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Applications of Green Synthesized Metal Nanoparticles — a Review

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Abstract
Green nanotechnology is an emerging field of science that focuses on the production of nanoparticles by living cells through biological pathways. This topic plays an extremely imperative responsibility in various fields, including pharmaceuticals, nuclear energy, fuel and energy, electronics, and bioengineering. Biological processes by green synthesis tools are more suitable to develop nanoparticles ranging from 1 to 100 nm compared to other related methods, owing to their safety, eco-friendliness, non-toxicity, and cost-effectiveness. In particular, the metal nanoparticles are synthesized by top-down and bottom-up approaches through various techniques like physical, chemical, and biological methods. Their characterization is very vital and the confirmation of nanoparticle traits is done by various instrumentation analyses such as UV–Vis spectrophotometry (UV–Vis), Fourier transform infrared spectroscopy (FT-IR), scanning electron microscope (SEM), transmission electron microscopy (TEM), X-ray diffraction (XRD), atomic force microscopy (AFM), annular dark-field imaging (HAADF), and intracranial pressure (ICP). In this review, we provide especially information on green synthesized metal nanoparticles, which are helpful to improve biomedical and environmental applications. In particular, the methods and conditions of plant-based synthesis, characterization techniques, and applications of green silver, gold, iron, selenium, and copper nanoparticles are overviewed.

Keywords Plants · Metal/metal oxide nanoparticles · Antimicrobial · Anticancer · Dye degradation · Wastewater treatment

Introduction

Green synthesis of nanoparticles using living cells through biological pathways is more efficient techniques and yields a higher mass when compared to other related methods. Plants are the sources of several components and biochemicals that can role as stabilizing and reducing agents to synthesize green nanoparticles. The green synthesized methods are eco-friendly, non-toxic, cost-effective, and also more stable when compared to other biological, physical, and chemical methods [1]. Green synthesis of nanoparticles is categorized into three groups, viz. extracellular, intracellular, and phytochemicals. The nanoparticle synthesis from plant extract is an inexpensive process and it results in higher yield due to the huge quantity of phytochemical components in the plant extract that can also act as reducing and stabilizing agents converting metal ions into metal nanoparticles [2]. Green synthesized metal and metal oxide nanoparticles have emerging applications in the biomedical sector like diagnostics, wound healing, tissue treatment, immunotherapy, regenerative medicine, dentistry, and biosensing

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platforms. Biotoxicology and its antimicrobial, antifungal, and antiviral characteristics were passionately contested [3]. Plant-mediated copper oxide nanoparticles synthesized from various plant extracts play a various role like diverse biological activities, environmental remediation, photocatalysis, catalytic reduction, sensing, energy storage, and several organic transformations such as coupling, reduction, and multicomponent reactions [4]. Green synthsized selenium nanoparticles are helpful to improve the activity in antioxidant, catalysis, anticancer, photocopiers, xerography, rectifiers, and solar cells [5]. Green synthesized cerium oxide nanoparticles have potential photocatalytic dye degradation, antioxidant activity, antidiabetic, anticancer antibacterial, and antifungal activity properties [6]. Green synthesized stannic oxide nanoparticles have potential photocatalytic, antioxidant, and antibacterial activity, and these nanoparticles are helpful to enhance the environment and human health applications [7].Green synthesized silver chloride nanoparticles are used to develop environmental and biomedical applications [8]. Green synthesized metal nanoparticles are produced from different parts of the plants and also these methods are eco-friendly, non-toxic, and cost-effective method. Green synthesized nanoparticles have more active performance to remove dyes, antibiotics, and metal ions compared to other physical and chemical methods [9]. Green synthesis method is the best method for the preparation of nanoparticles, and these methods are helpful to reduce the toxicity, increase the stability, eco-friendly, and cost-effective methods. Green synthesis methods have more beneficial response in environmental and biomedical applications [10]. Plants contain many types of phytochemical compounds like phenolics, terpenoids, polysaccharides, and flavonoids that possess oxidation–reduction capabilities. Thus, they are preferably utilized for the green synthesis of nanoparticles [11]. Phytochemical compound synthesis of nanoparticles is not a general procedure as essential knowledge of the exact phytochemical components is needed for the synthesis of stabilized nanoparticles [12]. It is a general point of view that plants' secondary metabolites (polyphenols) are the mainly significant elements playing a very important function in the progression of the green synthesis of nanoparticles. The green synthesis practice is more advanced, safe and cost-effective, easily reproduce, and stable [13]. There are some positive impacts on the plant-based green synthesis of nanoparticles when compared to the other related biological methods using bacteria, fungi, actinomycetes, and algae [14]. Diverse plant parts (roots, stem, leaf, seed, and fruit) are concerned with such synthesized green nanoparticles because of the presence of notable phytochemicals [15]. Plant-synthesized nanoparticles in dissimilar parts of plants involve washing the particular part with tap or distilled water followed by squeezing, filtering, and adding particular salt solutions. Then, metallic salt was added and nanoparticles are extracted. A variety of metallic nanoparticles are synthesized by this method. The green nanoparticles are used in personal care, medicine, nano-enabled devices, food, aquaculture sciences, and agricultural products. Green synthesis of nanoparticles is eco-friendly; this method is generally used for the industrial production of metal nanoparticles. Green synthesized metal nanoparticles are produced from physicochemical methods [16]. A biosynthesis approach is a vital mechanism to avoid harmful by-products via eco-friendly and sustainable development. The biosynthesis process is involved in several biological structures, namely plant extracts, bacteria, yeast, seaweeds, and algae to produce metal and metal oxide nanoparticles [17]. Sharma et al. (2015) reported the green synthesis, characterization, and application of a variety of metal nanoparticles, which can eliminate pollutant dyes from water such as azo dyes, acid dyes, and cationic dyes. The metallic nanoparticles are used to remove water pollutants from water bodies such as rivers, lakes, and other water streams, thereby enhancing aquatic life. Green synthesized nanoparticles can be applied to treat environmental pollutants. Earlier studies report that the catalytic characteristics of some nanoparticles can reduce the toxicity of environmental pollutants [18, 19]. Green synthesis processes to metal nanoparticles are eco-friendly, non-toxic, and cost-effective. Also, these methods are playing a very significant role in the pharmaceutical industry [20]. The broad application of metallic nanoparticles utilized in various fields like biology, medicine, pharma, and other fields has led to high demand for these nanoparticles and thereby resulting in a significant need for better production of such nanoparticles. The efficiency of metallic nanoparticles used against human pathogenic microbes has made nanoparticles attractive in biomedical fields [21]. Particularly, metal nanoparticles have elevated outside the region and more attractive sites to support quicker response which enhances production yields. These metallic nanoparticles are generally divided into two groups, namely noble and non-noble metallic groups based on nanoparticle types. The metallic nanoparticles are inexpensive, eco-friendly, non-toxic, and reduce the accumulation of hazardous wastes. Green syntheses of metallic nanoparticles are safer for biomedical and environmental applications [22, 23]. A notable perspective of different metal nanoparticles is to be used as antimicrobial medicine (antiviral, antibacterial, fungicidal, antiparasitic, and pesticide agents, etc.) alongside some plant diseases [24]. A cancer nanobullet is significant in treating cancer because it is very effective and safe. The use of cancer nanodrugs considerably increased drug delivery to the target when compared to the conventional drug administration system. It notably improves the safety and competence of the regularly utilized anticancer drugs. Effective targeting, delayed release, long-lasting half-life, and reduced toxicity are the major positive effects of nanomedicine delivery systems [25]. This review paper overviews the only green synthesis and characterization of metal nanoparticles, namely silver, gold, iron, selenium, and copper, and the applications of such nanoparticles are used to treat antimicrobial, anticancer, reduce metal toxicity, dye degradation, and wastewater treatment and not for other biological, chemical, and physical methods. The green synthesized different metal nanoparticles are eco-friendly, non-toxic, cost-effective, and also more stable when compared to other ones as well as these nanoparticles have more active performance compared to other methods.

Nanoparticle Synthesis Methods

Top-down and Bottom-up Approaches

The nanoparticles synthesized through a biological system have numerous advantages like non-toxicity, high yield production, easy scaling up, and well-defined morphology. Hence, it has to turn into an innovative way of nanoparticle production. The green synthesis technique has been established to synthesize extremely effective nanoparticles. The green synthesized nanoparticles are safe, eco-friendly, and easy to handle [26–28]. Different practices of green synthesis of nanoparticles have been reviewed by Saratale et al. [29] and their biomedical and agricultural applications have been summarized (Saratale et al. 2018a). The synthesis of green nanoparticles is categorized into two classes, namely "top-down" and "bottom-up" based on the way of nanoparticle formation (Fig. 1). In the "top-down" approach, the dimension of nanoparticles was larger and hence a mechanical method or the additions of acids are necessary to decrease the particle size of the nanoparticles. Generally, the top-down approach requires the use of complex analysis (thermal decomposition method, mechanical method/ball-milling method, lithographic methods, laser ablation, sputtering). The "bottom-up" approach was quite different from the top-down process and was commenced at the atomic level via forming molecules. The bottom-up methods are carried out using different manners (chemical vapor deposition (CVD) method, sol–gel method, spinning, pyrolysis) [30].

Factors Influencing the Green Synthesis of Various Nanoparticles

The green synthesis of nanoparticle morphology characterization can be adapted by different specifications such as pH, temperature, reaction time, and reactant concentration.

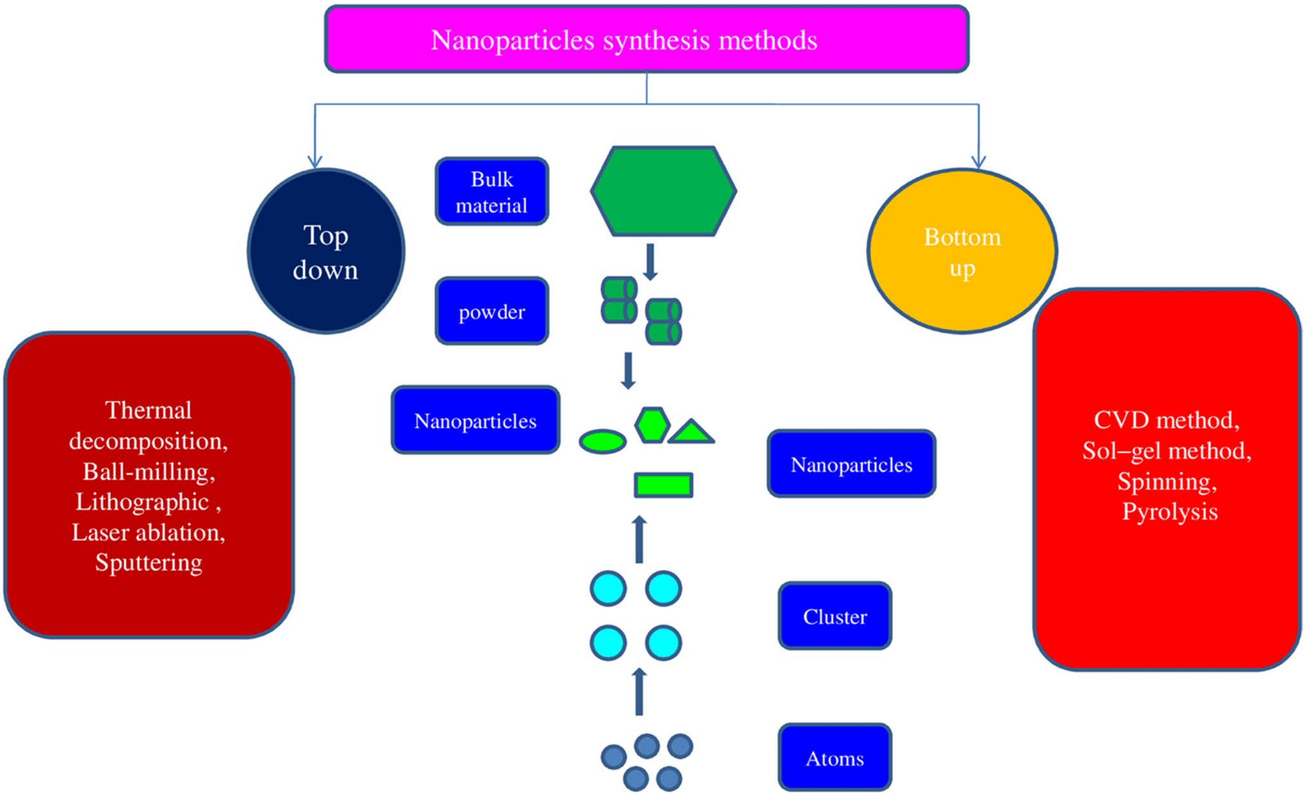


Fig. 1 Summary of the top-down and bottom-up approaches to green synthesizing nanoparticles

These parameters have majorly recognized the impact of environmental factors on the synthesis of nanoparticles as well as these elements may play an imperative function during the optimization of metallic nanoparticle synthesis [31].

Temperature

Different levels of study reports are being undertaken worldwide to learn the control of temperature over nanoparticles. Temperature is the most important factor in disturbing the dimension and form of the nanoparticles and their level of synthesis. Dissimilar types of shapes (triangle, octahedral platelets, spherical, and rod) and the dimension of the synthesis of nanoparticles can be tailored as a function of temperature. As the temperature level increases, the reaction response rate is also strengthening the formation of nucleation centers [32]. During the green synthesis of nanoparticles, the reaction time is a major factor that plays the most important function in influencing the shape, size, and yield of synthesized nanoparticles [33, 34].

pH

The pH of response plays a significant function in the structure of nanoparticles. Namely, pH and temperature also control the formation of nucleation centers. The pH level increases mean automatically enlarged the number of nucleation centers, which is most important to boost the formation of metal nanoparticles. It has been recognized that pH takes a significant function in formulating the structural morphology and size of the nanoparticles [35]. The medium pH reaction is a major function in the formation of nanoparticles [36].

Reaction Time

The reaction time is the most important aspect that controls the structural morphology of nanoparticles along with temperature and pH. Karade et al. [37] mentioned that reaction time plays a crucial role in the synthesis of magnetic nanoparticles [38].

Characterization of Nanomaterials

The nanoparticle characterization can be classified according to the physical and chemical instrumentation analysis used (Fig. 2), including UV–Vis spectroscopy, Fourier transforms infrared spectroscopy (FT-IR), scanning electron microscope (SEM), X-ray diffraction (XRD), atomic force microscopy (AFM), dynamic light scattering (DLS), surface-enhanced remain spectroscopy (SERS), atomic absorption spectroscopy (AAS), energy dispersive spectroscopy (EDS), ray photoelectron spectroscopy (XPS), and high angle annular dark-field (HAADF) [39, 40].

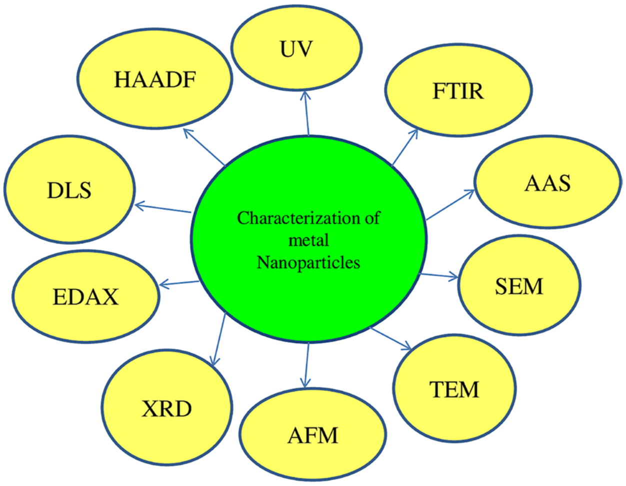


Fig. 2 Summary of the various techniques characterizing metal and metal oxide nanoparticles

FTIR

In FTIR analysis, infrared red rays are passed through the sample, some IR rays are engrossed by the sample, and the remaining rays pass through it. The spectrum provides absorption or transmission as a function of wavelength, which characterizes the sample substances [41]. FTIR analysis is a suitable, cost-effective, simple, and non-invasive practice to recognize the function of biomolecules in the decrease of nanoparticles (silver nitrate to silver) [42].

UV–Vis Spectrophotometry

In the characterization of nanoparticles by using UV–Vis absorption spectroscopy, the nanoparticle size level is varying from several metals while the size range is 2–100 nm. Generally, the nanoparticles confirmed by UV–Vis absorption spectroscopy are analyzed with wavelengths ranging from 300 to 800 nm. The metallic nanoparticles synthesized under particular salt conditions have strong absorption to give a point spectrum in the noticeable area [43]. Previous study reports exposed that absorption of wavelength 200–800 was appropriate for the categorization of nanoparticle size range 2–100 nm [44].

Scanning Electron Microscope (SEM)

Nanoparticles can be characterized by SEM. This instrumentation investigation is used to identify the shape, size, morphology, and distribution of synthesized nanoparticles [39, 40]. The SEM analysis assessed the alteration of a morphological structure before and after treatment. Previous studies reported that noticeable modifications in cell shape and perforations of nanoparticles in the cell wall have been used as indicators of the antimicrobial action of nanoparticles [45, 46].

X-ray Diffraction (XRD)

Material atomic structures can be analyzed XRD. This system is helpful to identify the qualitative and quantitative levels of materials. XRD investigation was used to recognize and confirm crystalline nanoparticle size and structure [39, 40]. To analyze the particle dimension of nanomaterials from XRD data, the Debye–Scherrer formula was applied by ruling the width of the Bragg reflection law according to the equation: $d = K\lambda/\beta \cos \theta$, where d is the particle size (nm), K is the Scherrer constant, λ is the wavelength of X-ray, β is the full width half maximum, and θ is the diffraction angle (half of Bragg angle) that corresponds to the lattice plane [47].

Atomic Force Microscopy (AFM)

Atomic force microscopy (AFM) classified and confirmed the size, shape, and outside the region of synthesized nanoparticles [39, 40].

Transmission Electron Microscopy (TEM)

Transmission electron microscopy (TEM) categorized and confirmed the crystal structure and particle size of material at the nanoscale level [39, 40].

Annular Dark-Field Imaging (HAADF)

Annular dark-field imaging (HAADF) recognized the interaction of nanoparticles with bacteria while providing information on the size distribution of nanoparticles interacting with each type of bacteria [39, 40].

Intracranial Pressure (ICP)

Intracranial pressure (ICP) spectrometry was confirmed by the metal concentration in deionized and original nanoparticle solutions. Experimentally, coupled plasma mass spectrometry (ICP-MS) and coupled emission spectroscopy (ICP-ES) are used to calculate the concentration of metal nanoparticles [39, 40].

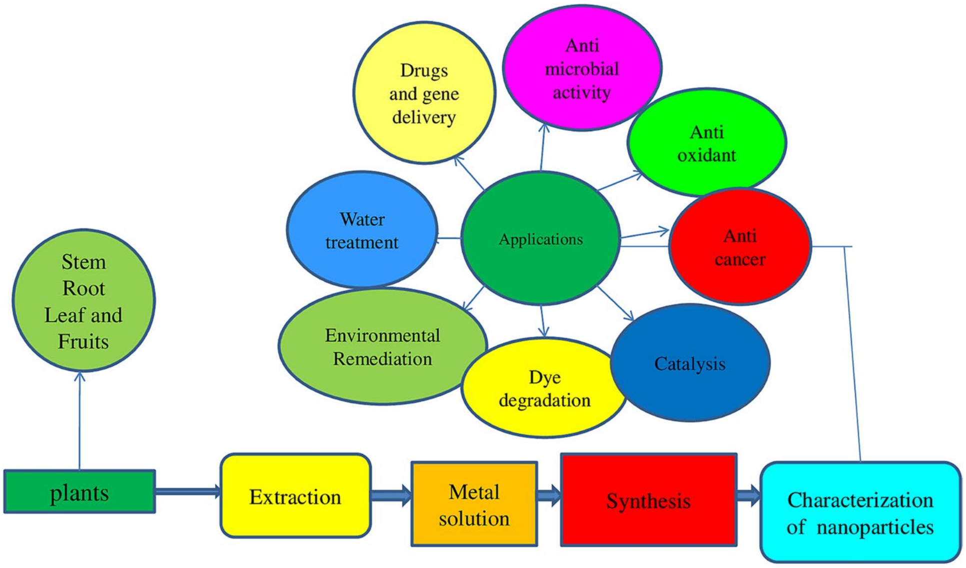
Green Synthesis of Metal Nanoparticles and Their Applications

Researchers affirmed that biologically synthesized nanoparticles are more pharmacological active compared to other physicochemical methods. Plant extract synthesized metallic nanoparticles are stable and monodispersed easily by controlling different influencing factors such as pH, temperature, retention time, and mixing ratio. Green metal nanoparticles synthesized by different plants such as neem leaves (*Azadirachta indica*), tulsi leaves (*Ocimum tenuiflorum*), curry leaves (*Murraya koenigii*), guava leaves (*Psidium guajava*), and mango leaves (*Mangifera indica*) [48]. The metallic nanoparticles green synthesized using diverse medicinal plants have shown the most important therapeutic properties, namely antimicrobial activity, insecticidal activity, antioxidant activity, wound healing properties, antidiabetic activity, immunomodulatory activity, hepatoprotective activity, and anticancer activity (Fig. 3). The medicinal plant-based synthesized metallic nanoparticles have a huge beneficiary effect in the sector of biomedicine [49]. The major significant concept of using green nanotechnology in agriculture reduced harmful environmental effects and the high expenditure of fertilizers, while green nanoparticles (GNPs) synthesized from dissimilar plants reduced the harmful emission of carbon dioxide, nitrous oxide, and methane. Also, green nanoparticles are used to increase productivity in agriculture and lower health risks concerned agricultural farmers [50]. Naturally, plants contain numerous phytochemical components (Table 1). These factors are eco-friendly and inexpensive. Green synthesized nanoparticles are exposed to the significant importance of heavy metal detoxification from the environment. In view of the number of heavy metals polluting soil and water, green nanoparticles are helpful to reduce metal toxicity in the environment [51]. As the different parts of plants roots, stem, leaf, seed, and fruit contain many phytochemical substances, the green synthesis metallic nanoparticles approach is cost-effective, non-toxic, and eco-friend and is more efficient compared to other biological methods [14]. For the synthesis of green nanoparticles, it is important for selected plant parts to be washed with tap or distilled water, after squeezing, filtering, and adding particular salt solutions. The color modification of the solution confirms the synthesized nanoparticles. Phytochemical components (phenolic acids: ellagic acid, caffeic acid, protocatechuic acid, and gallic acid) play an important role in the synthesis of metal nanoparticles. The phytochemical factors are reducing and stabilizing agents of synthesized metal nanoparticles [52].

Green Synthesis of Silver (Ag) Nanoparticle and Its Applications

Different kinds of plant parts like root, stem, latex, leaf, and seed are utilized for the synthesis of metal nanoparticles. Earlier studies have reported that silver nanoparticles are synthesized by plant extract [23, 54, 168, 169]. López-Miranda et al. [170] pointed out that plant synthesized silver nanoparticle by plant extract French tamarisk (*Tamarix gallica*). Chinnappan et al. [171] described that

Fig. 3 Green synthesis of metal and metal oxide nanoparticles and their applications



butterfly tree (*Bauhinia purpurea*) flower extract synthesized silver nanoparticles as a simple and cost-effective method. Lakshmanan et al. [172] pointed out that plant extract of Asian spider flower (*Cleome viscose*) synthesized by silver nanoparticles. This has an enhanced ability to reduce silver nitrate into metallic silver. Similarly, plant oregano (*Origanum vulgare L.*) synthesized by silver nanoparticles in an aqueous solution. The synthesis of the nanoparticle is based on the reduction of Ag^+ ions and also color changes (light brown to dark brown) of the nanoparticle solution [173]. The methanolic leaf extract of a five-leaved chaste tree (*Vitex negundo*) is synthesized by spherical shape silver nanoparticles; this nanoparticle has a broad-spectrum antibacterial response [174]. Rodrıguez-Luis et al. [175] pointed out that licorice (*Glycyrrhiza glabra*) root extract and cuachalalate (*Amphipterygium adstringens*) bark extract synthesized by the spherical shape of silver nanoparticles in the size range 3–9 nm (TEM). Ibrahim [176] mentioned that banana (*Musa paradisiaca Linn.*) peel extract synthesized by spherical and crystalline silver nanoparticles in the size range of 23.7 nm, and showed that the same material was a better capping and reducing agent by characterizing nanoparticles with various instrumentation techniques such as TEM, SEM, FE-SEM, DLS, and SAED.

Silver nanoparticles are broadly explored in the structure range 1–100 nm. Primarily, the silver nanoparticle is the alternative way to improve biomedical applications such as drug delivery, wound healing action, tissue scaffolding, and protective coating applications. In addition, nanosilver has a notable accessible surface area that allows the binding of any ligands. Silver nitrate is commonly used in the form of antimicrobial activity. A silver nanoparticle is a unique and emerging field against harmful microbes [177]. A such nanoparticle is of significant importance in its physical, chemical, and biological properties. Silver nanoparticles are considerably more positive effects such as broad-spectrum antimicrobial response, non-toxic, anticancer properties, and other therapeutic purposes, and also capable to form unique, diverse nanostructures and low-cost production [178–180]. Several researchers reported that silver nanoparticles are strong antibacterial effects against *E. coli*, *S. aureus*, *S. typhus*, *P. aeruginosa*, *V. cholera*, and *B. subtilis* [40, 181, 182]. A silver nanoparticle is used to break down the cell wall of organisms and interrupt the whole synthesis process [183, 184]. Martinez et al. (2018) examined that silver nanoparticles are good bactericidal properties depending on the size and shape of the nanoparticle, the size range of the nanoparticle decreasing and increasing the antibacterial response. The silver nanoparticle has different shapes like spherical, rod-shaped, and truncated triangular. The truncated triangular shape of the silver nanoparticle has strong antibacterial effects against *E. coli*. Truncated triangular silver nanoplates have a high contact area and surface reaction [185, 186]. Green synthesis of silver nanoparticle structure and dimension also plays a most important role in catalyzing various types of dyes and photocatalytic degradation [134] and in the wastewater treatment process [187]. Green synthesized and characterization of silver nanoparticles used to treat antibacterial, antifungal, antimycobacterial, and antimalarial activity against *Pseudomonas aeruginosa* MTCC-1688, *Streptococcus pyogenes* MTCC-442, *Staphylococcus aureus* MTCC-96, *Escherichia coli* MTCC-44, *Candida albicans* MTCC 227, *Aspergillus niger* MTCC 282, *Aspergillus clavatus* MTCC 1323, *Mycobacterium tuberculosis* H 37 RV, and *Plasmodium falciparum* [188]. Green synthesized (*Leucaena leucocephala*) silver nanoparticles have potential antibacterial, antimycobacterial, and antimalarial activity against *Streptococcus pyogenes*,

Table 1 List of green synthesized metal nanoparticles and their response

Plants (scientific name)	Plants (common name)	Source of the plant (leaf, stem, root, flower, fruit)	Metal salts or powder	Phytochemical components	Applications	References
Vitex negundo	Five-leaved chaste tree	Leaf extract	Silver	Alkaloids, glycosides, flavonoids, phenolic compounds, reducing sugars, resin, tannins	Broad spectrum antibacterial response	[53]
Musa paradisiaca Linn	Banana	Peel extract	Silver	Alkaloids, glycosides, steroids, saponins, tannins, flavanoids, and terpenoids	Antibacterial response	[54]
Carica papaya	Pawpaw	Leaf extract	Silver	Alkaloids, saponin, tannin, flavonoids, anthraquinone (free and bound), phlobatannin, cardiac glycosides, terpenoids, and proanthocyanidin	Antiviral activity	[55, 56]
Andrographis paniculata	Bitter weed	Leaf extract	Silver	Diterpenoids, flavonoids, and polyphenols	Antiviral activity	[57, 58]
Piper nigrum	Black pepper	Leaf extract	Silver	Palmitic, hexadecenoic, stearic, linoleic, oleic, higher saturated acids, arachidic, and behenic acids	Anticancer activity	[59, 60]
Viburnum opulus	European cranberry	Fruit extract	Silver	Polyphenol anthocyanins	Antiinflammatory activity	[61]
Moringa oleifera	Drumstick tree	Leaf extract	Silver	Phenols, B-sitosterol, caffeoylquinic acid, quercet in, kaempferol	Antibacterial response	[62, 63]
Ficus benghalensis	Banyan	Leaf extract	Silver	Flavonoids, phenols, terpenoids, and terpenes	Antimicrobial response	[64, 65]
Syzygium cumini	Java plum	Seed extract	Silver	Gallic acid, P-coumaric acid, quercet in, 3,4-dihyroxybenzoic acid	Antifungal activity	[66, 67]
Panax ginseng	Korean ginseng	Leaf extract	Silver	Ginsenosides, polysaccharides, alkaloids, glucosides, and phenolic acids	Anticancer activity	[68, 69]
Artemisia vulgaris	Mugwort	Leaf extract	Silver	Sabinene, B-thujone, chrysanthenone, camphor, borneol, and germacrene D	Antibacterial, antifertility, antimalarial, antitumor	[70, 71]
Andrographis echioides	False waterwillow	Leaf extract	Silver	Two new 2′-oxygenated flavonoids and two new phenyl glycosides	Antibacterial activity	[72, 73]
Coffee arabica	Arabian coffee	Seed extract	Silver	Caffeic, P-coumaric, vanillic, ferulic, and protocatechuic acids	Antibacterial activity	[74, 75]
Alcea rosea	Hollyhock	Flower extract	Silver	Ferulic acid, caffeic acid, tricin, luteolin-3′,4′-dimethyl ether	Antibacterial activity	[76, 77]
Centella asiatica	Gotu kola	Leaf extract	Silver	Isoprenoids and phenylpropanoid derivatives	Antimicrobial activity	[78, 79]
Achillea biebersteinii	Yellow milfoil	Flower extract	Silver	Flavonoids, phenolic acids, coumarins, terpenoids, and sterols	Anticancer activity	[80, 81]

Table 1 (continued)

Plants (scientific name)	Plants (common name)	Source of the plant (leaf, stem, root, flower, fruit)	Metal salts or powder	Phytochemical components	Applications	References
Ocimum sanctum and *Azadirachta indica*	Tulasi and Indian lilac	Leaf extract	Silver	Oleanolic acid, rosmarinic acid, ursolic acid eugenol,, linalool, carvacrol, β elemene, β caryophyllene, germacrene and nimbolide, azarirachtin, and gedunin	Antiplasmodium activity	[82]
Anethum graveolens	Dill	Leaf extract	Silver	Anethine, phellandrene, and d-limonene, and its leaves are rich in tannins, steroids, terpenoids, and flavonoids	Antiparasitic activity	[83]
Nigella arvensis	Wild fennel flower	Leaf extract	Gold	Arachidonic, eicosadienoic, linoleic, and linolenic), campesterol, stigmasterol, B-sitosterol, A-spinasterol, (+)-limonene, and (+)-citronellol	Antioxidant, antibacterial, anticancer activity	[84, 85]
Punica granatum	Pomegranate	Fruit extract	Gold	Phenolic acids, hydrolysable tannins, and flavonoids	Antibacterial activity	[86, 87]
Mentha piperita	Peppermint	Leaf extract	Gold	Diterpenes, steroids, tannin, flavonoids, cardial glycosides, alkaloids, phenols, coumarin, and saponin	Antibacterial activity	[88, 89]
Anacardium occidentale	Cashew nut	Leaf extract	Gold	Phenols, alkaloids, anthraquinolones, flavonoids, glycosides, tannins, glycoside, terpenoids, and tannins	Antibacterial activity	[90, 91]
Phyllanthus amarus	Gale of the wind	Leaf extract	Gold	Flavonoids, alkaloids, terpenoids, lignans, polyphenols, tannins, coumarins, and saponins	Anticancer activity	[92, 93]
Mimusops elengi	Tanjong tree	Leaf extract	Gold	Tannin, some caoutchouc, wax, coloring matter, starch, and ash-forming inorganic salts	Anticancer activity	[94, 95]
Allium cepa	Onion	Extract	Gold	Flavonoids, carbohydrates, glycosides, proteins, alkaloids, saponins, acid compounds, reducing sugars, and oils	Anticancer activity	[96, 97]
Syzygium aromaticum	Clove buds	Bud extract	Gold	Sesquiterpenes, monoterpenes, hydrocarbon, and phenolic compounds	Anticancer activity	[98, 99]
Limnophila rugosa	Wrinkled marsh weed	Leaf extract	Gold	Phenolics, flavonoids, terpenoids, and amino acids	Catalytic activity in the reduction of different nitrophenols	[100, 101]

Table 1 (continued)

Plants (scientific name)	Plants (common name)	Source of the plant (leaf, stem, root, flower, fruit)	Metal salts or powder	Phytochemical components	Applications	References
Lantana camara	Lantana	Leaf extract	Gold	Flavonoids, carbohydrates, proteins, alkaloids, glycosides, saponins, steroids, triterpenes, and tannin	Antibacterial activity and dye degradation	[102, 103]
Phragmites australis	Common reed	Leaf extract	Gold	Tanin, terpenoids, glycosides, and flavonoids	Anticancer activity	[104, 105]
Sageretia theazans	Mock buckthorn	Leaf extract	Gold	Friedeline syringic acid, bet a-sitosterol, daucosterol, gluco-syringic acid, and taraxerol	Antibacterial activity and antioxidant activity	[106, 107]
Syzygium jambos (L.) Alston	Rose apple	Leaf extract	Iron	Flavonoids, ellagitannins, phloroglucinols, and phenolic acids	Removal of chromium metal from environment	[108, 109]
Cupressus sempervirens	Mediterranean cypress	Leaf extract	Iron	Cosmosiin, caffeic acid, and P-coumaric acid cupressuflavone, amentoflavone, rutin, quercitrin, quercet in, myricitrin	Wastewater treatment	[110, 111]
Camellia sinensis	Tea plant	Leaf extract	Iron	Epigallocatechingallate (EGCG) ranged from 117 to 442 mg/L, epicatechin 3-gallate (EGC) from 203 to 471 mg/L, epigallocatechin (ECG) from 16.9 to 150 mg/L, epicatechin (EC) from 25 to 81 mg/L and catechin (C) from 9.03 to 115 mg/L	Reduction of bromophenol blue indicator	[112, 113]
Eucalyptus globules	Gum trees	Leaf extract	Iron	Saponins, tannins, phenols, and glycosides	Wastewater treatment	[114, 115]
Albizia adianthifolia	Flat-crown	Leaf extract	Iron	Apocarotenoids, chalcone, dipeptide, elliptosides, essential oils, fatty acids, flavonoids, histamine, imidazolyl carboxylic acid, prosapogenins, steroids, triterpene saponins, and triterpenoids	Anticancer activity	[116, 117]
Psoralea corylifolia	Babchi	Leaf extract	Iron	Coumarins, flavonoids, and meroterpenes	Antitumor activity	[118, 119]
Camellia sinensis	Green tea	Leaf extract	Iron	Alkaloids, flavonoids, steroids, terpenoids, carotenoids, benzoic acid, ascorbic acid, tocopherols, folic acid, and tannins consisting of catechin (flavonol), and gallic acids	Dye degradation	[120, 121]
Sageretia thea	Mock buckthorn	Leaf extract	Iron	Alkaloids, flavonoids, steroids, terpenoids	Antibacterial activity	[122]

Table 1 (continued)

Plants (scientific name)	Plants (common name)	Source of the plant (leaf, stem, root, flower, fruit)	Metal salts or powder	Phytochemical components	Applications	References
Albizia adianthifolia	Flat-crown	Leaf extract	Iron	Apocarotenoids, chalcone, dipeptide, elliptosides, essential oils, fatty acids, flavonoids, histamine, imidazolyl carboxylic acid, prosapogenins, steroids, triterpene saponins, and triterpenoids	Anticancer activity	[123, 124]
Dodonaea viscosa	Hop bush	Leaf extract	Iron	Flavonoids such as tannins, santin, pendlet on, saponins, and pinocembrin	Antibacterial activity	[125, 126]
Eucalyptus	Gum trees	Leaf extract	Iron	Quinones, saponins, carbohydrates, tannins, phenols, flavonoids	Wastewater treatment	[127, 128]
Allium sativum	Garlic	Bud extract	Selenium	Alkaloid, saponins, flavonoids, glycoside, anthraquinones, tannin, and terpenoids	Antioxidant activity	[129, 130]
Pelargonium zonale	Horseshoe geranium	Leaf extract	Selenium	Linalool, citronellol and geraniol, and their esters, menthone, nerol, isomenthone, rose oxides, terpineol, pinene, and myrcene	Antibacterial and antifungal activity	[32, 131]
Diospyros montana	Bombay ebony	Leaf extract	Selenium	Alkaloids, flavonoids, tannin, terpenoids, and essential oils	Antibacterial, antioxidant and anticancer activity	[132, 133]
Allium sativum	Garlic	Bud extract	Selenium	Alkaloid, saponins, flavonoids, glycoside, anthraquinones, tannin, and terpenoids	Anticancer activity	[134, 135]
Aloe vera	True *Aloe*	Leaf extract	Selenium	Flavonoids, steroids, terpenoids, proteins, phenols, carbohydrates, reducing sugar, starch, tannins, glycosides	Antimicrobial activity	[136, 137]
Asteriscus graveolens	Graveolens	Leaf extract	Selenium	Phenoilic compounds and flavonoids	Anticancer activity	[138, 139]
Clausena dentate	Dentate clausena	Leaf extract	Selenium	Coumarins, carbazole alkaloid, and sesquiterpenes	Larvicidal activity	[140, 141]
Psidium guajava	Common guava	Leaf extract	Selenium	Quercet in, avicularin, apigenin, guaijaverin, kaempferol, hyperin, myricet in, gallic acid, catechin, epicatechin, chlorogenic acid, epigallocatechin gallate, and caffeic acid	Antibacterial and anticancer activity	[142, 143]
Spermacoce hispada	Shaggy button weed	Leaf extract	Selenium	B-sitosterol, ursolic acid, quercet in, dalspinin, rutin, kaempferol, tannic acid, and epigallocatechin	Antibacterial, antioxidant, anti-inflammatory, and anticancer activity	[58, 144]
Theobroma cacao	Cocoa	Seed extract	Selenium	Procyanidins, theobromine, (-)-epicatechin, catechins, and caffeine	Antibacterial activity	[145, 146]

Table 1 (continued)

Plants (scientific name)	Plants (common name)	Source of the plant (leaf, stem, root, flower, fruit)	Metal salts or powder	Phytochemical components	Applications	References
Syzygium aromaticum	Clove	Bud extract	Copper	Sesquiterpenes, monoterpenes, hydrocarbon, and phenolic compounds	Antimicrobial and antioxidant	[147, 148]
Magnolia kobus	Kobus magnolia	Leaf extract	Copper	Flavonoids, phenols, citric acid, ascorbic acid, polyphenolic, terpenes, alkaloids, and reductase	Antibacterial activity	[149]
Hibicus rosa-sinensis	China-rose	Leaf extract	Copper	Proteins, vitamin C, organic acids (essentially malic acid), flavonoids, anthocyanins	Antibacterial activity	[150, 151]
Duranta erectai	Golden dewdrop	Fruit extract	Copper	Flavonoids, phenols, saponins, sterols, tannins, alkaloids	Water treatment process	[152, 153]
Gnidia glauca	Fish poison bush	Leaf extract	Copper	Alkaloids, saponin, steroids, tannin, coumarin, flavonoids, diterpenes, cardial glycosides, phenols, and phytosterol	Antidiabetic	[154, 155]
Citrus medica Linn	Citron	Fruit extract	Copper	Iso-limonene, citral, limonene, phenolics, flavonones, vitamin C, pectin, linalool, decanal, and nonanal	Antibacterial activity	[156, 157]
Euphorbia nivulia	Dog's tongue	Leaf extract	Copper	Glycosides, alkaloids, saponins, flavonoids, phenols, tannins, carbohydrates	Antibacterial activity and antioxidant	[158, 159]
Capparis zeylanica	Ceylon caper	Leaf extract	Copper	Fatty acids, flavonoids, tannins, alkaloids, E-octadec-7-en-5-ynoic acid, saponins glycosides, terpenoids, saponin, P-hydroxybenzoic, syringic, vanillic, ferulic, and P-coumanic acid	Antibacterial activity and antioxidant	[160, 161]
Arevalanata leaves	Mountain knot grass	Leaf extract	Copper	Phenol and alkaloids	Antimicrobial and catalytic properties	[162, 163]
Tinosporia cardifolia	Guduchi	Leaf extract	Copper	Tinosponone, tinosporin, berberine, palmitine, choline, tembet arine, isocolumbin and tetrahydropalmatine and other alkaloids, steroids, lactones, glycosides, and sesquiterpenoids	Antimicrobial activity	[164, 165]
Calotropis procera	Calotrope	Leaf extract	Copper	Cardenolides, flavonoids, and saponins	Antitumor activity	[166, 167]

Pseudomonas aeruginosa, *Bacillus subtilis*, *Staphylococcus aureus*, *Escherichia coli*, *Salmonella typhi*, *Mycobacterium tuberculosis*, and *Plasmodium falciparum* [189].

The silver nanoparticle is considered to be a successful and novel pharmacological agent that regulates efficient antiviral activity against *Influenza virus*, *Human parainfluenza virus type 3*, *Chikungunya virus*, *Herpes simplex virus*, *Norovirus*, *bovine Herpes virus*, *Dengue virus*, *Adenovirus*, *feline coronavirus* (FCoV), and HIV [55, 190–199]. The silver nanoparticle was used to suppress antiviral effects in a dose-dependent manner by in vitro methods. It also showed that at 9.3 g/mL (EC50 concentration) for 2-h incubation time, the silver nanoparticle can only affect virally infected cells, and not toxic to uninfected cells [197]. Likewise, silver nanoparticles have decreased the transmission of viruses in personal protection instruments. Graphene-silver nanocomposite was inhibited against feline coronavirus infection 4.7×10^4 TCID50 (tissue culture infective dose required to kill 50% of the infected host) at a lower concentration (0.1 mg/mL) of nanoparticle [198]. The red flush flower (*Lampranthus coccineus*) extract synthesis of silver nanoparticles has significant antiviral activity against *Coxsackievirus* infection at a lower concentration (12.74 μg/mL). In addition, a molecular docking report pointed out that green synthesized silver nanoparticle was an active binding *Coxsackievirus 3c* protease against antiviral infection [200]. Kaushik et al. [201] showed that a plant pawpaw (*Carica papaya*) leaf extract synthesized silver nanoparticles (125 μg/mL and 62.5 μg/mL) performed as the antiviral factor against *chikungunya* infection using Vero cells. A lower-level concentration of silver nanoparticles (62.5 μg/mL) was inhibited by 52% against the *chikungunya virus*. Sharma et al. [202] reported that bitterweed (*Andrographis paniculata*) leaf extract synthesized silver nanoparticle has significant antiviral activity against *chikungunya* viral infection. Maximum non-toxic dose concentration 31.25 μg/mL (MNTD) and 15.63 μg/m (½MNTD) showed that level of inhibition (75–100% and 25–49%) was a cytopathogenic response, respectively.

Cancer is one of the mainly dangerous diseases in the world. The several side effects performed in classical cancer therapy and their poor tolerance performance became the purpose for an enormous level of search for novel drugs of natural origin that are capable to regulate the disease's progress and heal it. The silver nanoparticle is a wide noteworthy factor for cancer analysis. The silver nanoparticles were stimulated to activate the p53 tumor suppressor. In addition, silver nanoparticles are performed to treat higher toxic response against cancer cells compared to non-cancer fibroblasts [203]. The plant catmint (*Nepeta deflersiana*) synthesized silver nanoparticle provoked apoptosis and cell death through cell necrosis HeLa stops the sub G1 cell cycle [61]. Jacob et al. [204] examined that pepper black pepper (*P. nigrum*) leaf extract synthesized silver nanoparticle has induced cytotoxic activity against cancer cells. The Indian gooseberry (*Phyllanthus emblica*) leaf extract synthesized silver nanoparticle has significant anticancer properties against *Hepatocellular carcinoma* (HCC) [205]. The two different size variations of silver nanoparticles demonstrated anticancer activity against MCF-7 and T-47D cells. The silver nanoparticle induced endoplasmic reticulum stress (EPR) through unfolded protein, and also increased the activation of caspase 9 and caspase 7, causing cell death [206]. The silver nanoparticles are recogniith an antiinflammatory reaction via playing a role in the wound healing progression, due to interleukin 1 and TNF-ά interferons and also suppression of COX-2 and MMP-3 expressions. The silver nanoparticle has significantly reduced the function of TNF-ά during the inflammatory process [207–210]. The black pepper (*Piper nigrum*) leaf extract synthesized silver nanoparticle has a selected cytokine inhibitory factor for IL-1 and IL-6 [211]. European cranberry (*Viburnum opulus*) bush fruit extracts synthesizing Ag nanoparticle was noted to show an antiinflammatory response by in vitro and in vivo methods, the Ag nanoparticles being used to enhance the potential therapeutic analysis for the treatment of inflammation [182]. Ag nanoparticle is an efficient tool for numerous biomedical applications such as antimicrobial, antifungal, antiviral, catalysis, wound healing and dressing, implanted materials, tissue engineering, anticancer therapy, and medical devices (catheters, prostheses, vascular grafts). In addition, an Ag nanoparticle is used in some diagnostic processes like anti-permeability factors, bio-sensing, and dental preparations [212].

Green Synthesis of Gold (Au) Nanoparticle and Its Applications

Green synthesized Au nanoparticles are in natural form. They also have chemical and thermal functionality. Gold-based nanoparticles can join photosensitizers for photodynamic antimicrobial chemotherapy [118, 213]. Green synthesized gold nanoparticle was a good catalytic reaction without a capping agent and non-toxic carrier, the gold nanoparticle was used to improve the drug and gene delivery applications [214]. With these systems, the gold core provides stability to the congregation through the single layer recognition to change the surface properties like charge and hydrophobicity. In addition, a characteristic feature of gold nanoparticles was connected to thiols, as long as the efficiency of controlled intracellular release [215]. The gold nanoparticles contain different kinds of characteristics; the distinguishing features can be changed in size, shape, and aspect ratio of nanoparticles. The gold nanoparticle is non-toxic and biocompatible for drug delivery and gene therapeutic applications. The gold nanoparticle has various aspects of the biomedical progression such as easily detecting and diagnosis heart disease, cancer, and infectious factor [216, 217].

The pummelo (*Citrus maxima*) aqueous extract solution synthesized gold nanoparticles [218]. The Indian long pepper (*Piper longum*) extract synthesized gold nanoparticle size range of 56 nm was confirmed by the DLS particle size analyzer [219]. The onion (*Allium cepa*) extract synthesized gold nanoparticles in the size range of 100 nm [220]. The wild spinach (*Chenopodium album*) leaf extract synthesized gold nanoparticle sizes ranging from 10 to 30 nm and its shape is quasi-spherical [221]. The Japanese Honeysuckle (*Lonicera Japonica*) flower extract synthesized gold nanoparticle size ranging from 8.02 nm (average diameter) [222]. The gold nanoparticle detected, diagnose, and healing of many diseases. Au nanoparticle is a very important tool for biomedical applications [223, 224]. The green synthesized gold nanoparticles are considered through various instrumentation techniques such as UV–Vis, Fourier transforms infrared (FTIR), SEM, and high-resolution transmission electron microscopy (HRTEM), and also the gold nanoparticle is mainly concerned to enhance various biomedical applications such as antibacterial, drugs delivering factor for therapeutic cancer level from chemical hazardous to biomolecules, catalysis, photonics, electronics, and sensing [84, 225–228]. The view-rakot (*Nepenthes khasiana*) leaf extract synthesized gold nanoparticles categorized by different instrumental analyses like XRD, SEM, and TEM after analysis to confirm the size range of 50–80 nm of nanoparticle [229]. The influencing factor is significantly important in the synthesis of nanoparticles; the gold nanoparticle factors range as follows: pH (6–9), temperature (20 to 80 °C), the concentration of mixture (5 to 10 mL), UV–Vis spectrum wavelength of 550 nm. These ranges are helpful to verify and synthesis gold nanoparticles [230–232].

Lysenko et al. [233] examined the synthesis of two gold nanoparticles coated with silicon dioxide shells and gold–silicon dioxide carrier nanoparticles; these gold nanoparticles reduced the toxicity of gold ions, and also both gold nanoparticles are strong antiviral effects against adenovirus. The synthesized gold nanoparticles were treated to antiviral activity against the dengue virus and were associated with the suppress action of RNA against the dengue virus. The gold nanoparticles performed to go into the infected Vero cells and reduced the response of dengue virus serotype 2 (DENV-2) replication and infectious virion release; these treatments were carried out during post- and pre-infection conditions [234]. The novel vaccine with hybrid coated gold nanoparticles and domain III of the viral envelope protein (EDIII) response antiviral activity against the dengue virus. The complex coated hybrid gold nanoparticle response differs, depending on the size and concentration [235]. The ethanolic and hydroalcoholic extract of gold nanoparticles showed antitubercular activity, and two different types of concentrations are identified as the response such as MIC (2.5 µg/mL and 20 µg/mL) and the highest concentration level (50 µg/mL and 75 µg/mL), respectively [236]. The wild fennel flower (*Nigella arvensis*) (NA- gold nanoparticles) leaf extract synthesized gold nanoparticles looked into that different applications such as antioxidant, catalytic activities antibacterial, and cytotoxicity. The plant-mediated synthesis of gold nanoparticles improved cytotoxic activity against cancer cell lines (H1299 and MCF-7) with an IC50 value of (10 and 25 µg/mL) and a catalytic reaction against methylene blue was 44%, respectively [237]. Au nanoparticles with size and shape range have some excellent characteristic features of biomedical applications such as antimicrobial and antibacterial activities, antiviral treatments, anticancer therapy, targeted drug delivery, medical imaging, molecular imaging in living cells, photothermal therapy, hyperthermic property to treat tumors, biocatalysis and biomarkers, biosensors, and intracellular analysis [238].

Green Synthesis of Iron (Fe) Nanoparticles and Their Applications

The green synthesized zero-valent iron nanoparticles are produced from different plants such as *thyme* (*Thymus vulgaris* (TV)), Damask rose (*Rosa damascene* (RD)), and stinging nettle (*Urtica dioica* (UD)) [239]. Green synthesized iron nanoparticles from various plants such as common water-hyacinth (*Eichhornia crassipes*), lantana (*Lantana Camara*), and sensitive plants (*Mimosa pudica*). This plant synthesized iron nanoparticle standard size ranges 20–60 nm and morphological structure is irregular and aggregated quasi-spherical shape respectively [240]. However, the green synthesis of iron nanoparticles was a major process in enhancing the physical, chemical, and biological properties of nanoparticles [241, 242]. Plant extract synthesized iron nanoparticle has antioxidant capability following some procedures like 2, 2-diphenyl- 1-picryl-hydroxyl (DPPH) radical scavenging assay, Folin-Ciocalteu method, and ferric reducing antioxidant power (FRAP) [243–245]. Different phytochemical components (polyphenols, flavonoids, and amino acids) played an imperative role in the synthesis of iron nanoparticles. These phytochemical synthesized nanoparticles are efficient antioxidant activity [108, 246, 247].

The green synthesis approach in developing zero-valent iron nanoparticles was an important process for the treatment of brominated organic compounds, pesticides, azo dyes, alkaline-earth metals, malachite green, nitrate, monochlorobenzene, antibiotics, and conversion of some metals like chromium, cobalt, and copper [112, 247–255]. The aqueous solution of rose apple (*Syzygium jambos (L.) Alston*) leaf extract synthesized zerovalent iron nanoparticles eliminated to hexavalent chromium metal. Complete removal of chromium was based upon nanoparticles dosage, temperature, and pH. The appropriate pH and concentration of nanomaterials are considerable factors in the removal of chromium metal [256]. However, the coconut husk extract synthesized magnetite iron nanoparticles absorbed a low level of calcium and cadmium [257]. The aqueous solution leaf extract at various ratios and temperatures synthesized zero-valent iron nanoparticles. The process confirmed by color changes of the nanosolution as well as phyto components was the significant agent for reducing and stabilizing factors in the synthesis of zero-valent iron nanoparticles [250, 258, 259]. Similarly, zero-valent iron nanoparticles are characterized by the following methods such as SEM, TEM, and zeta potential. The classification analysis was confirmed by the shape, size, and stability of nanoparticles. The zero-valent iron nanoparticle was helpful in the removal of lead based on time duration and concentration (low quantity of lead removal takes lesser time and low concentration higher quantity removal of lead takes high concentration and more time) [260, 261]. Nanotechnology and iron nanomaterials have different kinds of applications such as drug delivery [262, 263], electronics, biotechnology, catalysis [110, 264, 265], environmental remediation [114, 266], cosmetics, space industry, anticancer and drug delivery [116, 267, 268], and materials science. Wei et al. [220] pointed out that those citrus maxima peel extract synthesized iron nanoparticles played a major role in waste minimization and well-organized resource utilization. The most comprehensive study reports pointed out that the synthesis of iron nanoparticles was utilized for remediation of water and soil, and the zero-valent iron nanoparticles are efficient catalytic properties [269].

The Mediterranean cypress (*Cupressus sempervirens*) aqueous leaf extract synthesized iron nanoparticle was important effects to removing dye from wastewater depending on time and concentration manner. The synthesized iron nanoparticle was used to remove methyl orange (95% at 6 h) [270]. In addition, tea plant (*Camellia* sinensis) leaf extracts synthesized iron nanoparticle was utilized for the reduction of bromophenol blue pH indicator [250]. The green leaf extract synthesized iron nanoparticle was used to treat malachite green dye degradation [271]. The gum trees (*Eucalyptus globules*) leaf extract synthesized iron nanoparticles demonstrated that the marvelous reduction possible against eutrophic wastewater [272]. The tangerine (*Citrus reticulate*) peel extract synthesized iron nanoparticles utilized to remove the cadmium in the water system [273]. The green synthesis approach to developing iron nanoparticles has reduced the level of chromium depending on the concentration manner (1 mg of iron nanoparticle reduces 500 mg of chromium) [274].

Iron nanoparticles are more significant in the biomedical field. The flat-crown (*Albizia adianthifolia*) leaf extract synthesized iron nanoparticles utilized to treat MCF-7 and AMJ-13 cancer cell lines and cause apoptosis [275]. In addition, sugar apple (*Annona squamosa*) leaf extract synthesized iron nanoparticles showed an efficient cytotoxic reaction against cancer cell line (HepG2) [274]. Similarly, Babchi (*Psoralea corylifolia*) leaf extract synthesized iron nanoparticle exhibited antitumor activity against renal carcinoma cell line (Caki-2 cells) [276]. The green synthesis approach to developing nanoparticles was of significant importance to treat human pathogens [277].

Green Synthesis of Selenium (Se) Nanoparticle and Its Applications

Green synthesis of selenium nanoparticles is environmentally safe, cost-effective, non-toxic, and easily produced in large quantities [278, 279]. The plant-mediated synthesis of selenium nanoparticles is non-toxic and cost-effective method as well as the plant phytochemical components (polyphenols, flavones, carboxylic acids aldehydes, amides, and ketones) were a significant role in the reduction of metal ions during the synthesis of selenium nanoparticle [132, 280–286]. Different types of plant parts such as leaf extracts, fruit, seed, fruit peels, and root synthesized selenium nanoparticle in different shapes and sizes [129, 132, 287–291].

The plant-mediated synthesis of selenium nanoparticles performs to remove the heavy metal from the contaminated solution depending on the size and shape of the nanoparticles. In addition, green synthesized selenium nanoparticles carry out to remove heavy metals (zinc, copper, and nickel) from the soil, and also another study reported that selenium nanoparticles performed to remove elemental mercury from soil and air [281, 292, 293].

The selenium nanoparticle applications in different ways include as follows: (1) increasing shelf life of food; (2) antioxidant and antimicrobial response in preserved food; (3) maintenance of health and growth [283, 294–296]. The selenium nanoparticle is the most imperative food supplement as well as increased the bioavailability, controlled release of selenium in organisms. Selenium nanoparticle medicine is a major biotherapeutic agent without any side effects [297]. The selenium nanoparticle has various kinds of physiological responses in humans like antioxidant action, preventing tumor formation, and regulating the immune system [298, 299]. Vyas and Rana [300] pointed out that cultivated garlic (*Allium sativum*) bud extract synthesized selenium nanoparticles demonstrated an antioxidant response following assays FRAPS, ABTS, and DPPH. The tea extract synthesized selenium nanoparticle was established for its antioxidant activity by using different methods such as ABTS and DPPH assays [301].

The cultivated garlic (*Allium sativum*) buds extract synthesized selenium nanoparticles investigated for its antibacterial response against *Bacillus subtilis* and *Staphylococcus aureus* by using the disc diffusion method [302]. The horseshoe geranium (*Pelargonium zonale*) leaf extract synthesized selenium nanoparticle was revealed antibacterial and antifungal activity against pathogenic bacteria, namely *Escherichia coli*, *Staphylococcus aureus*, and fungi, namely black dot of potato (*Colletotrichum coccodes*) and green mold (*Penicillium digitatum*) [136]. The bombay ebony (*Diospyros montana*) leaf extract synthesized selenium nanoparticles expressed by antibacterial activity against *Escherichia coli*, *Aspergillus niger*, and *Staphylococcus aureus*, anticancer activity in (MCF-7) concentration manner, and antioxidant activity (DPPH), respectively [291]. Selenium nanoparticle was significantly active against enterovirus. Combined with oseltamivir, the combined drugs strongly inhibited enterovirus and also reduced ROS production in astrocytoma cells [303]. The selenium nanoparticle was indicated to suppress p38 kinase, ROS production, and Jun amino-terminal kinase (JNK) signaling pathway. The selenium nanoparticles reduced the viral protein and viral yield, and control the ROS production [304, 305]. *Ulva fasciata* (UF extract) synthesized selenium nanoparticles have strong antibacterial activity against *S. aureus* and *P. aeruginosa* and also potential anticancer agents [306]. Green synthesized (*Solanum nigrum*) selenium nanoparticles have strong inhibitory action against gram-positive and gram-negative bacteria as well as antioxidant and anticancer (inhibition of breast cancer cells) efficacy posed by selenium nanoparticles [307].

Cancer nanobiotechnology is a new way to detect, diagnose, and treatment of cancer. Green synthesized selenium nanoparticle is a rapid technique in different cancer cells, namely human colon adenocarcinoma, liver cancer cells, human breast cancer cells, and Ehrlich ascites carcinoma [291]. The cultivated garlic (*Allium sativum*) bud extract synthesized selenium nanoparticles demonstrated a positive cytotoxic response against the Vero cell line [308]. The smaller size of selenium nanoparticles connected with cancer cells through the action of DNA breakage ultimately leads to cause cell death and also performs cytotoxic activity against cancer cells [309]. The green synthesized selenium nanoparticle exhibited anticancer properties in some cancer cells (human cervical carcinoma cells, liver cancer, and lung cancers) whereas a few cancer cells (ovarian cancer, leukemia cancer, colon cancer, skin cancer, prostate cancer) are still needed to be investigated [310]. The green synthesized selenium nanoparticle still needs to be investigated in the therapeutic approaches in glioma, and also the size and spherical shape of the selenium nanoparticle were a significant response to anticancer activity [311].

Green Synthesis of Copper (Cu) Nanoparticle and Its Applications

The green synthesis technique is a significantly imperative approach for the production of nanoparticles. The process is an effective and efficient tool compared to other methods, while being non-toxic, eco-friendly, and cost-effective. The copper nanoparticles are utilized to enhance biomedical applications such as antibacterial, antifungal, and antiviral activity [312]. Plant-mediated synthesized copper nanoparticles from various types of plants such as fire lily (*Gloriosa superba L.*), common grape (*Vitis vinifera, Nerium*), Nerium (*Nerium oleander*), Ceylon caper (*Capparis zeylanica*), and jackfruit-Champa (*Artabotrys odoratissimus*) [147, 152, 154, 313, 314]. The fire lily (*Gloriosa Superba L*) leaf extract and bark extract of pomegranate (*Punica granatum*) synthesized copper nanoparticle enhanced reducing and capping agents size range of nanoparticle 23 nm [315–317]. Different kinds of plant extract, namely Magnolia (*Nag Champa*) (*Artabotrys Odoratissimus*) and angel's trumpet (*Datura innoxia*) synthesized by copper nanoparticles in 8–10 min and size range of 4–100 nm [152]. Saranyaadevi et al. [154] showed the classification confirmation of green synthesized copper nanoparticles through the UV–Vis absorption peak 531 nm, XRD — particle size 5 nm, and TEM — size (50–100 nm).

Copper is an essential micronutrient for plants, and also 70% of total copper presence in chloroplasts as well as copper plays a significant role in the synthesis of plant pigments, chlorophyll, carbohydrate metabolism, and amino acids [150]. Copper is an important mineral for humans with dissimilar kinds of functions: strength of the skin, blood vessels, the connective tissue of the body, production of hemoglobin, myelin, and melanin, and regulation of the thyroid functions [318]. The copper nanoparticles role in many fields such as agricultural, industrial engineering, and technological fields. The green synthesis of the copper nanoparticle is a cost-effective, cheap, non-toxic, and eco-friendly method. The copper nanoparticles were confirmed to provide an efficient antibacterial response in agricultural research fields [319]. Copper nanoparticles have numerous types of properties such as mechanical, thermal, magnetic, and electrical and are also used for antimicrobial coatings for surgical tools, water treatment, and heat transfer processes [320].

Golden dewdrop (*Duranta erecta*) fruit extract synthesized copper nanoparticle reduced toxic dye (methyl orange, azo dyes, Congo red) degradation from water [321]. The fish poison bush (*Gnidia glauca*) leaf extract and Ceylon leadwort (*Plumbago zeylanica*) leaf extract synthesized copper nanoparticle's response as an antidiabetic factor [322].

The clove (*Syzygium aromaticum*) bud extract synthesized copper nanoparticles are a more effective response in antimicrobial and antioxidant function [323]. The copper nanoparticles act as a fungicide agent against different plant pathogens, namely black rot (*Alternaria alternata*), basal rot (*Fusarium oxysporum*), crown and root rot (*Rhizoctonia solani*), blue mold (*Penicillium italicum*), fruit and stem rot (*Phoma destructive*), basal rot (*Fusarium* sp.) green mold (*Penicillium digitatum*), and black kernel (*Curvularia lunata*) [324]. Similarly, Kobus magnolia (*Magnolia kobus*) leaf extract synthesized copper nanoparticle was a significant antibacterial response against *E. coli* [325]. Green synthesized copper oxide nanoparticles have strong antibacterial and antifungal effects against *Staphylococcus aureus* (*S. aureus*), *Streptococcus pyogenes* (*S. pyogenes*), *Pseudomonas aeruginosa* (*P. aeruginosa*), and *Escherichia coli* (*E. coli*), and good antifungal performance against *Aspergillus niger* (*A. niger*), *Candida albicans* (*C. albicans*), *Aspergillus clavatus* (*A. clavatus*), and *Epidermophyton floccosum* (*E. floccosum*) [326]. Green synthesized copper nanoparticles have potential antibiofilm, antibacterial, and antioxidant activity, and these nanoparticles used as an alternative therapy for microorganisms that have been improved antibiotic resistance [327]. Green synthesized (*Sesbania aculeata* leaf extract) copper nanoparticles are helpful to increase plant growth of *Brassica nigra* at lower dose (25 and 30 mg/100 mL) and also play a good antimicrobial agent, and these nanoparticles are helpful to enhance protection and production of plants [328].

Several studies report strongly that copper nanoparticle was a good antiviral agent [329]. The green synthesis of copper nanoparticle size about 160 nm demonstrated the antiviral activities against influenza virus of swine-origin by plate titration assay. The copper nanoparticle reduced the viral protein so these nanoparticles are utilized to produce face masks and kitchen cloths. The copper nanoparticle (40–120 µg/mL) size (39.3 nm) and spherical shape were significant cytotoxic effects against human cancer cell lines such as human skin carcinoma cells (B16F10) and normal mouse embryonic fibroblasts (NiH3T3) within 24 h [330]. The China-rose (*Hibiscus rosa-Sinensis*) leaf extract synthesized copper nanoparticles are confirmed that an effective antimicrobial response against clinical pathogens like *E. coli* and *Bacillus subtilis*, and also this element reaction is an achievement against lung cancer [53].

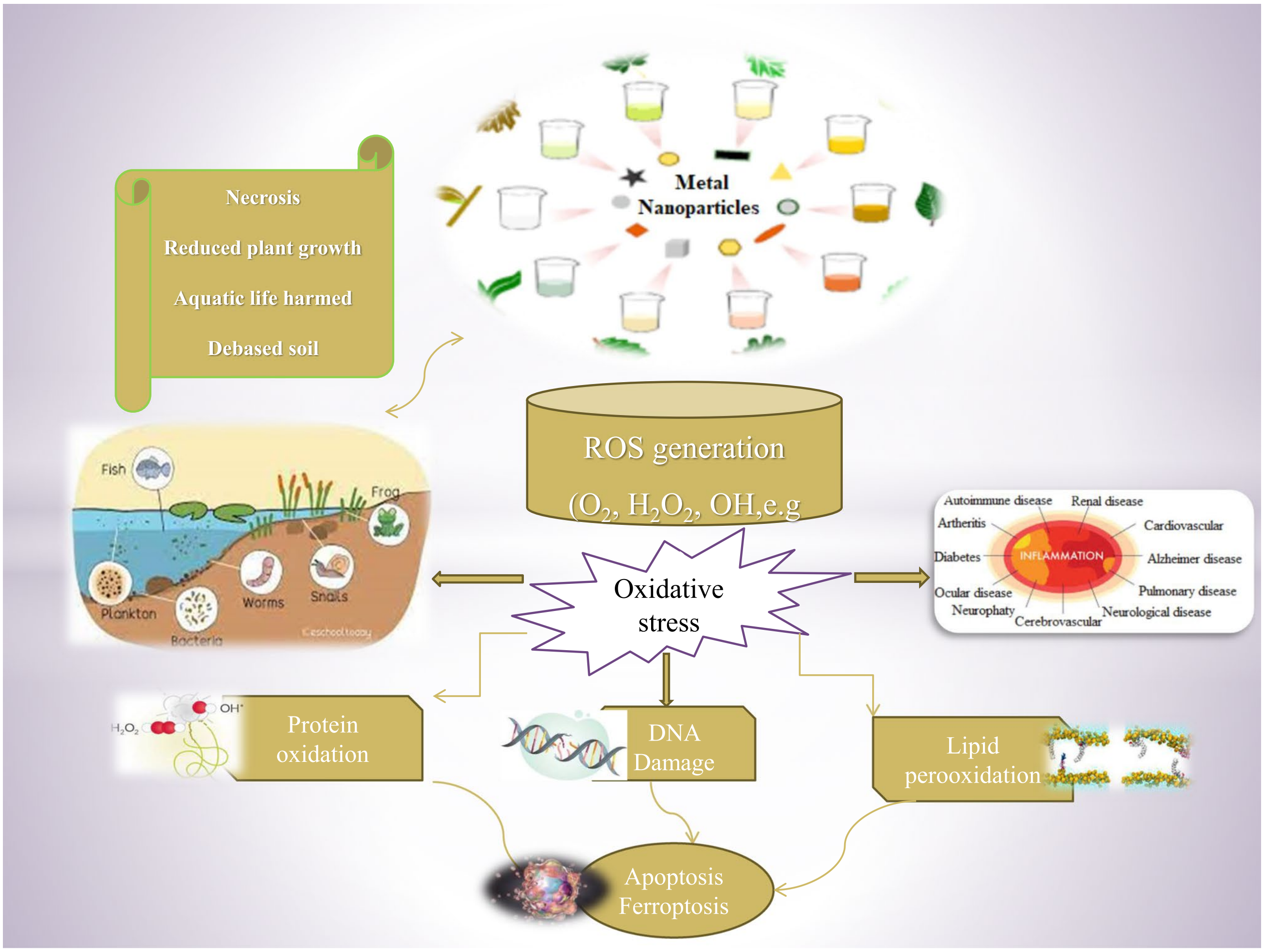


Fig. 4 Mechanism of metal nanoparticles in biomedical and environmental applications

Toxicity of Metal Nanoparticle Aspects

The toxicity of metal nanoparticles is associated with oxidative stress reactions and intracellular reactive oxygen species (ROS) production, as well as the activation of pro-inflammatory mediators. As a result of this, DNA and protein damage, lysosomal hydrolases, mitochondrial dysfunction, apoptosis, cell membrane damage, cytoplasm disorder, changes in ATP, and cell membrane permeability can be considered, which finally includes cell dysfunction. However, depending on the size, type of particles, individual particles, and mixtures, it can change the toxic effects (Fig. 4) [56].

Conclusion

Nanoparticles are an effective tool in different fields such as food, agriculture, medicine, micro-wiring, electronics, and energy harvesting. The synthesis of nanoparticles uses physical, chemical, and biological methods. Green synthesis ways appear more effective and efficient compared to other related methods. The green synthesis method is an eco-friendly, non-toxic, and cost-effective method. In this review, we summarize especially information about various syntheses, characterization, and applications of plant-based synthesized metal and metal oxide nanoparticles are utilized to analyze antibacterial, antifungal, antimalarial antioxidant, anticancer, photocatalytic, and metaltoxicity properties. These studies strongly recommended green synthesis approach to develop metal and metal oxide nanoparticles more beneficial response in environmental and biomedical applications. In the future, our research group focuses to synthesis different types of green nanoparticles utilize to develop the application different sectors like pharamaceutical, medical, environment, aquaculture, and agriculture. This study result enlightens the direction of future research in the green nanoparticle development in environmental and biomedical sectors.

Author Contribution SV did the supervision, resources, writing — original draft of the paper. HR, YZS, HG, SHH, and MR performed writing — review and editing the paper. SV did the process of investigation and conceptualization. SV wrote and prepared the original draft. SV had close supervision on the process of preparing paper, too. HR, YZS, and SHH did the project administration. All authors have read and agreed to the published version of the manuscript.

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Data Availability The datasets generated during and/or analyzed during the current study are available from the corresponding author on reasonable request.

All applicable international, national, and/or institutional guidelines for the care and use of animals were followed.

Declarations

Conflict of Interest The authors declare no competing interests.

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