions or disease identification, allowing for timely management and crop safety, which helps farmers reduce losses and improve their financial situation [1]. Several nanoparticles have been used in the lab and greenhouse as nano fertilizers, nano insecticides, and in nano- sensing. Commercialized nano fertilizers include Nano-GroTM, Nano green, a plant nutrition product created by Nano Green Sciences, Inc. in California, and Agro Nanotechnology Corp. In Florida's plant growth controller and immune inducer Biozar Nano fertilizer, established by Fanavar Nano-Pazhoohesh Markazi Company in Iran and containing micro and macro-Nano nutrients, Nano Max NPK Fertilizer, developed by JU Agri Sciences Pvt Ltd. in New Delhi, India [2]. and Organic Fertilizer developed by Pannaraj Intertrade in Thailand, Master Nano Chitosan, developed by JU Agri Sciences Pvt. Ltd. in New Delhi, India. Nano-Ag Answer®, a plant nutrition product developed by Urth Agriculture in California [3]. Even though nano insecticides of known active chemicals have been created as nano formulation, further data on toxicity, stability, and the destiny of nano pesticides in the environment, as well as regulatory agency permission for commercial manufacturing, is required.

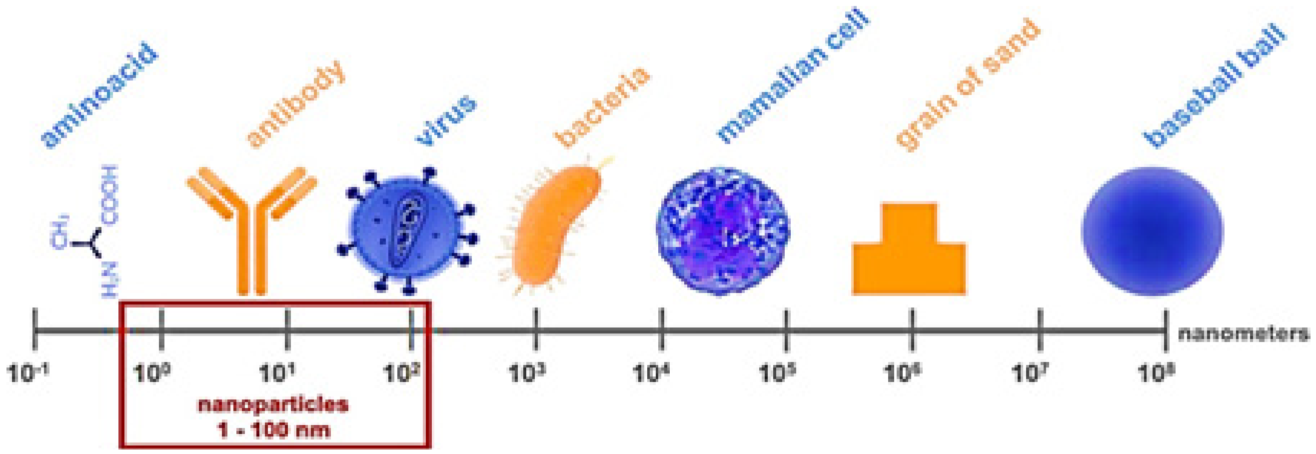

Figure 1: Nano particles.

Figure 2: Nanotechnology applications in agriculture.

Nano fertilizers

Nano fertilizers are a relatively new agricultural discovery. They are more effective than traditional fertilizer due to their nano-size and high-volume surface area ratio. Silver, iron, zinc, titanium, and carbon are some of the most common metals. Nanotubes, molybdenum, and silica have all been manufactured and employed as nano fertilizers in various agricultural systems. At concentrations, nanomaterials were found to have a significant impact on root development (elongation), shoot dilation, plant biomass, chlorophyll content and seed germination [3]. Fertilizers with nanoparticles travel faster than traditional fertilizers. In contrast to standard fertilizers, nano fertilizers follow thermodynamic principles and have increased entropy due to the colloid suspension condition [4]. The entropy of colloidal state nano fertilizers is proportional to Gibbs energy, allowing them to move quicker and more readily breach plant cell walls. The usage of hydroxyapatite in smart urea delivery and discovered that urea release using urea- hydroxyapatite Nano hybrids may be controlled for up to one week. Urea and hydroxyapatite were combined in a 6:1 ratio to make these Nanohybrids (urea: HANPs). Hydroxyapatite is bio-compatible phosphorus-rich substance that can be used to make smart fertilizer carriers for a long time. Urea was weakly bonded to hydroxyapatite nanoparticles (HANPs) and released slowly and on demand into the soil, increasing plant growth. Nano-chitosan-nitrogen, phosphorus, and potassium (NPK) was synthesized for wheat growth [5]. After foliar spraying nano chitosan-NPK fertilizers onto wheat plants, researchers discovered that nano fertilizers entered the plant through the stomata and were transported through the phloem tissue. Nano fertilizers increased wheat production by 23.5 percent while simultaneously reducing the lifetime of wheat plants, according to the researchers. It functions as a biological nutrition pump and enhance the water absorption, the nano-NPK boosted photosynthesis [6]. Endocytosis, or the trafficking of implanted on transporter carrier proteins into the cytoplasm, has been shown to increase plasma membrane permeability and cell death [7]. The mobile target may use the signal measured by GPS in the open environment, such as on the ground or in the air, to establish its location. Various measuring methodologies and technologies have been offered to realize the shearer location in the subterranean confined environment in response to the necessity of positioning service [8]. Nanoparticles in conjunction with diverse cytoplasmic organelles change plant metabolic pathways, Nanoparticles of zinc oxide (ZnO NPs) have been employed as fertilizers, have both positive as well as negative impacts on plant development [9]. The metal oxide concentration determines whether ZnO NPs have beneficial or harmful effects on plants. The addition of ZnO NPs at a 10 mg/kg concentration to lettuce enhanced photosynthesis and biomass [10]. ZnO NPs boosted photosynthesis by increasing CO_2 availability in chloroplasts, at the carboxylation site [11]. In the biomass, roots, stem, and root area of Guar at a concentration of 10 mg/kg ZnO NPs. When the concentration was raised to 400 – 1000 ppm seedling growth and seedling strength index improved in groundnut. When groundnut seedlings were given 400 - 1000 ppm ZnO NPs, their root length, chlorophyll content, and biomass all improved [12]. Using micronutrient iron, zinc nano fertilizer, and nano titanium dioxide in the field, chlorophyll, number of grains per spike, grain quantity, and grain mass all showed modifications (TiO_2).The ZnO nano fertilizer improved germination, chlorophyll content, triggered antioxidative chemical synthesis, decreased oxidative stress, and promoted root development in a variety of crops, including *Arachis hypogaea*, *Cicer arietinum*, *Lupinus termis*, *Solanum lycopersicum*, *Vigna radiata*, *Helianthus annuus*, *Glycine max*, and *Cyamopsis tetragonoloba* [13]. In field studies, zinc-chitosan nanoparticles (Zn-CNPs) were synthesized and applied to wheat crops. Zc efficiency was enhanced without reducing grain production, protein content, or spikelet's per spike, according to the researchers. They found that Zn-CNP nano fertilizers were one-of-a- kind, nano fertilizers that boosted fertilizer efficiency while lowering costs [14]. Zn nanoparticles in plants were examined in depth. To combat nanoparticle toxicity, scientists created polymer-based nanoparticles that decreased or eliminated metal nanoparticle toxicity in plants. Iron oxide nanoparticles were employed to boost germinating seeds, chlorophyll, and root development in *Citrullus lanatus* (watermelon) and *Vigna radiata* plants [15]. Zn and boron (B) chitosan nanoparticles, which is utilized to treat coffee plants at concentrations ranging from 0 to 40 ppm. According to the research, the micronutrients nano fertilizer boosted chlorophyll concentration and photosynthesis [16]. As a result, plant growth and leaf area both increased significantly [17]. The particles' nano size allowed for better penetration into the plant's leaf stomata, cuticle, and root system, as well as simple transport to the xylem and phloem, where they boosted physiological and metabolic processes and encouraged plant development. Plant development is influenced by nanoparticles, which impact a variety of plant processes. Compared to bulk alternatives, these materials' high specific surface area ratio and nano size increased catalytic activity. Seed germination was improved by up to 20% in rice when ZnO NPs were used at doses of 0 – 750 ppm. When combined with bio-fertilizers, nano fertilizers, like nanoparticles alone, have synergistic advantages on plant development. *Mycorrhizal fungus, Piriformospora indica* and *Glomus mosseae* were combined with calcium phosphate nanoparticles (CaPNPs) and applied to *Zea mays* [18]. Experts say that the *Zea mays* plant has a higher chlorophyll content and more root growth. Several micronutrient nano fertilizers, such as zinc, iron, and titanium oxide, improved nutritional absorption and encouraged higher enzymatic activity in Peanuts, Chickpea, Spinach, soybean, and Pearl millet [19].

Nano pesticides

One c rop insects, which cause disease and impair a farmer's production, are also a significant problem in agriculture. Each year, crop disease cost the global agriculture business $220 billion [20]. Fungal, bacteria, virus, worms, insects, parasites, and protozoa are diseases that cause plant diseases. Chemical and biological pesticides have been used to control them. On the other side, chemical insecticides have harmed the ecosystem and bred bug resistance. To counter the damaging effects of increasing crop disease resistance on agriculture, new strategies to regulate environment instability are needed, and the agriculture business is hopeful that nanotechnology can deliver on this potential. Agricultural productivity has grown because of nanotechnology in plant protection. Agriculture has also been affected [21]. Metal nanoparticles have been utilized to protect agricultural crops in a variety of forms, including nano formulations, nano encapsulated active compounds, and nanocomposites. In both the lab and the greenhouse, Several nanomaterials have been discovered to have powerful antibacterial capabilities in the fight against crop diseases (Figure 3).

In agriculture, nano pesticides such as nano fungicides, nano bactericides, and nano insecticides have been used to tackle a variety of fungal, bacterial, and insect diseases. Silver nanoparticles nano copper, nano silica, and nano formulations of chemical pesticides such as hexaconazole and sulphur have all been proven to be beneficial against a variety of insect pests and fungal diseases [22]. Active chemicals' solubility and shelf life, as well as the activity of controlled-release nanocarriers, are all improved by nano formulations (nano fungicide, nano bactericide, and nano insecticide) in agriculture [23]. Essential oils, plant extracts (such as capsaicin from chili peppers and Lansiumamide B extract), and nano formulations (such as neem oil, wormwood essential oil, garlic oil, and alecrimpimenta oil) have all been demonstrated to extend shelf life. Aside from metal and polymer nanoparticles, nano-emulsion is currently a hot issue in the field of nano-pesticides. In nano-emulsions, the quantity of surfactant utilized has been reduced from 20 to 5 percent because of its smaller size and greater absorption. The retention capacity of active chemicals in plants was improved by using nano emulsion as a larvicidal treatment [24]. A nano emulsion of permethrin and neem oil was more effective than the active component. nano-emulsions also allowed for more accurate targeting while simultaneously lowering the impact on non-targeted species.

Nano sensors

Agriculture has also shown to be a good use for nano sensors. They can be used to monitor agricultural and field operations in real time, as well as crop growth, insect assault, plant disease, and environmental stress. Nano sensor development has played an important role in agricultural progress and continues to do so. Real-time monitoring has helped to decrease environmental impact and product cost by preventing the misuse of pesticides and fertilizers. Traditional agricultural techniques are being transformed into smart farming, which is a much more energy-efficient and environmentally friendly approach to agricultural sustainability. Nano-formulation-based smart agricultural fertilizers or pesticidal delivery systems that encourage nutrient distribution and wettability, nano-detectors for residues of pesticides or fertilizers, and disease occurrence and crop growth monitor systems based on remote sensing are all examples of smart agricultural fertilizers or pesticide's delivery systems that promote nutrient dispersion and wettability [25]. Nano sensors are used in agriculture to detect soil moisture, pesticide residue, nutritional demands, and crop pests. Nano-sensors are more useful for smart agriculture because of their detection limit is low, and sensitivity is strong. Pesticide detection nano sensors have

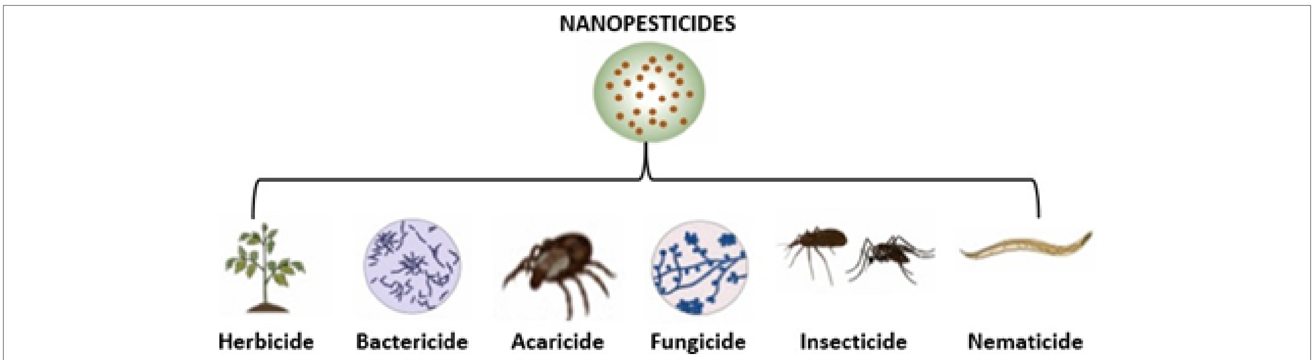

Figure 3: Nano pesticides.

been developed using gold nanoparticles (AuNPs), carbon nanotubes QDs and other metal nanostructured materials with polymers. Outperformed traditional sensors in terms of sensitivity (because to a high surface-to-volume ratio), reaction time (seconds), and more consistent and precise results, lower detection quantities (nanogram or less), adaptability to varied matrixes, and enable rapid electron transfer kinetics [26]. TiO_2 nanotubes and nano-sensors to detect atrazine levels parts per trillion in the soil. MWCNT-fixed acetylcholinesterase enzyme and chitosan nanocomposites modified with a glassy carbon electrode were also employed to detect methyl parathion in soil and water at ultra-trace levels [27]. The acetylcholinesterase enzyme's inhibitory action was exploited to identify methyl parathion. To detect acetamiprid in soil, a nano- biosensor was developed using AuNPs that were functionalized with an acetamiprid-binding aptamer. This nano-biosensor can detect acetamiprid at concentrations ranging from 75 nM to 7.5 mm [28]. They developed a nano - biosensor for identifying phosphorus-containing amino acid type herbicides in soil using a nanofilm on a pencil graphite electrode, with detection limits of 0.35 and 0.19 ng/mL, respectively. By utilizing pulse anodic stripping voltammetry, the electrode was able to detect glyphosate and glufosinate. Working mechanism of nano sensors are explained with diagram (Figure 4).

Absorption of nutrients from the soil is a serious issue, and soil conditioning needs must be determined as soon as feasible. Soil nutrient quantification would increase productivity while minimizing excess component leaching. The development of nano-biosensors for fertilizer estimation has become a hot topic in the last ten years. Farmers could save money by reducing fertilizer waste by adopting nanotechnology-based sensors to offer precise information on fertilizer needs [29]. Cysteamine- modified AuNPs to develop a colorimetric method for detecting nitrate levels in soil. Graphene oxide-based nitrate sensors was created by researchers [30]. Developed a biosensor to detect urea, urea activity, and urea inhibition based on the AuNP-3,30,5,50-tetramethylbenzidine- H_2O_2 reaction. The presence of AuNPs which acts as a catalyst in this system, gives the reaction its yellow color. Urease activity in soil has a 1.8 U/L detection limit [31]. Traditional end-to-end routing techniques are contrasted to the data-centric approach. This article claims that data-centric routing improves performance. To increase the performance of sensor networks, data aggregation uses a data-centric routing method [32]. Another important aspect of agricultural production is crop pest identification. Traditional techniques of detection might take a long time to complete. Nanoparticles have been used to identify pests, and the findings have been swift and accurate, allowing crops to be protected and damage mitigated as quickly as possible. QD FRET based nano-biosensor was used to detect *Polymyxa betae*, the vector of the beet necrotic yellow vein virus, which causes Rhizomania disease in sugar beets [33]. A synthesized oligonucleotide to identify *Ganoderma boninense* using the FRET method. Due to the fast expansion of computer software, more mobile, smaller, and more practical computing applications are becoming more accessible to the public, making it simpler for consumers to use internet applications at any time and from any location. DNA probes and modified QDs were also used to create the sensor. Nanoparticles of gold were also used to identify pathogens (AuNPs). Researchers employed an electrochemical enzyme connected immunoassay to detect the plant bacterial disease *Pantoea stewartii* using AuNPs linked with horseradish peroxidase-labeled antibody. A detection method of detection for *Cymbidium mosaic* virus and *Odontoglossum ringspot* virus was designed and tested at 48 and 42 pg/mL LOD (limit of detection), respectively, using label-free surface plasma resonance of Au nanorods. Researchers created a nano biosensor for detecting the soil- borne fungal infection *Trichoderma harzianum* using ZnO NPs and chitosan nanocomposite modified Au electrodes [34]. Using fluorescent silica nanoprobes and a secondary goat anti rabbit Ig antibody, the bacterial plant pathogen *Xanthomonas axonopodis* pv. *vesicatoria* was found in Solanaceous crops.

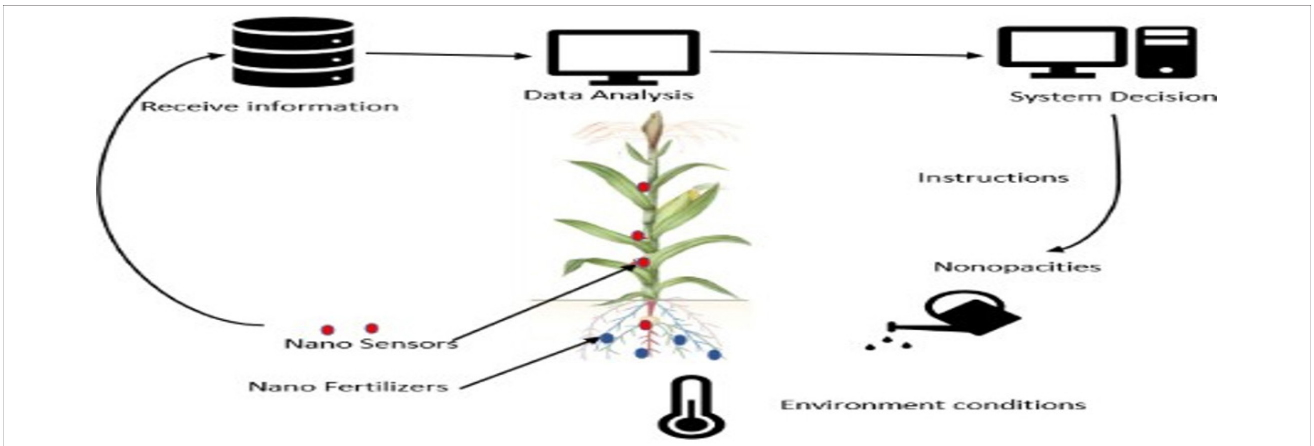

Figure 4: Working mechanism of nano sensors.

Smart food management

Food safety and processing are two other areas where nanotechnology has shown potential. Food packaging made from nanomaterials was used to keep food fresh and extend its shelf life. Food packaging nanocomposites have been demonstrated to be effective antibacterial agents, as well as improving the thermal and mechanical robustness of packaging materials and lowering the oxygen trans- fer rate in food packaging. Vitamin supplement and flavor enhancer capsule- based nano formulations have shown controlled release properties [35]. To improve shelf life and prevent rapid decomposition, vitamins and flavor enhancers were nano encapsulated. Anthocyanin nanoencapsulation to increase pigment stability [36]. Encapsulated rutin (a dietary flavonoid) in ferritin nanocages and observed higher solubility in a number of culinary applications. Silicon oxide and titanium were utilized as colorants, scent enhancers, and flavor enhancers in the food sector. Food packaging materials incorporating nanoparticles increase strength and barrier effectiveness by detecting food pathogens. Characteristics, antibacterial activity, and food hygiene [37].

Conclusion

In plant development and agricultural production, nanotechnology has proven its effectiveness as a nano fertilizer, nano pesticide, and nano sensor. Nanoparticles are important mechanisms for smart agricultural systems because of their nanoscale-controlled release and site-specific delivery. At specific concentrations, metal oxide and metal nanoparticles increased germination of seeds, root and shoot development, plant biomass, and growth of plants. On the other hand, some metal oxide and metal nanoparticles harm plant growth. The use of nanoparticles and the production of green nanoparticles can help solve these problems. It has been established that nanomaterial-based sensors can detect leftover pesticides or diseases, ensuring consumer food safety. Lately nanoencapsulation and nanoparticles' usage in food packaging has progressed. Food items' shelf lives have been increased, and long-term solutions for food deterioration and transportation degradation have been established. More research is needed to determine the appropriate parameter concentrations for each crop system to decrease toxicity. A long-term examination of each agricultural nanoparticle system is required to understand the future of nanomaterials in the environment.

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