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Advances in plant-based green synthesis of nanoparticles

Anamika Roy[1], Md. Iqbal Hossain[2], and Pantu Kumar Roy[3]*
[1]Department of Chemistry, Khulna University, Khulna 9208, Bangladesh.
[2]Deptartment of Food and Nutrition, Chung-Ang University, Anseong 4726, Republic of Korea.
[3]Institute of Marine Industry, Department of Seafood Science and Technology, Gyeongsang National University, Tongyeong 53064, Republic of Korea.
**Corresponding authors' email address: vetpantu88@gmail.com (P.K.R.)*

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Abstract. Important routes for the synthesis of nanoparticles include physical and chemical processes, which are typically costly and potentially dangerous to the environment. The assessment of eco-friendly chemistry or biological strategies for producing nanoparticles from plant extracts has attracted the interest of a large number of scientists in recent years. Before establishing a generally accepted method, researchers must investigate the plant-assisted synthesis of nanoparticles and their effects. It is gaining popularity because of its ability to facilitate the creation of alternative, safer, less toxic, sustainable, and environmentally friendly methods. The synthesis of novel nanoparticles with the necessary properties is mandatory for the development of cosmetics, biomedicine, biosensors, nano-biotechnology, and other applications involving antibacterial, catalytic, electronic, electrochemical, and sensing processes. Environmental and biological fields have numerous possible uses for the green synthesis of nanoparticles. It attempts specifically to decrease the use of harmful chemicals. Typically, employing biological resources, such as plants, is harmless. Also found in plants are reducing and capping agents. Here, we discuss the advancement of green synthesis of nanoparticles, the most current applications, and future perspectives.

Keywords: *Biogenic nanoparticles, biomedical applications, green chemistry, metal nanoparticles, and nanoparticle applications*

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1. Introduction

Nanotechnology involves the separation, consolidation, and deformation of materials at the atomic or molecular level (Abdelbaky et al., 2022). In his words, it is the field of science concerned with manipulating matter at the atomic or molecular level. In the twenty-first century, nanotechnology became a scientific breakthrough. It is an interdisciplinary field that encompasses the invention, manipulation, and application of sub-100 nm-scale materials. It has focused on the molecular level and penetrated the enormous arena of applications (Mansoori, 2005; Afessa et al., 2022). Innovative practical and basic frontiers in a new sector of research, including materials science and engineering, have been unlocked by nanotechnology's exponential expansion (Dvir et al., 2011). Nanoscale structures (nanoparticles) play a crucial role in numerous significant technologies, including biomedical science, drug-gene delivery, electronics, mechanics, optics, the catalysis industry, the chemical industry, energy science, nonlinear optical devices, optoelectronic devices, photoelectrochemical systems, and space industry applications (Singh et al., 2020). Nanoparticles are extremely small in size (in nm), which results in both chemical and physical changes compared to most particles with a similar chemical makeup (Ray, 2010; Bakand et al., 2012).

Numerous academics have shown a great deal of interest in the unique characteristics of nanoparticles and discovered their remarkable uses in a variety of areas; however, some have demonstrated nanoscale toxicity. To combat the issue of toxicity, green chemistry and nanotechnology combine to produce nature-friendly nanoparticles using microorganisms, plants, and other natural sources (Lateef et al., 2016). Numerous synthetic routes for nanoparticle production have been explored by scientists, revealing a significant benefit to nature and the environment through the use of "green chemistry" techniques, including creatures such as bacteria, fungi, and plants (Duan et al., 2015). *Bacillus subtilis* (Sundaram et al., 2012), *Penicillium* sp. (Du et al., 2011), and *Fusarium oxysporum* (Durán et al., 2005; Clark & Macquarrie, 2008) have already been used to make metal nanoparticles.

This review focuses on the synthesis of nanoparticles from plant extracts and their applications, as well as future perspectives. This pathway drew the interest of researchers and scientists because of the great availability and spread of plants and the eco-friendly use of nanoparticles.

2. Principles of green and sustainable chemistry

Since less than 15 years ago, "green chemistry" for "sustainable development" has been universally explored (Clark & Macquarrie, 2008). Sustainable development means satisfying the demands of the present without compromising future generations' ability to fulfill their needs (Robert et al., 2005). Due to pollution and the unsustainable use of natural resources, sustainable development has particular significance for chemistry-based companies (Omer, 2008). Chemistry has historically been regarded as a hazardous field of study, and the public often associates the term “chemical” with danger and toxicity (Wilson & Schwarzman, 2009). Under conditions of high risks and exposure failure, the repercussions can be catastrophic, causing damage or death (Anastas & Eghbali, 2010). Al Ansari (2012) said that in order to make chemicals and processes that are safe and long-lasting, the risks of accidents and damage must be kept to a minimum.

3. Green synthesis

The three most important parameters of nanoparticle synthesis are the selection of a green or eco-friendly solvent, an effective reducing agent, and a nonhazardous stabilizing substance. Extensive physical, chemical, and biosynthetic approaches have been utilized for nanoparticle production. In general, the chemical methods used are very expensive and require the use of dangerous chemicals that pose many risks to the environment (Khan et al., 2022). Using plants and microbes, the biosynthetic method offers a biocompatible, safe, and environmentally friendly way to produce nanoparticles for biomedical applications (Khan et al., 2022). This synthesis can be performed by algae, bacteria, fungi, and plants, among others. Due to the presence of phytochemicals in the extract of some plant parts, such as fruits, leaves, seeds, roots, and stems, these plant parts have been utilized in the synthesis of different nanoparticles (Khan et al., 2022). Figure 1 depicts the production of nanoparticles by diverse green synthesis methods.

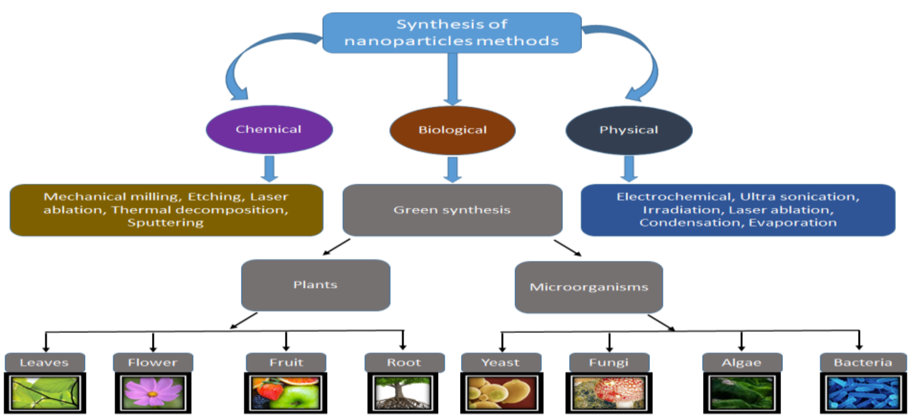

Figure 1. Nanoparticle synthesis methods.

4. Role of plants in green synthesis

Mostly in the synthesis of nanoparticles, the eco-friendly "green chemistry" concept has been used in the production of clean and environmentally friendly nanoparticles employing fungi, plants, bacteria, and actinomycetes. This process is known as “green synthesis” (Pal et al., 2019). Utilizing these organisms to biosynthesize nanoparticles offers a sustainable alternative to the development of nanoparticles with novel features with which unicellular and multicellular organisms can interact (Mohanpuria et al., 2008). Plants are sometimes referred to as the cost-effective and low-maintenance chemical factories of nature.

Plants have demonstrated an exceptional capacity for heavy metal detoxification and accumulation, allowing for the elimination of environmental pollutants, as even tiny amounts of these heavy metals are harmful (Shahid et al., 2017). Nanoparticle synthesis with plant extract has advantages over other biological synthesis methods, such as those involving microbes, because it can be accomplished through the complex operations of maintaining microbial cultures (Hulkoti & Taranath, 2014). One of the benefits of plant-based synthesis of the nanoparticle is that the kinetics for this method are substantially higher than for other biosynthetic methods equivalent to chemical nanoparticle creation. Due to the outstanding phytochemicals they provide, many plant components, such as leaves, roots, stems, and fruits, have been extensively utilized in the green production of nanoparticles (Iravani, 2011). The plant portion required for nanoparticle manufacturing can be cleaned and cooked in distilled water before usage. After compressing, filtering, and adding the corresponding solutions from which we wish to synthesize nanoparticles, the color of the solution begins to change, showing the synthesis of nanoparticles, which can be separated, as shown in Figure 2. We can avoid using any intermediate base groups by using plant extracts, which are cheap and good for the environment.

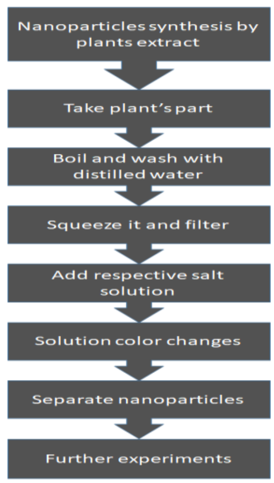

Figure 2. Plant extracts can be used to make nanoparticles in a way that is cheap and good for the environment.

According to the literature, *Thlaspi caerulescens*, *Arabidopsis helleri*, *Maytenus founieri*, *Sesbania drummondii, Clethra barbinervis*, *Acanthopanax sciathophylloides,* and *Brassica juncea* may accumulate, detoxify, and perform phytoremediation of harmful metals. A lot of people are interested in using these plants to remove heavy metals from aqueous solutions because they have a lot of potential to remove contaminants and toxicity from wastes in a way that is safe for the environment (Carolin et al., 2017).

Numerous nanoparticles, including silver, gold, iron, and zinc oxide, were synthesized with relative ease by using a sustainable strategy (Singh et al., 2018). The phytocompounds in the plant extract, such as terpenoids, polyols, and polyphenols, cause bioreduction of metal ions (Ovais et al., 2018).

5. Extraction of biological synthesis nanoparticles

Leaves and flowers of plants can be used to synthesize nanoparticles after being carefully cleaned with tap water, sterilized with double-distilled water, and dried at room temperature. The dried specimen is subjected to weight and crushing. The plant extract is then combined with Milli-Q H_2O at the correct concentration and heated with constant stirring. The resulting solution is next filtered with Whatman filter paper, and the portion containing a clear solution serves as the sample (plant extract) (Wang et al., 2019).

6. Instruments used to synthesize nanoparticles

Using a green method, different nanoparticles have been made and analyzed using atomic force microscopy (AFM), energy dispersion analysis of X-rays (EDAX), fourier transform infrared spectroscopy (FTIR), photoluminescence analysis (PLA), Raman spectroscopy, scanning electron microscopy (SEM), and transmission electron microscopy (TEM).

6.1. Silver (Ag) nanoparticles

For the eco-friendly generation of silver nanoparticles (AgNPs), a silver metal ion solution and a reducing biological agent are required. The simplest and most cost-effective approach for producing silver nanoparticles is the reduction and stabilization of silver ions by biomolecules such as alkaloids, amino acids, phenolics, polysaccharides, proteins, saponins, terpenes, and vitamins (Tolaymat et al., 2010). Silver nanoparticles may be recovered from numerous medicinal plants, including *Saccharum officinarum* (Chaudhari et al., 2012), as depicted in Figure 2. For the manufacture of shape-controlled and stable silver nanoparticles, eco-friendly bio-organisms present in plant extracts serve as a capping and reducing agent by utilizing protein. Silver nanoparticles slightly modified with polymers and surfactants exhibited strong antimicrobial action against Gram-positive and Gram-negative bacteria (Sharma et al., 2009). Using the methanolic extract of the *Eucalyptus hybrid* species, some scientists have synthesized silver nanoparticles (Dubey et al., 2009). By boiling 10 g of *Nelumbo nucifera* leaves in 100 mL of distilled water, silver nanoparticles can be produced. The filtrate solution (12 mL) was then treated with 88 mL of a 1 mM aqueous solution of $AgNO_3$ and incubated in the dark at room temperature. Silver nanoparticles were characterized by a solution of a brownish-yellow hue (Santhoshkumar et al., 2011). 25 mL of a 103 M solution of $AgNO_3$ was combined with *Hibiscus rosa-sinensis* leaf extract and vigorously agitated for 5 min. With the light brown silver nanoparticles, a temperature decrease occurred at 300 K and lasted 30 min (Philip, 2010). Also, silver nanoparticles were produced by combining *Jatropha curcas* seed extract (5 mL) with a 103 M aqueous solution of $AgNO_3$ (20 mL) and heating the mixture for 15 min at 80 °C. In the meantime, the solution turned red, which Bar et al. (2009) reported meant that silver nanoparticles were made.

Kumar et al. (2019) demonstrated the manufacture of silver nanoparticles from silver precursors utilizing an extract of the bark of the *Cinnamomum zeylanicum* plant. They suggested that the usage of plant materials is an example of green technology because it does not involve the use of dangerous chemicals. The primary catalysts for the reduction of silver ions and their transformation into nanosized silver particles are the water-soluble organics present in such plant materials. Other factors, such as the medium's pH, also had a special impact on the biogenesis of silver nanoparticles since pH affects the size of the particles. Silver nanoparticles were formed in greater quantities in the bark extract of the *Cinnamomum zeylanicum* plant than in the powder form. This suggests a high availability of reducing agents in the bark extract. According to zeta potential investigations, the surface charge is extremely negative, and the EC_{50} values against the *Escherichia coli* BL-21 strain are 111.72 mg/L (Gopinath et al., 2013). Therefore, the bark extract of the above-mentioned plant is the ideal material for synthesizing silver nanoparticles with potent antibacterial activity (Sathishkumar et al., 2009).

6.2. Gold (Au) nanoparticles

The enormous potential for the application of gold nanoparticles in the fields of absorption (El-Sayed et al., 2005), biocompatibility (Sperling et al., 2008), tunable surface plasmon resonance (Huang & El-Sayed, 2010), low toxicity (Jeong et al., 2011), medicine and biology (Khan et al., 2022), strong scattering, and simple synthesis methods. Several investigations demonstrated that in plant extracts, biomolecules such as flavonoids, phenols, and proteins, among others, have a significant role in the reduction of metal ions and the coating of gold nanoparticles (Figure 2). Shankar et al. (2003) conducted the first investigation on the manufacture of gold nanoparticles in 2003, utilizing geranium leaf extract as a reducing and capping agent. Utilizing the terpenoids present in leaf extract, which were responsible for the reduction of gold ions to gold nanoparticles, this process was conducted for 48 h. Numerous morphologies, including triangular, spherical, decahedral, and icosahedral, were suggested by morphological analyses of these nanoparticles (Shankar et al., 2003). They also created gold nanoparticles in 2.5 hours using Azadirachta indica leaf extract. The neem extract, which is rich in terpenoids and flavanones, was likely absorbed by the nanoparticles' surface and controlled their stability for four weeks. The previous study reported that nanoparticles are spherical and primarily planar, with most having triangular and a few hexagonal shapes (Shankar et al., 2004).

Chandran et al. (2006) utilized Aloe vera leaf extract for modifying the size and form of gold nanoparticles. The triangle shape and 50–350 nm range were discovered in leaf extract. Adding less leaf extract to the $HAuCl_4$ solution generated larger nanogold triangles, whereas adding more leaf extract produced more nanospherical particles, resulting in a decrease in the ratio of nanotriangles to nanospherical particles.

By utilizing a modest amount of mushroom extract, it was possible to produce some anisotropic gold nanoparticles with a preponderance of triangles and prisms and a negligible amount of hexagons and spheres. The nanoparticles' hexagonal and spherical form and size increased when the amount of mushroom extract was increased. Figure 2 demonstrates the green synthesis of silver nanoparticles using plant extract and $AgNO_3$, and their characterization and applications in several biomedical fields (Table 1). When the extracted quantity was concentrated to its maximum level, 25 nm nanoparticles were produced. Temperature also had an effect on nanoparticles, which was taken away by making nanoparticles in the shape of dendrites at 353 K with the highest extract quantity (Philip, 2010).

Table 1. Biogenic nanoparticles synthesized utilizing plant extracts

Nanoparticle	Plant origin	Size (nm)	Application	References
Au	*Hibiscus sabdarifa*	15–45	Antiacute myeloid leukemia	Zangeneh & Zangeneh (2020)
Au	*Gelidium pusillum*	12±4.2	Anticancer activity	Jeyarani et al. (2020)
Au	*Pimenta dioica*	13±4	Anticancer activity	Kharey et al. (2020)
Au	*Croton sparsiforus*	16.6–17	UV-protection, antibacterial, and anticancer agents	Boomi et al. (2020)
Au	*Desmodium gangeticum*	16±4	Antioxidant	Ghosh et al. (2020)
Au	*Litsea cubeba*	8–18	Catalytic reduction of 4-nitrophenol	Doan et al. (2020)
ZnO	*Calotropis gigantea*	31	Nitrite sensing, photocatalytic, and antibacterial	Kumar et al. (2019)
ZnO	*Urtica dioica*	20–22	Antidiabetic	Bayrami et al. (2020)
ZnO	*Acalypha fruticosa*	50	Antimicrobial	Vijayakumar et al. (2020)
ZnO	*Prosopis julifora*	31.80–32.39	Degradation of methylene blue dye	Mydeen et al. (2020)
Ag	*Nauclea latifolia*	12	Antimicrobial and antioxidant	Odeniyi et al. (2020)
Ag	*Malus domestica*	16	Antimicrobial	Kazlagić et al. (2020)
Ag	*Cestrum nocturnum*	20	Antioxidant and antibacterial	Keshari et al. (2020)
Ag	*Ganoderma lingzhi* (Reishi mushroom)	15–22	Antifungal	Aygün et al. (2020)
Ag	*Elaeagnus umbellata*	40	Antimicrobial	Ali et al. (2020)
Ag	*Dionaea muscipula*	5–10	Antioxidant	Banasiuk et al. (2020)
Cu	*Hagenia abyssinica*	34.76	Antimicrobial	Murthy et al. (2020)
Cu	*Anacardium occidentale*	<20	Efficient removal of uranium	Chandra and Khan (2020)
Cu	Juglans regia (Walnut shells)	15–22	Antibacterial, antioxidant, and anticancer	Mehdizadeh et al. (2020)
Cu	*Orobanche aegyptiaca*	<50	Nematicidal activity	Akhter et al. (2020)

Song et al. (2009) also reported a temperature consequence in the synthesis of gold nanoparticles by *Diospyros kaki* and *Magnolia kobus* leaf extracts. At higher temperatures and higher extract concentrations, the nanoparticles generated were smaller in size and had a spherical shape, and vice versa at lower extract concentrations and temperatures. *Terminalia catappa* leaf extract was utilized as a reducing and capping agent in the manufacture of gold nanoparticles. By adding leaf extract to chloroauric acid solutions, chloroaurate ions were rapidly reduced to gold nanoparticles. Morphological studies using transmission electron microscopy revealed the nanoparticles have a size range of 10-35 nm (Ankamwar, 2010). Using high-resolution transmission electron microscopy, morphological investigations of gold nanoparticles generated from coriander leaf extract revealed triangle, truncated triangle, spherical, and decahedral forms with an average size of 20.65 nm (Table 1). These nanoparticles were found to be stable in solution for one month at room temperature (Narayanan & Sakthivel, 2011).

Zhang et al. (2011) obtained Trifolium chloroplasts and utilized leaf chloroplasts as a stabilizer and a reductant. These nanoparticles exhibited remarkable crystallinity, with the plane being the predominant orientation and 20 nm in diameter for spherical particles. By using the 3-(4, 5-dimethylthiazol-2-yl)-2, 5-diphenyltetrazolium bromide (MTT) technique, nanoparticles were shown to be harmless to the gastric mucous cell line GES-1 and the gastric cancer cell line MGC-803. Surface-enhanced Raman spectroscopy (SERS) tests showed that gold nanoparticles could boost the Raman signals of rhodamine 6G without any other treatment.

Consequently, these nanoparticles were biocompatible and had enormous promise for the hypersensitive detection of the biomarker *in vivo* and *in vitro* experiments (Zhang et al., 2011). The nanoparticles were measured using scanning electron microscopy and atomic force microscopy to be 50–80 nm and 63 nm, respectively. FTIR studies confirmed the participation of aromatic, amine, and amide groups. These nanoparticles were highly stable in different pH solutions and salt concentrations, but unstable at high temperatures. Due to their good antinociceptive, exceptional antifungal, and muscle relaxant capabilities, gold nanoparticles produced from *Salix alba* leaf extract were suited for several pharmacological and biological applications (Islam et al., 2019). Gold nanoparticles were also recently produced by a variety of plant extracts, including *Coffea arabica* (Keijok et al., 2019)*, Croton caudatus* Geisel leaf extract (Kumar et al., 2019), *Bacillus marisfavi* (Nadaf & Kanase, 2019)*, Croton sparsiforus* leaf extract (Boomi et al., 2020), and the leaf extract of *Citrus lim* (Fernando & Judan Cruz, 2020).

6.3. Zinc oxide (ZnO) nanoparticles

Nanoparticles of zinc oxide have gotten a lot of attention from researchers and scientists in the last 4 to 5 years because they can be used in a wide range of ways in medicine, optics, and electronics. ZnO nanoparticles are very interesting because they are inexpensive, safe, and easy to make. These nanoparticles have a high exciton binding energy of 60 meV and a large band gap of 3.37 eV. As a result, they have many semiconducting properties, such as high catalytic activity, wound healing, anti-inflammatory, and UV-filtering properties, and are widely used in cosmetics like sunscreen. It also had a lot of medical uses, like being antifungal, antibacterial, drug transporting, antidiabetic, and anticancer. A lot of research has been done on how plants, microbes, and other organisms make and use ZnO. ZnO nanoparticles are produced using plant parts such as flowers, roots, seeds, and leaves.

ZnO nanoparticles can be synthesized by combining a clear solution of plant extract with a 0.5 mM solution of hydrated zinc sulfate, zinc oxide, or zinc nitrate and boiling the mixture for the specified amount of time and temperature. At this point, temperature, time, pH, and other variables can be optimized. The color change confirmed the presence of ZnO nanoparticles. Various approaches for spectroscopic, morphological, and thermal examination were used to characterize these nanoparticles. Energy-dispersive X-ray analysis (EDAX) and scanning electron microscopy research uncovered dissimilar X-ray diffraction outcomes (XRD). *Azadirachta indica* leaves have been used extensively for the production of ZnO (Bhuyan et al., 2015). According to the Debye–Scherrer equation of XRD (Ambika & Sundrarajan, 2015), the flower and leaf of the *Vitex negundo* plant contain 38.17 nm nanoparticles. FTIR investigations confirm the presence of functional groups such as amide, amine, alcohol, alkane, carbonate, and carboxylic acid in nanoparticle formation.

B. licheniformis generated ZnO nanoparticles of uniform size that exhibited greatly increased photocatalytic and photostability activity for methylene blue (MB) dye degradation, whereas breakdown was 83% of the dye, self-degradation was zero, and three repeated repetitions of the experiment demonstrated 74% degradation (Badry et al., 2022). Selvarajan and Mohanasrinivasan (2013) found that ZnO nanoparticles made with Lactobacillus plantarum had a zeta potential of 15.3 mV, which means that they were pretty stable.

7. Applications and future perspectives

Due to their wide range of applications in industries (Abdelbaky et al., 2022), biomedical fields (Afessa et al., 2022; Aghili et al., 2022; Akdogan et al., 2022), electronics (Aisida et al., 2022), markets (Akyildiz et al., 2022), energy (Aghili et al., 2022), and especially chemistry, there is a growing commercial demand for nanoparticles (Ahmad & Maqsood, 2022). Figure 3 shows that the most common nanoparticles used in biomedical applications, like imaging, are gold and silver.

In cancer therapy, gold nanoparticles have been utilized for the detection of cancer cells via immunoassay, protein assay, and capillary electrophoresis. Gold nanoparticles are of significant interest in the medical field as biomarkers.

After cellular absorption, they act as precise and influential heaters to kill cancer cells and promote apoptosis in B-cell chronic lymphocytic leukemia. *Suaeda monoica* leaf-produced gold nanoparticles had significant antioxidant ability, with DPPH radical-scavenging activity of 43% at 1 mg/mL (Rajathi et al., 2014). Using different nanoparticles and *Nerium oleander* leaf extract on gold nanoparticles of varying concentrations also showed a high level of antioxidative activity (Roy et al., 2021a; Roy et al., 2021b).

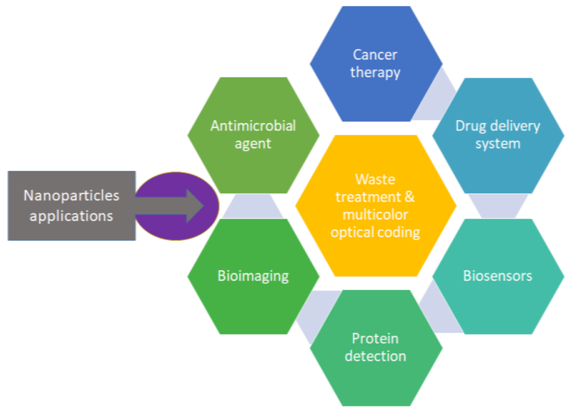

Figure 3. Environmental and medicinal applications of green generated nanoparticles

On increasing nanoparticle concentration, increased antioxidant activity was discovered (Tahir et al., 2015). In the reduction of 4-nitrophenol to 4-aminophenol, gold nanoparticles isolated by *Gymnocladus assamicus* demonstrated exceptional catalytic activity (Tamuly et al., 2013). The *Sesbania grandiflora* plant showed exceptional catalytic activity in the reduction of methylene blue dye. These results demonstrated a decline in methylene blue absorption over time (Das & Velusamy, 2014).

The same dye was decreased by the photocatalytic activity of Au nanoparticles produced from the leaf of *Pogostemon benghalensis*. These nanoparticles were manufactured without the need for an external reducing agent (Abdelbaky et al., 2022). Due to the photocatalytic activity of gold nanoparticles produced from *Eucommia ulmoides,* Congo red and yellow reactive dyes resulted in discoloration (Guo et al., 2015). Silver nanoparticles have drawn a lot of interest from researchers and scientists due to their diverse range of applications, including biolabeling, sensors, antimicrobial and antibacterial activities, cell electrodes, and integrated circuits.

Due to their antibacterial properties, they can be used in a variety of fields, including accessories, animal husbandry, cosmetics, health, medicine, the military, packaging, and various industries. These nanoparticles show potential antibacterial effects against pathogenic species such as *Bacillus subtilis*, *E. coli*, *Pseudomonas aeruginosa*, *Staphylococcus aureus*, *Syphilis typhus*, and *Vibrio cholera* (Shang et al., 2022). Pathogenic bacteria like *Bacillus subtilis*, *E. coli*, *Pseudomonas aeruginosa*, *Staphylococcus aureus*, *Syphilis typhus*, and *Vibrio cholera* may be killed by these nanoparticles (Shang et al., 2022).

8. Conclusion

The employment of green synthetic methods for the manufacture of nanomaterials via plants, microorganisms, and others has been pushed by the rise in demand for green chemistry and nanotechnology over the past few decades. In the past few years, eco-friendly nanoparticle synthesis has been the subject of intensive study by scientists. Numerous studies have been conducted on the synthesis of plant extract-mediated nanoparticles and their prospective uses in numerous fields due to the cost-effectiveness, nontoxicity, accessibility, and eco-friendliness of this method. In addition, they have an extensive range of applications, including bioengineering sciences, biomedical fields, biotechnology, catalysis, dye degradation, electronics, imaging, medicine, optics, sensors, textile engineering, and water treatment. In addition, plants have unique chemicals that aid in synthesis and speed up the rate of synthesis. An innovative and growing component of nanotechnology that has a big impact on the environment in terms of sustainability and the development of nanoscience is the use of plants for the green synthesis of nanoparticles. Future hopes for the green approach to nanoparticle synthesis are that their applications will increase rapidly, but there are concerns about their long-term effects on animals and humans and their accumulation in the environment, which must be addressed in the future. These biogenic nanoparticles can be utilized as nanoweapons against phytopathogens and to sterilize water in various forms for environmental cleanup. These nanoparticles might be a sign of where the biomedical industry will go in the future in terms of drug delivery systems.

Conflicts of interest. There are no conflicts of interest.

ORCID

Anamika Roy: https://orcid.org/0000-0003-2958-3628
Md. Iqbal Hossain: https://orcid.org/0000-0002-0184-7153
Pantu Kumar Roy: https://orcid.org/0000-0002-1938-1566

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