International Journal for Multidisciplinary Research (IJFMR)
E-ISSN: 2582-2160 ● Website: www.ijfmr.com ● Email: editor@ijfmr.com

Green Synthesis of Metal Nanoparticles: A Therapeutic Boon from Nature to Mankind

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Abstract

The pharmaceutical and biomedical industries are increasingly using novel nanomaterials or nanostructures, which encourage the biogenic synthesis of nanoparticles with lower toxicity because of its straightforward mechanism, wide availability, affordable price, and environmental friendliness. Green nanoparticles, which are increasingly important in the disciplines of medicine, agriculture, and bioremediation, are created primarily through the phytogenic reduction process. When used effectively, the phytochemicals in the plant extract can act as reducing agents to convert metal salts or ions into metal or metal oxide nanoparticles. Although metal nanoparticles are being used in various economic sectors, there is a growing curiosity about how safe their production is for humans and for the environment. The two main processes for making nanoparticles are chemical and physical, both of which can be expensive and potentially damaging to the environment. The potential for synthesizing metal nanoparticles from plant extracts is the focus of the current review. It has been actively pursued in recent years as a different, efficient, economical, and environmentally friendly way to make nanoparticles with specific properties.

Keywords: Plant extract, Nanoparticle synthesis, Green synthesis

Introduction

Due to its applications in numerous areas of human welfare, nanotechnology has advanced significantly to rank among the most researched and thriving fields over the past 20 years. Nanoparticles (NPs) are incredibly small particles ranging from 1 to 100 nm, created naturally or artificially. They exhibit unique and valuable chemical and physical trait [1]. The nanoscale enhances the catalytic, magnetic, electric, mechanical, visual, chemical, and biological capabilities of particles. Because of their high surface-to-volume ratio, nanoparticles have increased reactivity, mobility, dissolving characteristics, and strength. Many industries, including those in food, agriculture, cosmetics, pharmaceutical, and other industries, are finding extensive use for NPs and the nanomaterials they have produced. Food processing and preservation as well as food packaging are examples of how nanoparticles are used in the food sector. Nanotechnology is used in the agricultural sector to create nano-fertilizers, insecticides, herbicides, and sensors. A variety of antibacterial, antifungal, anti-plasmodial, anti-inflammatory, anticancer, antiviral, antidiabetic, and antioxidant medicines are produced in the pharmaceutical sector using nanotechnology. Another application for nanotechnology is the early diagnosis of deadly diseases like cancer. The capacity of NPs to degrade a wide range of contaminants, including organic compounds and dyes, has also led to their use in bioremediation. It has been demonstrated over the past ten years that numerous biological systems, including plants, algae, diatoms, bacteria, yeast, fungi, and human cells, are capable of reducing inorganic metal ions into metal nanoparticles [2]. Notably, the method for creating plant-based nanoparticles described in this review has many benefits over other biological systems [3]. Plants are a desirable platform for nanoparticle synthesis due to their low cultivation costs, rapid production times, safety, and capacity for increased production [4]. Four main classes of NPs are identified based on their chemical make-up: composite-based, metal, and metal oxide-based, and bio-organic-based. Additionally, NPs can be categorized as organic or inorganic in nature. In contrast, inorganic NPs are based on inorganic substances that are composed of metals and metal oxides, such as silver oxide, zinc oxide, etc. Polymeric NPs, lipid-based nanocarriers, liposomes, carbon-based nanomaterials, and solid lipid NPs are examples of organic nanoparticles that degrade naturally. Silver nanoparticles (Ag NPs) are the most frequently used synthetic NPs, with over 25% of consumer products containing them. The major application of silver nanoparticles is that they can be used as antibacterial, antifungal, and antiviral agents.

Properties of nanoparticles

Microorganisms, plants, and other biological structures are included in the process of removing toxins and waste materials from the environment. This is done by oxidizing, reducing, or catalyzing the metals with metallic nanoparticles [5]. Due to their special qualities as an insulator, optic, antimicrobial, antioxidant, anti-metastasis, biocompatible, stable, and manipulable particles, these metallic nanoparticles made through biological processes are used in the biomedical field for a number of biomedical uses, including drug delivery, bioimaging, cancer treatment, medical diagnosis, and sensor construction. Metallic nanoparticles are now very important because they can be used in the industrial field due to their catalytic activity. Figure 1 shows in detail the uses of metallic nanoparticles.

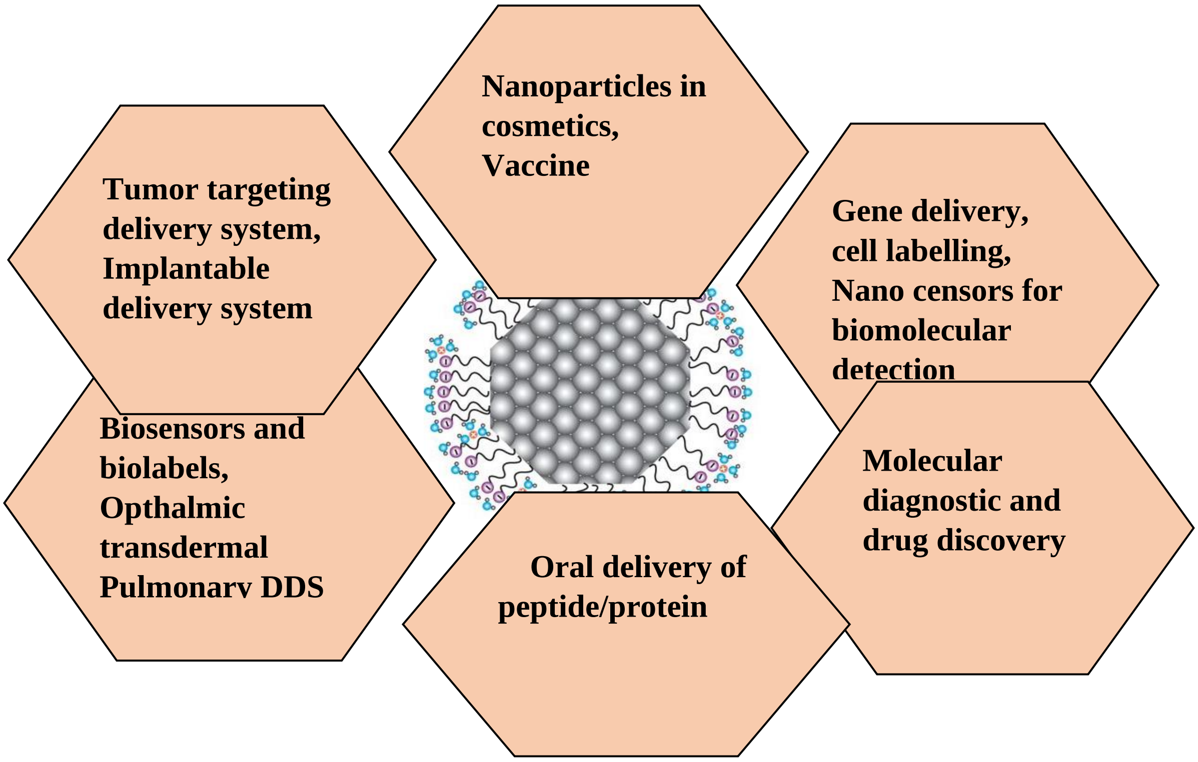

Fig 1: Applications of nanoparticles

The fact that nanoparticles can display different properties and functions than typical bulk materials is why scientists are currently interested in them. The effects of classical physics are reduced and quantum physics becomes active, which is the most crucial element that makes it possible to produce nanostructures with the desired size, shape, and properties and to use them in various fields [6]. Other causes for the distinct behavior of nanoparticles include the lack of load carriers, size-dependent electronic structures, and an increase in the surface-to-volume ratio.

Methods of nanoparticle synthesis

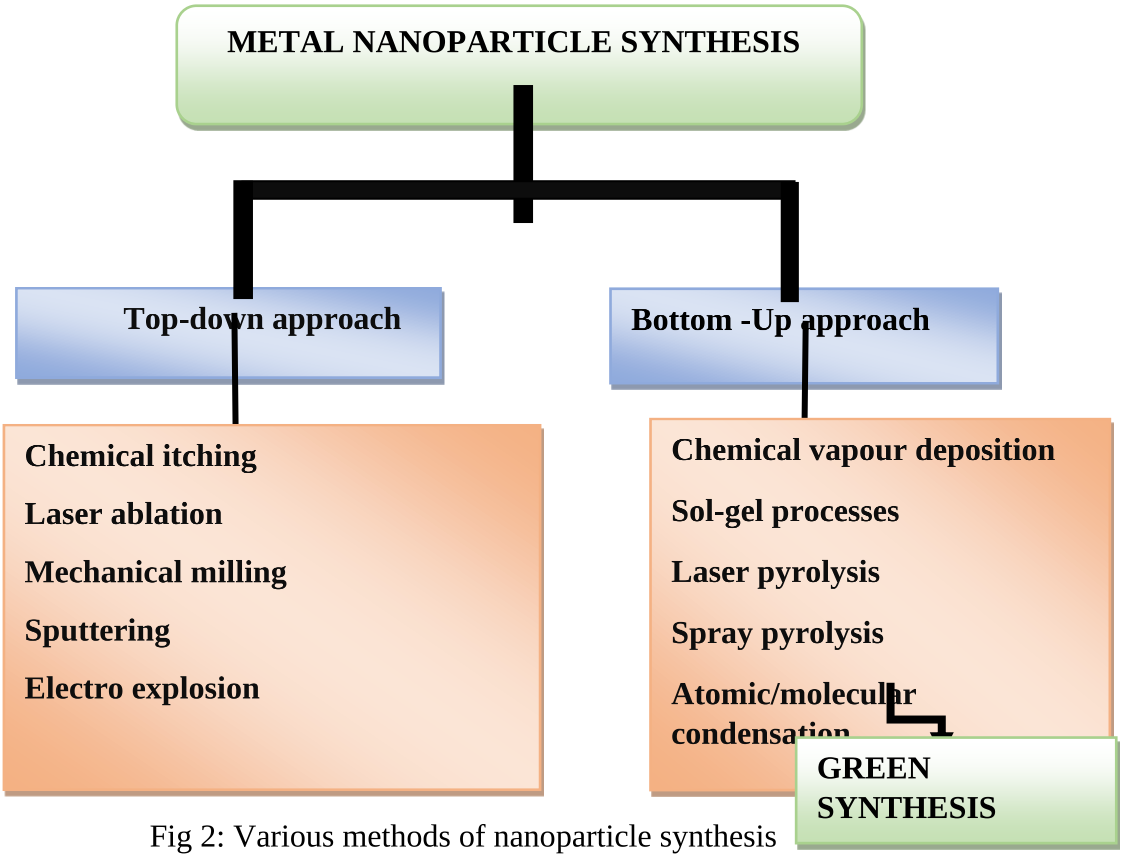

Fig 2: Various methods of nanoparticle synthesis

Top-down approach

Using a top-down approach, smaller objects are processed to create larger ones at the nanoscale. Top-down nanotechnology is demonstrated in the fabrication of integrated circuits. It has now developed to the point of fabricating nanoelectromechanical systems (NEMS), which incorporate tiny mechanical parts like levers, springs, and fluid channels along with electronic circuits on a very small chip. Large structures, like silicon crystals, serve as the starting point for these fabrications. A variety of lithography techniques, including photon, electron, and ion beam lithography, have made it possible to produce such tiny chips. In order to improve the surface area to volume aspect ratio and boost reactivity, larger-scale materials are occasionally ground down to the nanometer scale. Nanogold, nanosilver, and nano titan dioxide are among the many applications for these nanomaterials. The creation of carbon nanotubes from graphite in an arc oven is another example of a top-down approach in nanotechnology.

Bottom-up approach

In nanotechnology, smaller building blocks like atoms and molecules are used as the foundation to create larger nanostructures. The term "self-assembly" describes the method by which desired nanoparticles come together on their own without help. As the size of the objects declines, the bottom-up technique in nanofabrication has become an increasingly essential supplement to top-down methods. In nature, biological systems have used chemical forces to construct the structures that cells require to function. This is a form of bottom-up nanotechnology. Research is being done to mimic this characteristic of nature in order to create small clusters of atoms, which can later self-assemble into more intricate structures. A good illustration of bottom-up nanotechnology is the production of carbon nanotubes through a metal-catalyzed polymerization process.

Green synthesis of metal nanoparticles

Recent research has demonstrated that it is possible to create nanoparticles that are both safe for use and eco-friendly by using microbes and plants. Microbes and plants have always been able to collect and store inorganic metallic ions from the environment. In order to minimize pollution and recover metals from industrial waste, many living things have strong biological factories. The ability of a living thing to use its metabolic activities to convert inorganic metallic ions into metallic nanoparticles has opened a relatively new and largely unexplored field of study [6]. Since it was discovered that microbes can interact with, remove and gather metallic elements from their environment, they are used in many biotechnological applications, including bioremediation and bioleaching etc [7]. They can interact with their environment and facilitate a wide range of oxidation-reduction processes and biochemical transformations to their lipid-based amphipathic membranes [8]. The formation of linked oxidation and reduction in nanoparticles may also be accelerated by microorganisms grown in particular environment [9]. This remains accurate even when considering the use of plants in nanoparticle production. Using plants instead of other biological systems, such as bacteria and fungi, which are less harmful to the environment, has many benefits, including avoiding costly and time-consuming isolation and preparation procedures. However, it is generally believed that using plants or plant extracts to make nanoparticles is both safer and more efficient than using other biological systems. An additional benefit of plant-based biosynthesis over competing techniques is that it is a straightforward process that is simple to scale up for the mass production of nanoparticles. This is a big advantage over the alternatives.

Each living thing has a unique capacity for processing biochemical information, which makes nanoparticle production possible. Due to their unique metabolic processes and enzyme activity, only specific biological organisms are able to produce nanoparticles. Therefore, it is essential to meticulously choose the appropriate biological entity in order to create nanoparticles with precisely articulated features such as size and form. Biological organisms with a high capacity for heavy metal accumulation are more likely to synthesize metallic nanoparticles, but there are a few exceptions to this generalization. Working with microorganisms requires knowledge of the cultivation methods. Numerous culturing factors need to be optimized to increase enzyme activity, including nutrition, light intensity, medium pH, temperature, mixing rate, and buffer strength [10]. In contrast to traditional chemical synthesis, the biological synthesis of nanoparticles using plants and plant extracts presents a novel alternative. It has been shown that several elements found in plant extracts can prevent and control the emergence of nanoparticles [11]. Due to their complexity and lack of toxicity, these biological molecules have gained popularity.

Plant-mediated synthesis of nanoparticles

Plants are the most suitable for the green synthesis of nanoparticles than microbes because they are non-pathogenic. A variety of metal nanoparticles have been produced using different plants. These nanoparticles have distinctive optical, thermal, magnetic, physical, chemical, and electrical properties that set them apart from their bulk counterparts and they can be used in a wide range of applications, especially in a variety of human-interest fields [12].

Due to its quick, environment-friendly, non-pathogenic, economical safe protocol, the use of plants as the production assembly of silver nano-particles has attracted attention. The production and stabilization of silver ions are achieved by combining biomolecules such as proteins, amino acids, enzymes, polysaccharides, alkaloids, tannins, phenolics, saponins, terpenoids, and vitamins, which are already accepted in plant extracts with medicinal value These are chemically complex but environmentally safe structures. Leaf extracts from *Acalypha indica* have demonstrated their ability to create silver nanoparticles. The resulting silver nanoparticles were extremely homogeneous and ranged in size from 20 to 30 nm [13]. In a different study, *Medicago sativa* seed exudates were used to create silver nanoparticles. At 30°C, 90 percent of the total of the Ag+ was reduced in about 50 minutes, and one minute after the metal salt exposure, nanoparticles were seen to form. The resulting nanoparticles ranged in size from 5 to 108 nm. They are like flowers, triangles, or spheres, and had a diverse size distribution [14]. Additionally, *Ocimum sanctum* leaves extract can reduce Ag+ to form silver nanoparticles that vary in size from 3 to 20 nm. Ag nanoparticles have been made quickly using fruit extract from *Terminalia chebula* [15]. Ag nanoparticles with a cubic shape and sizes between 50 and 200 nm were produced from the extract of *Eucalyptus macrocarpa* leaves. The extract of *Nyctanthes arbotristis* flowers produced gold nanoparticles with a size of 20 nm, whereas the extract of *Coriandrum sativum* produced silver and gold nanoparticles with diameters ranging from 7 to 58 nm [16]. Phyllanthin derived from *Phyllanthus amarus* can be used to create gold and silver nanoparticles.

The production of copper and copper oxide nanoparticles was carried out using plant extracts. Cu nanoparticles made from *Syzygium aromaticum* and *Magnolia kobus* leaves displayed spherical to granular shapes with an average particle diameter of 40 nm and 40 to 100 nm [17]. Latex from the stem of *Euphorbia nivulia* (Common Milk Hedge) was utilised to create a significant class of stabilised and coated copper nanoparticles. *Sterculia urens* (Karaya gum) was used in the synthesis of significantly stable spherical nanoparticles of CuO with a particle size of 4.8 nm· *Azadirachta indica*, *Anacardium occidentale* and extracts from cruciferous vegetables are just a few plants that have been successfully used to create Ag-Au bimetallic nanoparticles.In order to create palladium nanoparticles with a size range of 75–85 nm, *Cinnamon zeylanicum* bark extract and *Annona squamosa* peel extract were both used in the process[18].

Using aqueous extracts from the bran of *Sorghum bicolor* and leaf extracts *from Azadirachta indica, Euphorbia milii, Tridax procumbens, Tinospora cordifolia, Datura innoxia, Calotropis procera, and Cymbopogon citratus,* iron (Fe) nanoparticles were produced [19]. Spherical lead nanoparticles between 10 and 12.5 nm in size have been created using the latex from the *Jatropha curcas* plant [20]. Metallic nanoparticles are produced using plant extracts from particular plant parts or entire plants. Furthermore, it was reportedly possible to make Palladium nanoparticles in a novel way by cultivating the plant *Arabidopsis thaliana*. Metallic nanoparticle production is possible in living plants also.

Algae-mediated synthesis of nanoparticles

The production of silver nanoparticles has been carried out using a variety of algae, including *Pterocladia capillacae, Jania rubins, Ulva faciata, and Colpmenia sinus* [21]. The NPs had a spherical shape and a diameter of 7–20 nm. Researchers believe that their antibacterial action is caused by the blockage of bacterial cell processes that occurs as a result of their adhesion to the cell wall. Recent studies have shown the effectiveness of antimicrobial silver nanoparticles made from *Sargassum longifolium* algae [22].

The production of silver nanoparticles with a diameter of 25–44 nm has been done with the help of the freshwater green algae *Pithophora oedogonia*. The reduction of $AgNO_3$ to silver nanoparticles by sugars, saponins, steroids, and proteins was proven with the help of IR spectroscopy and quantitative analysis. It was discovered that they were more efficient than Gram-positive bacteria, *Euglena gracilis* microalgae living cells were used by Dahoumane and others to make gold nanoparticles [23]. Similar to other marine algae, the biomaterial in the algae serves as a reducing agent, capping agent, and catalyst. Several parameters, including pH, reaction time, temperature, and concentration, influence nanoparticle yield. The production and emission of gold nanoparticles are believed to occur in three steps: After absorbing Au^{3+}, it is reduced to Au and then released as gold nanoparticles into the solvent. This hypothesis is generally accepted. They are dispersed, so they don't congregate in one place. They can range in size from 10 nm to several hundred nm. This shows that all algae possess tolerance and growth limits.

Nanoparticle synthesis from bacteria

Because of their remarkable ability to reduce heavy metal ions, bacteria are one of the promising ones for the manufacturing of nanoparticles. For example, certain bacterial species have evolved the capacity to use defence mechanisms to counteract stresses like toxicity of heavy metal ions or metals. For instance, it was discovered that *Pseudomonas stutzeri* and *Pseudomonas aeruginosa* could develop and endure in environments with high metal ion concentrations. An innovative combinational synthesis method for the green biosynthesis of silver NPs has been described by Saifuddin et al.using a mixture of *Bacillus subtilis* culture supernatant and microwave irradiation in water. With the help of B. *subtilis* supernatants, they reported the extracellular biosynthesis of monodispersed silver NPs (5–50 nm). They used microwave radiation, which might provide uniform heating around the NPs and could facilitate the digestive ripening of particles without aggregation. Silver NPs (40 nm) were produced extracellularly by bioreducing aqueous Ag+ ions with the culture supernatant of *Bacillus licheniformis* [24].

By incubating the bacterial cells with gold chloride at room temperature and pressure, *Bacillus subtilis* 168 was reportedly able to convert Au3+ ions to octahedral gold NPs (5–25 nm) inside the bacterial cells. It was discovered that B. *subtilis* uses different reduction processes to reduce chloroaurate and silver. Unlike silver NPs, which can only be biosynthesized extracellularly, gold NPs can be produced both intracellularly and extracellularly. *Bacillus megaterium* D01 has demonstrated a significant capacity for Au3+ adsorption. Gold nanoparticles (nm) can be produced using *Escherichia coli* strain DH5 (wang et al., 2007). The NPs had irregular shapes and sizes. They were mostly spherical, but there were also some triangles and quasi-hexagons present... In a different study, the nonpathogenic strain of *Esrechia coli* MC4100 and *Desulfovibrio desulfuricans* ATCC 29577 were used to recover gold from jewelry wastes [25].

Because of their distinctive optical and electrical characteristics, zinc oxide (ZnO) nanoparticles (NPs) are increasingly used in biosensors, nanoelectronics, and solar cells. These NPs are also employed as food additives and are also used in cosmetics and sunscreen sectors due to their transparency and ability to reflect, scatter, and absorb UV rays. Additionally, the zinc oxide nanoparticles can be used in various biological applications such as antibacterial agents, medication delivery, and bioimaging probes etc. It has been revealed that the repeatable bacterium *Aeromonas hydrophila* can be used to make zinc oxide nanoparticles in an inexpensive and simple manner. Atomic force microscopy (AFM) revealed that the NPs were round, oval, and 57.72nm in size on average. X-ray diffraction (XRD) proved that the NPs' are crystalline in nature.

Nanoparticle synthesis from fungi

The exploration of fungi's involvement in nanobiotechnology is deemed essential. Fungi have acquired significant attention in research on the biological synthesis of metallic nanoparticles because of their tolerance and potential to bioaccumulate metals. Fungi are advantageous because they are simple especially, in the creation of nanoparticles. As highly effective extracellular enzyme secretors, fungi are capable of producing huge amounts of enzymes [26]. The economical viability and simplicity of using biomass are the two benefits of adopting a green approach to make metallic nanoparticles. Additionally, a few species develop quick which make maintenance and culture in the lab quite simple. Most fungi have significant intracellular and wall-binding metal absorption capabilities. Fungi can create metal nanoparticles and nanostructures by employing reducing enzymes either intracellularly or extracellularly along with the biomimetic mineralization process. *Aspergillus fumigatus* is utilized to make extracellular silver nanoparticles that are between 5 and 25 nm in size as compared to *Fusarium oxysporum*, however, the disadvantage is that it is difficult to anticipate the catalytic activity provided by the size variance across batches [27]. The ability of A. *fumigatus* to convert silver ions into nanoparticles after only about 10 minutes of contact makes it an attractive option for the bioproduction of silver nanoparticle. *Trichoderma reesei*, a fungus, was also used to create extracellular AgNPs with a size range of 5–50 nm nanoparticles.

Platinum nanoparticles were created biologically using the fungus *Neurospora crassa* (PtNPs). It produced single Platinum nanoparticles inside of cells that ranged in size from 4 to 35 nm. They can also produce spherical nano-agglomerates with diameters ranging from 20 to 110 nm. Using both biomass and N. crassa extract, PtNPs were produced. Single-crystal nano agglomerates are found in PtNPs produced from N. *crassa* extract. Both extracellular and intracellular production of Platinum nanoparticles by F. *oxysporum* has been documented, however the amount generated intracellularly was not as good. It has been noted that the fungi *Verticillium sp.* and the phytopathogenic F. *oxysporum* produce magnetite, a common form of iron oxide, inside the cells. In comparison to bacteria, using fungi to synthesize nanoparticles has some advantages, including easier scaling up and downstream processing, improved economics, and a larger surface area [28].

Nanoparticle synthesis from yeast

Yeast production is straightforward to manage in lab conditions, and its quick growth and usage of basic nutrients have various advantages in the bulk synthesis of metal nanoparticles. Gold nanoparticles are produced by the yeast strains *Candida glabrata* and *Saccharomyces Pombe*. Further, research has been done on the extracellular production of silver and cadmium sulphide nanoparticles. Quinones and membrane-bound (cytosolic) oxidoreductases could be used to explain the most prevalent principle of nanoparticle production by yeast. The pH-sensitive oxidoreductases were mentioned as having the potential to function in different ways depending on pH. The increased pH in the internal environment of yeast may activate reductases, which in turn may reduce metal ions during the formation of nanoparticles [29]. Additionally, the production of phytochelatin synthase, which is responsible for internal stress elimination, and could be potentially initiated by a metabolic cascade of reactions in response to the presence of metals in the nutrient medium.

Nanoparticle synthesis from cyanobacteria

The creation of nanoparticles with environment-friendly techniques is more advantageous than synthetic techniques [30]. Nanometals can be made inexpensively and sustainably using cyanobacteria strains. Time savings during extensive manufacturing at ambient temperatures is one of the benefits of cyanobacterial technology. They develop significantly, more quickly and are easier to control than plants. Studies on molecular biology and ecology connected to nanoparticle synthesis substantially enhance the creation of efficient application-oriented nanoparticles. Different types of unicellular and colonial species of cyanobacteria are used frequently in the biosynthesis of nanoparticles. Colonies can develop into filamentous, spherical, or even solid balls. During photosynthesis, they may also fix atmospheric nitrogen in addition to carbon dioxide. They require less chemical input because they are all photoautotrophic and may thrive on chemo-autotrophic situations in both light and night. Out of the 30 cyanobacterial strains (unicellular, colonial, undifferentiated, and differentiated filamentous) tested for the silver nanoparticles biosynthesis, *Cylindrospermum stagnale*, a filamentous heterocystous cyanobacteria strain, developed nanoparticles of 38–40 nm. Nanosilver was created using a productive strain of the cyanobacterium *Gloeocapsa* species[31]. The extracellular synthesis of AgNPs was initially determined by visual examination of the cultured flask solutions for color changes from transparent brown to black. They may be essential since cyanobacteria are a strong candidate for the production of nanoparticles.

Green nanotechnology and its applications

Agriculture

It is used in the field of agriculture to increase food production and security. Nano fertilizers are used to increase agricultural yields. They are required only in smaller amounts and can increase the efficacy of fertilizers. Nano pesticides can be utilized against various crop pests which can be used as an important tool in upcoming agricultural pest management. Nanostructured alumina can be used which acts as a negatively charged insecticide and come in contact with a positively charged insect body and may ultimately result in dehydration and detachment of insect from the crop. Permethrin in nanoform has a higher adsorption rate as compared to conventional form, especially against *Aedes aegypti*. Copper oxide nanoparticles also show enhanced activity against various crop pests [32].

Food Industry

Nanoparticles play an important role in the production, packaging, storage, and transportation of food products. Nanocomposites in food packaging act as nanosensors for checking the quality of food produced. Nanocarriers act as an extraordinary delivery system to carry the food additives into the food ingredients without changing the normal physiochemical properties of food particles. Nanoparticle materials such as starch and sorbic acid-based films are utilized in various packaging applications for their microbial-inhibiting properties [33]. Nano-enabled packaging is also used in the bread and meat industries. Nanotechnology also includes another important area called nanoencapsulation which is also used for the effective delivery of food ingredients and additives. This technique also uses to mask the taste of tuna fish oil which is rich in omega-3 fatty acids.

Medicine

Nanoparticles are extremely small-sized particles and have the ability to travel through fine blood capillaries. Nanoparticles have a high ability to bind with biomolecules and thereby reduce oxidative stress in tissues. Because of their peculiar structure, they can be effectively used for delivering the drugs at target sites and thereby help in the quick penetration of drugs in diseased tissue. Silver nanoparticles have high catalytic activity and stability. They possess anti-viral, anti-bacterial, and antifungal properties. They have a high retention time hence used to treat cancerous cells. Silver nanoparticles from *Allium sativum* can be used to treat gastrointestinal carcinoma. Nanoparticles of gold possess anti-cancer properties. They act by absorbing protons and convert that proton into heat which destroys the cancer cells. Nanoparticles obtained from iron exist in two forms magnetite and maghemite. Iron oxide nanoparticles possess various properties like high solubility, stability, distribution biocompatibility, and high circulation time. But iron nanoparticles may get precipitated and aggregated when given in vivo. Hence it should be coated to avoid aggregation. They are also capable of producing various cellular modifications including apoptosis and necrosis [34]. However, the use of nanoparticles as drugs requires further investigation. A thorough study on all the possible hazards and toxic impacts of nanoparticles on humans and the environment should be done before applying them in medicines.

Purification of water

Water obtained from natural sources is contaminated with organic, inorganic, biological, and radiological substances. The most common method used for the removal of waste from water is the process of adsorption. With the help of nanotechnology, it is possible to use nano adsorbents as they exhibit high efficacy and a faster adsorption rate. Nanofiltration is another technique used for the removal of waste particles from water. Various commercially available home water purification systems contain silver which includes Aqua Pure and QSI-Nano. The metal nanoparticles can also be used as nanocatalysts in wastewater treatment because of their surface-to-volume ratio and high surface catalytic activity. They act by degrading contaminants [35].

Limitations

Even though nanoparticles have a wide range of applications. Its use is limited as it possesses some amount of toxicity. The release of nanoparticles into the environment from industries may damage the ecosystem balance. Nanoparticles have also increased the number of ailments, including diabetes, cancer, and bronchial asthma. Animal reproductive systems are also impacted by nanoparticles. Nanoparticles enter the animal body by inhalation and ingestion, where they may produce reactive oxygen species that cause lipid peroxidation, mitochondrial damage, and other problems. Green synthesis of nanoparticles is economical as compared with the conventional method however they possess certain challenges. These challenges need to be addressed to make them more useful to humans. The toxicity of nanoparticles should be studied in detail so that it can be applied in various fields

Conclusion

Metallic nanoparticles can be produced safely, non-toxically, environmentally, and beneficially using green synthesis technology. Protocols must be changed in order to make these methods more widely available, practical, and economical for the mass production of nanoparticles. An important development in applied nanotechnology is the development of trustworthy and environment-friendly methods for the manufacture of metallic nanoparticles. Many of these solutions are still in the early stages of development, therefore issues must be resolved. Controlling the stability and aggregation of nanoparticles, as well as crystal formation, shape, and size, are some of these. Nanoparticle separation and purification is another crucial component that requires more research. Metal nanoparticles generated by plants or plant extracts are more stable than those created by other living things. It is remarkable that how much more of the proteins, enzymes, and biomolecules required for the biosynthesis and stability of nanoparticles can be produced by genetically modified organisms. We believe that a genetic alteration to raise the metal tolerance and accumulation capacity is the best long-term strategy to enhance the creation of metal nanoparticles utilising the "green synthesis" method.

Acknowledgment

We express our gratitude to our college, guides and colleagues for their priceless support and direction. We successfully finished this review publication with their help and timely advice. Throughout the whole process, we appreciate their constant encouragement and support. Additionally, we want to thank our journal for providing an opportunity to publish this review. We are grateful to their team's expert reviewers for their insightful comments and recommendations, which helped us to publish this review publication.

References

1. Sahoo, M.; Vishwakarma, S.; Panigrahi, C.; Kumar, J. Nanotechnology: Current applications and future scope in food. *Food Front.* 2021; *2*:3–22.
2. Govindaraju K., Khaleel Basha S, Ganesh Kumar V, Singaravelu G., *J. Materials Sci.* 2008;43:5115–5122
3. Kowshik, M., Ashtaputre,S., Kharrazi, S., Vogel˒ V., Urban,J., Kulkarni˒ S, Paknikar., M. Extracellular synthesis of silver nanoparticles by a silver-tolerant yeast strain MKY3. Nanotechnology.2002; 14(1): 95–100
4. Rautaray D., Ahmad A., Sastry M.. *J. Am. Chem. Soc.* 2003;125(48):14656–14657.
5. Pandey, R.K.; Prajapati, V.K. Molecular and immunological toxic effects of nanoparticles. *Int. J. Biol. Macromol.* **2018**;*107*:1278–1293.
6. Baker, S, Harini, B. P, Rakshith, D, and Satish, S. Marine Microbes: Invisible Nanofactories. *J. Pharm. Res.*2013:383–388.
7. Vicas, S. I., Cavalu, S., Laslo, V., Tocai, M., Costea, T. O., and Moldovan, L. Growth, Photosynthetic Pigments, Phenolic, Glucosinolates Content and Antioxidant Capacity of Broccoli Sprouts in Response to Nanoselenium Particles Supply. *Not Bot. Horti Agrobo*.2019;47:1-10
8. Cavalu, S., Fritea, L., Brocks, M., Barbaro, K., Murvai, G., Costea, T. O., et al. Novel Hybrid Composites Based on PVA/SeTiO2 Nanoparticles and Natural Hydroxyapatite for Orthopedic Applications: Correlations between Structural, Morphological and Biocompatibility Properties.2020:7

9. Kowshik, M., Deshmukh, N., Vogel, W., Urban, J., Kulkarni, S. K., and Paknikar, K. M. Microbial Synthesis of Semiconductor CdS Nanoparticles, Their Characterization, and Their Use in the Fabrication of an Ideal Diode. *Biotechnol. Bioeng.*2002;78:583-588
10. Singh, A., Jain, D., Upadhyay, M. K., Khandelwal, N., and Verma, H. N. Green Synthesis of Silver Nanoparticles Using Argemone Mexicana Leaf Extract and Evaluation of Their Antimicrobial Activities. *Dig. J. Nanomater. Biostructures.2010;* 5: 483.
11. Narayanan KB, Sakthivel N. Biological synthesis of metal nanoparticles by microbes. Advances in Colloid and Interface Science.2010;156:1–13.
12. Hussain I, Singh NB, Singh A, Singh H, Singh SC. Green synthesis of nanoparticles and its potential application. Biotechnology Letters.2016; 38:545–60.
13. Krishnaraj C., Enthai Ganeshan J., Seetharaman R., Kumar S., Kalaichelvan P., Mohan N. Synthesis of silver nanoparticles using *Acalypha indica leaf* extracts and its antibacterial activity against water borne pathogens. *Colloids Surf. B Biointerfaces*.2009;76:50–56
14. Lukman A., Gong B., Marjo C., Roessner U., Harris A. Facile synthesis, stabilization, and anti-bacterial performance of discrete Ag nanoparticles using *Medicago sativa* seed exudates. *J. Colloid Interface Sci.* 2010;353: 433–444.
15. Jebakumar Immanuel Edison T. N., Sethuraman M. Instant green synthesis of silver nanoparticles using *Terminalia chebula* fruit extract and evaluation of their catalytic activity on reduction of methylene blue. *Process Biochem.2012;* 47: 1351–1357.
16. Mittal, D.; Kaur, G.; Singh, P.; Yadav, K.; Ali, S.A. Nanoparticle-Based Sustainable Agriculture and Food Science: Recent Advances and Future Outlook. *Front. Nanotechnol.* **2020**, *2*, 579954.
17. Subhankari I., Nayak P. Synthesis of copper nanoparticles using *Syzygium aromaticum* (Cloves) aqueous extract by using green chemistry. *World J. Nano Sci. Technol.2013;* 2:14–17
18. Roopan S., Thakur R., Rahuman A., Kamaraj D. C., Annadurai B., Tammineni S.Low-cost and eco-friendly bio-synthesis of silver nanoparticles using *Cocos nucifera* coir extract and its larvicidal activity. *Ind. Crops Prod*. 2013;43: 31–635.
19. Shah S., Dasgupta S., Chakraborty M., Vadakkekara R., Hajoori M. Green synthesis of iron nanoparticles using plant extracts. *Int. J. Biol. Pharm. Res.2014;* 5:549–552.
20. Joglekar S., Kodam K., Dhaygude M., Hudlikar M. Novel route for rapid biosynthesis of lead nanoparticles using aqueous extract of *Jatropha curcas* L. *latex*. *Mater. Lett.* 2011;65:3170–3172.
21. El-Rafie, H. M., El-Rafie, M. H., and Zahran, M. K. Green Synthesis of Silver Nanoparticles UsingPolysaccharides Extracted from marine Macro Algae. *Carbohydr.Polym.2013;* 96:403–410.
22. Rajeshkumar, S., and Malarkodi, C. *In Vitro* Antibacterial Activity and Mechanism of Silver Nanoparticles against Foodborne Pathogens. *Bioinorganic Chem. Appl.* 2014: 1–10.
23. Dahoumane, S. A., Yéprémian, C., Djédiat, C., Couté, A., Fiévet, F., Coradin, T., et al. Improvement of Kinetics, Yield, and Colloidal Stability of Biogenic Gold Nanoparticles Using Living Cells of Euglena Gracilis Microalga. *J. Nanopart Res.2016;* 18
24. K. Kalishwaralal, V. Deepak, S. Ramkumarpandian, H. Nellaiah, and G. Sangiliyandi, Extracellular biosynthesis of silver nanoparticles by the culture supernatant of *Bacillus licheniformis*. *Materials Letters*.2008;98:4411–4413
25. K. Deplanche and L. E. Macaskie. Biorecovery of gold by *Escherichia coli* and *Desulfovibrio desulfuricans*. *Biotechnology and Bioengineering*.2008;9:1055–1064

26. Castro L., Blázquez M. L., Muñoz J., González F., Ballester A. Biological synthesis of metallic nanoparticles using algae. *IET Nanobiotechnol.*2012;7:109–116
27. Parker HL, Rylott EL, Hunt AJ, Dodson JR, Taylor AF, Bruce NC, Clark JH. Supported palladium nanoparticles synthesized by living plants as a catalyst for Suzuki-Miyaura reactions. PLoS One. 2014;9(1):29
28. Mukherjee P., Ahmad A., Mandal D., Senapati S., Sainkar S.R., Khan M.I., Parishcha R., Ajaykumar P.V., Alam M., Kumar R., et al. Fungus-Mediated Synthesis of Silver Nanoparticles and Their Immobilization in the Mycelial Matrix: A Novel Biological Approach to Nanoparticle Synthesis. *Nano Lett.* 2001;1:515–519.
29. Salunke, B. K., Sawant, S. S., Lee, S. I., Kim, B. S.,Comparative study of MnO2 nanoparticle synthesis by marine bacterium Saccharophagus degradans and yeast Saccharomyces cerevisiae. Applied Microbiology and Biotechnology.2015; 99(13): 5419–5427
30. Sundrarajan M., Gowri S. Green synthesis of titanium dioxide nanoparticles by *Nyctanthes arbor-tristis* leaves extract. *Chalcogenide Lett.* 2011;8: 447–451.
31. Al-Katib M, Al-Shahri Y, Al-Niemi A. Biosynthesis of silver nanoparticles by cyanobacterium *Gloeocapsa* sp. *Int. J. Enhanced Res. Sci. Technol. Eng* .2015*;*4: 60–73
32. Mittal A. K., Chisti Y., Banerjee U. Synthesis of metallic nanoparticles using plant extracts. *Biotechnol. Adv.* 2013;31:346–356.
33. Kalita, D.; Baruah, S. The impact of nanotechnology on food. In Nanomaterials *Applications for Environmental Matrices*.2019: 369–379.
34. Peng, X.H.; Qian, X.; Mao, H.; Wang, A.Y.; Chen, Z.G.; Nie, S.; Shin, D.M. Targeted magnetic iron oxide nanoparticles for tumor imaging and therapy. *Int. J. Nanomed.* 2008; *3*:311–321.
35. Anjum, M.; Al-Makishah, N.H.; Barakat, M.A. Wastewater sludge stabilization using pre-treatment methods. *Process Saf. Environ.* 2016;*102*: 615–632.