Green Nanotechnology for Biomedical, Food, and Agricultural Applications

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Abstract

In green nanotechnology, nanomaterials or nanoparticles are synthesized or developed by biological approaches, such as biogenesis (biosynthesis). Green nanotechnology has great potential for improving the quality of life through its applications in the biomedical, food, and agricultural fields, among others. Green nanotechnology plays an important role in many controlling processes, especially because of its small dimension. Additionally, green nanotechnology offers many potential benefits, such as the enhancement of biomedical diagnostics, improved food quality and safety, reduction of agricultural inputs, and enrichment of nanoscale nutrient absorption from the soil. There is great potential for green nanoscience and technology to be used in state-of-the-art solutions for current and future challenges faced by the biomedical, food, and agricultural fields, as well as society in general, such as sustainability, susceptibility, and human health and well-being. This chapter reviews some potential applications of green nanotechnology and recommends approaches for the development of scientific and technological knowledge in the biomedical, food, and agricultural fields.

Keywords

Green nanotechnology · Antimicrobials · Anticancer agents · Food safety · Sustainable agriculture · Nanofertilizer · Nanopesticides · Nanoencapsulation

Introduction

Nanoparticles have great potential in the development of sustainable technologies. For example, the production of plant nanoparticles is a green chemistry approach that interconnects nanotechnology and plant biotechnology. Plant extracts can be used for

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the bioreduction of metal ions to create nanoparticles. Plant metabolites such as sugars, terpenoids, polyphenols, alkaloids, phenolic resin acids, and proteins play a crucial role in the reduction of metal ions into nanoparticles and the support of their stability [1–4].

The properties of nanometric material atoms are completely different from those of the majority materials. Figure 1 illustrates the differences in a material's scale size from macro to nano. However, the conventional synthesis of nanoparticles uses toxic chemicals; thus, great interest exists in developing an environmentally friendly approach [6]. Biological methods are now springing up, such as green synthesis using biological methods. The extracts derived from plant sources have exhibited superiority over chemical and biological approaches [5, 8, 9].

Nanomedicine has several potential applications in the fight against cancers, neurodegenerative disorders, and other diseases. The biosynthesized nanomaterials may treat a variety of endemic diseases with fewer adverse effects. The interest in natural products has increased, so active plant extracts are often investigated for new drug discoveries. Thus, green synthesis using biomolecules derived from plant sources, particularly nanoparticles, may have significant advantages over chemical approaches. Recently, several studies have examined plant extracts as possible precursors for the non-hazardous synthesis of nanomaterials. The plants were used with success for the synthesis of many green nanoparticles, such as metals, Cu, Ag, Au, Pd, Pt, ZnO, and Fe_2O_3 [11–15].

Previously, a number of biological schemes, together with plants and alga, diatoms, bacterium, yeast, fungi, and human cells, were used to transform inorganic metal ions into metal nanoparticles using the subtractive capacities of proteins and metabolites in these organisms. The synthesis of silver nanoparticles using biological entities was investigated because of their uncommon optical and chemical properties. Several plants were successfully used for the economical and rapid extracellular synthesis of gold and silver nanoparticles. For example, geranium (*Pelargonium graveolens*), leaf extracts of lemongrass (*Cymbopogon flexuosus*), Cinnamommum camphora, neem (*Azadirachta indica*), *Aloe vera*, tamarind (*Tamarindus indica*), and the fruit extract of *Emblica officinalis* demonstrated potential for reducing Au(III) ions to create gold nanoparticles Au(0) and silver nitrate to create silver nanoparticles Ag(0). Biomasses of wheat (*Triticum aestivum*), oat (*Avena sativa*), alfalfa (*Medicago sativa*, native and with chemicals to change the hop biomass), and remnant water

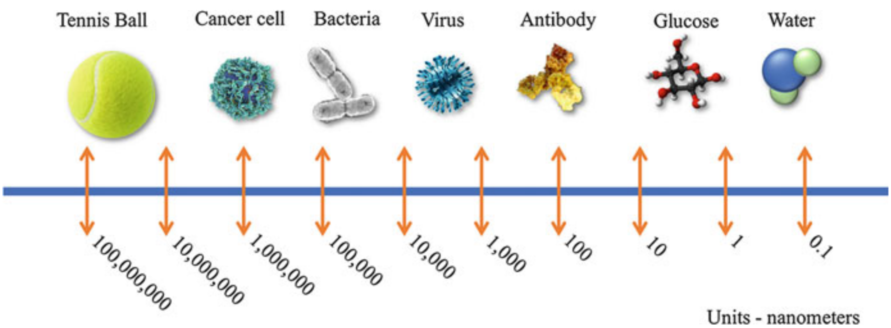
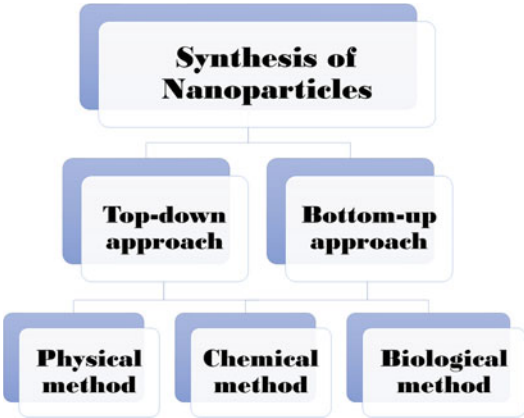


Fig. 1 Nanometric scale

Fig. 2 Different approaches and methods for synthesizing nanoparticles



collected from soaked bengal gram beans (*Cicer arietinum*) have also been used for gold nanoparticles synthesis. Alfalfa (*Medicago sativa*), *Chilopsis linearis,* and legume seedlings were used in the synthesis of gold nanoparticles within living plant components. Alfalfa (*Medicago sativa*) sprouts and *Brassica juncea* germinating seeds were used for Ag and AgAuCu alloy nanoparticle synthesis [16–18].

The birth of matter at the nanoscale has created excitement among researchers and has begun to transform several aspects of materials science in the twenty-first century. The word *nano* comes from Greek word for "dwarf," but indicates "a billionth." A micromillimeter is billionth of a meter—that is, 250 millionth of an inch, approximately 1/80,000 of the diameter of an individual's hair, or 10 times of the diameter of atom. Although nanoparticles are generally thought to be a recent scientific discovery, they actually have a long history. For example, the medical and preservative characteristics of silver have been known for over 2000 years. Nanoparticles were used by artisans in the ninth century to create a glittery finish on the surface of pots. Potteries from the Middle Ages and Renaissance period often still retain this unique metallic glitter. The luster is caused by a silver film that was applied to the clear surface of a glazing. The brightness can still be visible if the film has resisted local chemical reactions and weathering effects. The luster originates from inside the film itself, which contains silver and copper nanoparticles spread homogeneously in a glassy matrix of the ceramic glaze [19–23].

Nature has formulated numerous methods for the synthesis of nanoscale and microscale inorganic materials that have been used in the development of the biosynthesis of nanomaterials. Synthesis using bio-organisms is compatible with green chemistry principles [24, 25]. The "green synthesis" of nanoparticles makes use of environmentally friendly, nontoxic, and safe reagents. Nanoparticles synthesized with biological techniques or green technology are diverse, with great stability and large dimensions. Nanoparticles can be synthesized with a variety of strategies together with chemical, physical, and biological techniques (Fig. 2) [40–45]. Chemical and physical methods use high radiation, extremely targeted reductants, and agents may be harmful to the environment and human health. Hence, the biological synthesis of nanoparticles could be a one-step eco-friendly bioreduction method that uses less energy than conventional synthesis [26–29].

In general, green nanobiotechnology synthesizes nanoparticles or nanomaterials biologically using micro-organisms, plants, and viruses or their byproducts, such as proteins and lipids, with the assistance of various bio-technological tools. Nanoparticles created by green technology are superior to those made with physical and chemical strategies in a number of ways. For example, green methods eliminate the need for pricey chemicals, consume less energy, and generate environmentally benign products and byproducts [30–35].

The 12 principles of green chemistry are a guide for researchers, scientists, chemical technologists, and chemists around the world in the development of less harmful chemical products and byproducts [36, 47]. In this regard, green nanobiotechnology could be a promising avenue for the synthesis of biocompatible stable nanoparticles [48]. The final procedure uses auriferous nanoparticles from the dried biomass of plants and auriferous salt as the bioreductant and precursor, respectively. The biological-based synthesis of nanoparticles uses a bottom-up approach, during which synthesis occurs with the assistance of reducing agents. Three main steps are followed for the synthesis of nanoparticles in a biological system: the selection of a solvent medium, the selection of an eco-friendly and environmentally benign reductant, and the selection of a nontoxic capping agent to stabilize the synthesized nanoparticles [49].

Physical Properties of Nanoparticles

Nanoparticles are unique because of their large surface area. The color of nanoparticles may vary, including gold and silver. Gold nanoparticles melt at much lower temperatures (~300 °C for 2.5-nm size) than do gold slabs (1064 °C). Silver nanoparticles have distinctive physico-chemical properties, together with high electrical and thermal conduction, surface-enhanced Raman scattering, chemical change activity, chemical stability, and nonlinear optical behavior [51]. The absorption of radiation within electrical cells is far greater in nanoparticles than in skinny films of continuous sheets of the majority material. Because the particles are smaller in size, they absorb larger quantities of radiation [50].

Advantages

The advantages of using nanoparticles for drug delivery result from two of their basic properties. First, because of their small size, nanoparticles can penetrate through the smaller capillaries of cells, which allows for economical drug accumulation at target sites. Second, the use of perishable materials for nanoparticle preparation allows for sustained drug release at the target site, over a number of days or even weeks [52]. Nanoparticles are fairly straightforward to create, which is why they are being used in drug delivery. Nanoparticles in drug delivery also offer protect fr the encapsulated drug. The retention of the drug at the target site results in

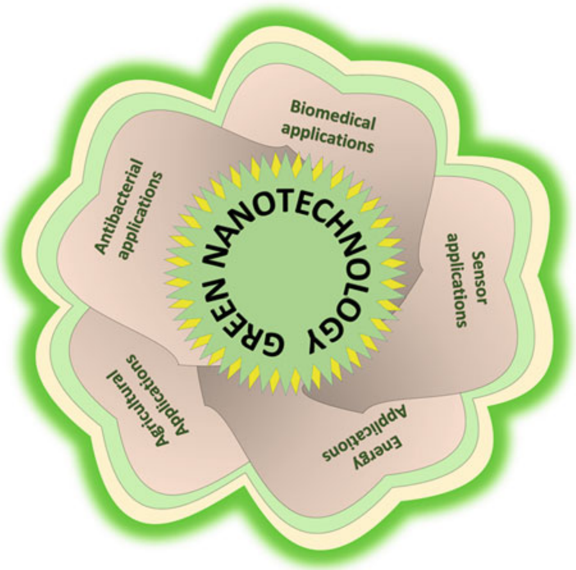


Fig. 3 Different applications of green nanotechnology

longer clearance time. Thus, they have increased therapeutic potency as well as bioavailability. They also have reduced variability, which increases drug stability compared with non-nanoparticulate doses. Furthermore, a nanoparticle drug carrier does not have any biotoxicity. There are no known issues with the large-scale production and sterilization of nanoparticles; however, most studies have not used solely organic solvents [54–56].

The importance of nanoparticles is not just limited to drug delivery. Applied science is expected to revolutionize many electronic products, procedures, and applications, including nanodiodes, nanotransistors, organic light-emitting diodes, plasma displays, and quantum computers. Applied science may also benefit the energy sector, such as in batteries, fuel cells, and star cells that are designed to be smaller and simpler. Manufacturing may also experience improvements from applied science in materials such as aerogels, nanotubes, and nanoparticles. These materials are expected to be sturdier, stronger, and lighter than conventional materials [53] (Fig. 3).

Biomedical Applications

Biomedical nanotechnology may provide ground-breaking opportunities in the battle against several diseases. One opportunity with near-term potential is the detection of molecules related to diseases such as cancer, diabetes, and neurodegenerative diseases, as well as the detection of microorganisms and viruses related to infections such as morbific bacterium, fungi, and human immunodeficiency virus. For example, in the field of oncology, promising novel nanoparticles can respond to external physical stimuli for use in therapeutic delivery systems. Other applications for biomaterials include medical implants and scaffolds for grafts. The technology could possibly create nanostructured surfaces that prevent the adsorption of non-specific macromolecules. The management of surface properties at the nanolevel has been shown to extend the biocompatibility of materials [57–60].

Although this technology is now reaching the market, data on the associated pharmacological risks are still lacking. Reducing the scale of structures to the nanolevel can result in totally different properties. Furthermore, because the chemical composition mostly defines the intrinsic nephrotoxic properties, an extremely small size seems to be a main indicator of aggressive or nephrotoxic effects of particles. From a regulatory standpoint, a risk management strategy is required for all medical technology applications. The impact of nanomaterials and nanoparticles in the medical field is discussed in the following section, followed by an outline of the potential technology tools for this field. Nanomedicine and "nanorobots" are considered, along with the myriad applications for diagnosis and treatment, such as biocompatibility, implants, cardiology, cancer, and theranostics. Finally, the risks to human health and ethical considerations are presented [61–63].

Nanomaterials and Nanoparticles in Medicine

Novel nanomaterials and nanoparticles will likely have a significant impact in a variety of areas. High-performance materials with distinctive properties will be created, which conventional synthesis and production strategies could not achieve. Future nanoparticles might serve as drug-delivery and drug-targeting systems. Because of their size, they are not recognized by the human body. Thus, they can travel through cell membranes and pass through the blood–brain barrier. These polymer structures include liposomes, compound nanoparticles, solid macromolecule nanoparticles, nanocrystals, and specialty compounds such as dendrimers, fullerenes, and inorganic nanoparticles.

Nanoparticles can transport pharmaceuticals exactly to a specific area. Different types of nanoparticles may be used as appropriate for drug and gene delivery. For example, carbon nanotubes and inorganic nanowires exhibit extraordinary mechanical, electric, electronic, thermal, and optical properties. Carbon nanotubes, magnetic iron nanoparticles, and gold-coated silicon dioxide nanoshells can transform electromagnetic energy into heat, causing a temperature increase that is deadly to cancer cells just by increasing the field. With infrared radiation from an external optical device supply at the precise location, these nanoparticles can target tumor cells at specified intervals [64–66].

Quantum dots possess exceptional optical and electronic properties, which may be precisely and dynamically tuned based on their size (2–10 nm) and composition. Because of their relatively cheap and easy synthesis, quantum dots have already entered the marketplace for experimental medical imaging applications. Quantum dots can be created to emit light at any wavelength within the visible and infrared ranges. Furthermore, they may be inserted virtually anywhere, along with liquids or

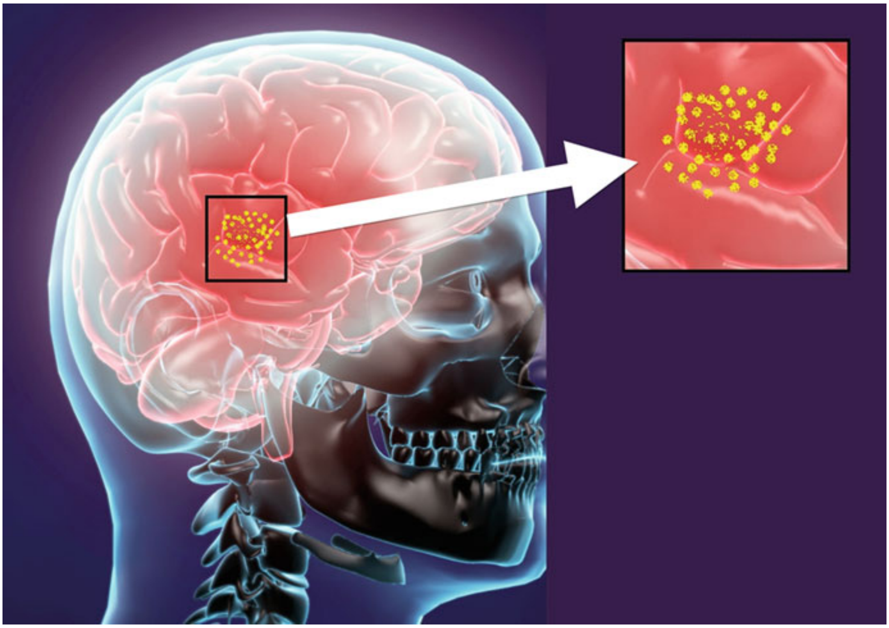


Fig. 4 Bioimaging applications

dyes. Quantum dots can be joined with various surface ligands and inserted into a range of organisms for in vivo analysis.

Dendrimers have improved physical, chemical, and biological properties compared to earlier polymers. Some distinctive properties include their spheric form and presence of internal cavities, making them possible candidates for medical nanovehicles. Dendrimers have a tree-like structure with several branches to which a range of molecules or medicines can be attached. At 5 nm in diameter, dendrimers are sufficiently small to pass through openings in cell membranes, vascular pores, and tissues. University of Michigan researchers attached an antimetabolite and an anticancer drug to the branches of a dendrimer. On alternating branches, they attached fluorescent imaging agents and a B vitamin. Additionally, novel biomaterials were created through structural surface modifications of macro, micro, and nano materials. Management of the surface properties at the nanolevel was shown to enhance the biocompatibility of the materials [69, 71].

Nanoparticles can be used in a number of bioimaging applications (Fig. 4), such as fluorescent biological markers, markers for the detection of proteins, searching for desoxyribonucleic acid structures, and for the separation and purification of biological molecules and cells. They also can be used for resonance imaging improvements, growth destruction via heating, tissue engineering, and drug delivery. For example, gold nanoparticles (gold composites with dielectrical cores and gold shells) may be used for drug delivery. By selecting the correct core-to-shell diameter, the particle will be tuned to be close to the infrared range. Irradiation with an appropriate wavelength will heat the particle, even in deeper skin areas. If the particles are embedded in a temperature-smart hydrogen matrix, the matrix can collapse and discharge the enclosed agents at a specific temperature.

Magnetic nanoparticles (between 2 and 30 nm) can be coated with biological molecules to interact with or bind to a biological entity. Because of their magnetism, they can be manipulated by an external field of force, thereby providing a way to "tag" or address the biological entity. Magnetic nanoparticles can be used to deliver a package (e.g., a malignant neoplasm drug, a cohort of radionuclide atoms) to a targeted region of the body. The magnetic particles can be supplied with energy from the external field, which may heat them to create smart hyperthermy agents that deliver toxic amounts of thermal energy to targeted bodies, such as tumors. In medical and physiological applications, these nanomaterials, nanoparticles, and devices can be designed to act with cells and tissues at a molecular (i.e., subcellular) level with a high degree of purposeful specificity, permitting a degree of integration between technology and biological systems that was not previously possible [71, 75, 82].

As a result of advances in organic chemistry analysis and biological science, diseases can be diagnosed all the way down to molecular abnormalities. Molecular imaging can find the corresponding molecular signatures of diseases and use them for diagnosis. This could ideally result in a diagnosis and medical treatment before the onset of symptoms. In molecular imaging, an imaging molecule is coupled to a transport molecule or particle that possesses a targeting unit (e.g., special receptors, ligands or peptides). The targeting system should be a selected molecular marker of a precise illness so the contrast material accumulates in the diseased tissue. Molecular imaging has been developed for many diagnostic procedures, such as resonance, supersonic imaging, nuclear, and optical imaging technologies [70–73].

Food Applications

Biosensors can be used to detect contaminants in food or environmental media. They provide high specificity and sensitivity, speedy response, user-friendly operation, and compact size at a reasonable cost. Although the direct accelerator inhibition sensors presently lack the analytical capability to discriminate among multiple cyanogenic substances in certain patterns (including the simultaneous presence of significant metals and pesticides), they would be useful as a screening device to determine whether a sample contains one or more contaminants.

These strategies are amenable to the preparation of single-use applications. Nanotechnology can provide solutions for a number of issues regarding food safety, veterinary care, medical treatments, and vaccines for domesticated animals. Medications such as antibiotics, vaccines, and probiotics may be useful in treating infections, vitamin deficiencies, and metabolic problems when used on the nanolevel. Medicines used on the nanolevel may eliminate the biological obstacles associated with the high potency of a distributed dose when their ability to adjust the discharge of a drug and self-regulate.

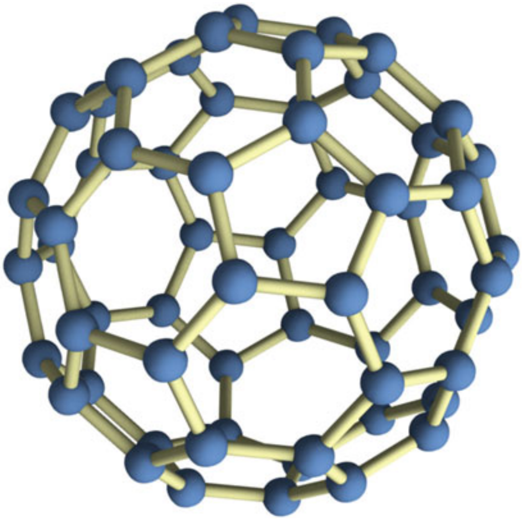


Fig. 5 C-60 carbon particle (Buckyball)

Figure 5 shows a C-60 carbon particle (Buckyball), which is a nontoxic, biocompatible spherical molecule of 1-nm diameter. It can be used to deliver soluble peptides and medicines as required for a specific drug behavior and target site. The nanoparticles will penetrate the skin via minor abrasions; the device is then returned after altering the cell behavior. Dendrimers are artificial three-dimensional macromolecules in which a core particle is encircled with the branches of a tree. They can be conjugated to the target molecule when the drug is biocompatible and are quickly cleared from the blood via excretory organs. The in vivo transport of dendrimer immunosuppressants can reduce the growth by tenfold.

Nanomagnets may also be used as drug delivery devices, especially to target tumors without damaging the surrounding tissues. A variety of proteins, such as simple proteins, gelatin, gliadin, and legumin, could also be used in nanoparticle-based drug delivery systems. Inert nanobeads have been shown to neutralize the substance inflicting arthritis in sports horses. Nano-based antibiotics have been used in the treatment of animal diseases, as lower amounts of antibiotics are needed in this form. Nanoparticle-based metal supplementation is helpful for increasing performance and body composition. Furthermore, iron deficiency is a commonplace problem in animals, especially during gestation and parasitic infestation because of lower bioavailability. However, this bioavailability may be increased with the supplementation of metallic nanoparticles [74–76].

Nanotechnology has been used to create vegetarian fowl/goat meat in the laboratory in massive quantities, maintaining the taste and texture of real meat with none of the risk. This can also address the issue of food shortages and hunger. Engineering can also be used to produce designer eggs with low cholesterol, more substantial vitamins, and desired antibodies. Nanobased sensors also can assist in the early detection of egg-borne pathogens.

Agricultural Applications

The increasing global population has reduced the per capita availability of natural resources. Agriculture around the world is facing a number of challenges, including managing food security due to rapid demographic changes, mitigating the effects of climate change around the globe, and conserving the world's diminishing natural resources [83–86]. Furthermore, this sector of the economy is highly susceptible to climatic changes and harsh weather conditions arising from greenhouse gases and fossil fuels. Thus, modern agriculture practices should not harm anything and anyone on the planet [69]. Crop production and nutritional security can benefit from eco-friendly agricultural inputs such as fertilizers and seeds [43, 86]. Thus, the aim of green nanotechnology is to use biodegradable nanomaterials with no harmful effects on the environment or human beings.

The use of green nanomaterials in contemporary agriculture practices can reduce harmful effects on the environment, reduce the cost of nutrient procurement for improved crops, and increase yields through the need for base management. Green technology aims to reduce the emissions of greenhouse gases into the atmosphere, including carbon dioxide (CO_2), nitrous oxide (N_2O), and methane (CH_4) from agricultural land. Scientific data have demonstrated the positive aspects of using nanomaterials in agriculture to boost crop yields, increase production, improve pest control, and provide farmers with a way to monitor field parameters. All of these aspects help to achieve food security through nanotechnology [43].

Researchers have investigated the effective utilization of agrochemicals, manipulating their physiological parameters for specific types of of plants and soil in the field known as agri nanotechnology. Agrochemicals include fungicides, insecticides, pesticides, and herbicides, which can be scattered and spread at different intervals between crop growth. These chemicals may be lost to the environment directly and indirectly by the leeching and degradation of agrochemicals through hydrolysis (along with water), photolysis (in the presence of sunlight), and microbial degradation. This method is mainly practiced in the European Union, Japan, and the United States. The use of nanomaterials in the field of agriculture reduces costs for crop protection, reduces nutrient loss from the agricultural fields, and increases crop production by various nutrient management techniques. Some nanomaterials for the agricultural sector have been marketed by technology-oriented companies that developed nanosized products for eco-friendly agriculture [46]. The use of nanomaterials also helps to provide accurate and thorough nutrient transport of agrochemicals. Previously, most pesticides primarily contained significantly toxic metals, including arsenic, mercury, lead, and copper [78–80].

Defense of the soil and the environment necessitates the quick, sensitive detectability of pollutants and pathogens with molecular accuracy. The conventional methods of soil fertility evaluation are outdated for crop production and monitoring. Precision sensors are required for onsite detection; moreover, portable devices are being developed for the detection of pests. Applications for these devices include the detection of impurities in diverse sources such as water (e.g., rivers), food ingredients, and packaged foods. A device known as an electronic nose (E-nose) can be used to find different types of odors and detect gases. It is made of gas sensors with nanoparticles as key constituents, such as ZnO wires. Using an algorithm in a collection of gas sensors, the E-nose can locate an odor-causing element—detect the smell much like a human nose can do. A resistance change modifies an electronic signal, which creates a blueprint pattern for detecting gases.

Biosensors are highly efficient at detecting toxins in food items, with more sensitivity, rapid response, user-friendly operation, short operation time at a lower cost than conventional methods. Although direct enzyme inhibitor detectors currently lack the critical capacity to differentiate between a few toxic materials, they are helpful as a screening device to select good-quality ingredients and check existing stock for contaminants. Biosensors are available in multiple-use test strips. Research has shown metallic nanoparticles are much more efficient at detecting flower pathogens and bugs. Hence, nanoparticles have been used in pesticides and insect repellants. Nanotechnology has potential for other applications, such as a nanoparticle-mediated genetic switch, which is an alternative for supplying DNA accompanied by chemical materials into crop tissues to protect the host crops from insects and other parasites.

Porous-hole silica nanoparticles (PHSNs) loaded with validamycin (pesticide) can be used as a green shipping apparatus for water-soluble pesticides. According to Wang et al. [81], nanoemulsions are advantageous in the preparation of insecticides for agriculture. The oil-loaded solid lipid nanoparticles are also useful for the synthesis of nanoinsecticides. Nanosilica, a specific nanomaterial, is synthesized from the element silica. It can be used in anesthetic and biological applications as an agitator and could be acclimated as a nanopesticide. Barik et al. [7] reported on the use of nanosilica as a nanopesticide. It is based on the fact that insects accustomed to the circulation of the lipids carefully create a barrier that prevents desiccation. However, nanosilica receives adsorbed lipids by physisorption and thereby harm the insects. Thus, farmers can kill the pests by just agitating the nanosilica.

Yang et al. [87] installed polyethylene glycol-coated nanoparticles loaded with garlic oil near adult *Tribolium castaneum* insects in a T-shaped ready-to-hit position. The release of additives from the nanoparticles caused the insects to fall onto the ground and die. Bhattacharya et al. [10] hypothesized that nanotechnology would transform current agricultural practices, with pest control as the focus of the study. For example, nanoencapsulation is a promising method to protect host flowers against competition from pests. In nanoencapsulation, an insecticide is slowly released along with uniquely shaped nanoencapsulated particles. Nanoencapsulation with nanoparticles has been reported to kill pests effectively [41]. Teodoro et al. [77] reported that an insecticidal spray of nanoalumina appeared to be effective against insect pests that were destroying wheat crops.

Nanotechnology and nanomaterials in the field of agriculture lessen the volume of sprayed chemicals through improved delivery of important nutrients, reduce nutrient losses in fertilization, and increase yields through optimized water and nutrient control systems. Devices primarily based on nanotechnology are also being researched within the disciplines of botany and genetics.

The main agricultural nanotechnology applications are as follows [20]:

- **Crop production**: Nanocapsules, nanoparticles, nanoemulsions and viral capsids are the major plant production products and fertilizers primarily based on nanotechnology. They are used as smart transport structures for nutrients, to protect against disease, and to fight pests in vegetation. Nanofertilizers have experienced great interest in recent times, including nitrogen fertilizers, potash fertilizers, nanoporous zeolite, zinc nanofertlizer, nanoherbicide, and nanopesticide [58].
- **Soil development**: Nanomaterials can be used for water/liquid retention, including zeolites and nanoclays for water or liquid agrochemical retention inside the soil or for gradual release to the vegetation.
- **Water purification and pollutant remediation**: Nanomaterials and nanoclays may be used as filters for the removal of toxins from the surroundings.
- **Diagnostic**: Nanosensors are surprisingly accurate biochemical sensors that may be used to monitor environmental situations, plant health, and growth, including nanofibers, fullerenes, electrochemically active carbon, nanoaptamers, and wi-fi sensors [58].
- **Plant breeding**: Nanomaterials may be used to deliver deoxyribonucleic acid or ribonucleic acid to plant cells for genetic transformation or to cause defense responses, activated with the aid of pathogens.
- **Nanomaterials from a plant**: Nanomaterials can be constituted of engineered flora or microbes and via the processing of agricultural product waste.

Thus, green nanotechnology concepts can decrease waste, lessen greenhouse gas emissions, and decrease the use of renewable materials [42]. A symbiotic technique referred to as the Green Internet of Nano Things (G-IoNT) holds the ability to greatly improve current agricultural practices. Green nanoparticles, nanosensors, nanorobots and nanodevices are associated with green nanonetworks via G-IoNT, which can revolutionize agriculture and food organization in the twenty-first century.

Summary

Materials decreased to the nano size can have different properties than materials of the same composition on the macromolecular scale, allowing for the unique applications of nanomaterials. For instance, copper in its standard shape has very good traction, when every atom of copper within the metal structure exceeds 50 nm. However, copper nanoparticles (<50 nm) have resounding hardness and do not show any traction.

A nanomaterial with some of the greatest potential is the carbon nanotube, which has very little resistance and freely circulating electrons. Moreover, carbon nanotubes are very strong, so they can be used as a construction material. Fullerenes are molecules composed of five- or six-membered rings of carbon atoms. They are spatially arranged in a spherical form, which makes them extraordinarily resistant to physical impacts. Their potential use may include the manufacture of tough disks or antiaging cream. Nanotechnologies are also used as dietary supplements. Companies are developing nanomaterials to change the taste of food, as well as improve food safety and the health benefits that food delivers.

Even though there are a large number of potential applications of nanotechnology within the food industry, many of them may be difficult to develop commercially because they are too expensive or too impractical to implement on a large scale. Most likely, the limited application of nanotechnology in the food industry will change as nanofabrication technology becomes more affordable.

Nanotechnology has the capacity to completely change the state of modern agriculture and food industries. Through recent advancements for the treatment of plant diseases, it is possible to quickly recognize pathogens using nanokits, enhance the potential of vegetation to absorb nutrients, and so on. Nanobiosensors used with other nanostructures can even fight specific crop pathogens and improve sustainability. In the future, nanostructured catalysts may be available to increase the effectiveness of insecticides and also reduce the dosage level for crop plants [31].

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