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(Review Article)

Green synthesized of novel iron nanoparticles as promising antimicrobial agent: A review

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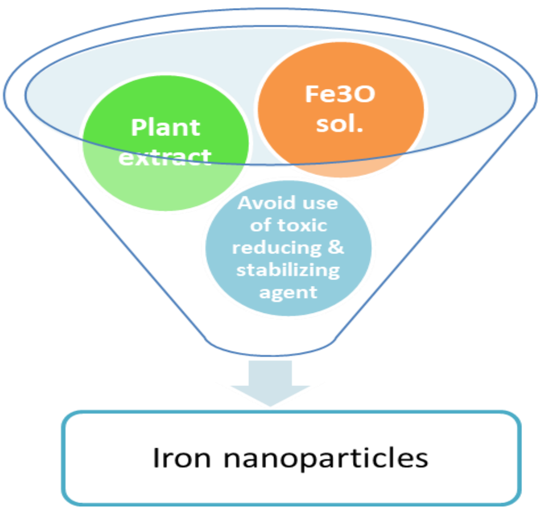
Abstract

Green synthesis of nanoparticles utilizing plant extract has shown enormous advantages over the methods of synthesis. Green nanoparticles are generally synthesized using metal atoms like silver, iron, copper, zinc, and plant extract containing reducible phytoconstituents like alkaloids, flavonoids, tannins, etc. Several Iron nanoparticles are reported using plant extracts. Iron nanoparticles have a greater advantage of small size, affordable cost stability, or having some biomedical application. Such as tissue repair, hypothermia, cell separation, and most important is the integral component of our body system. In the present review, the account of methodologies for the synthesis of iron nanoparticles and the various plant extract having antimicrobial activity has been discussed.

Keywords: Iron nanoparticles; Plant extract; Green synthesis; Antimicrobial activity

Graphical Abstract



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1. Introduction

Nanoparticles are submicron moieties with diameters range starting from 1-100 nm made up of organic or inorganic materials having novel properties as compared to a large number of materials [1]. The nanotechnology process depends on synthesis, manipulation, and use of materials that are of nanoscale size. In the new era, nanoparticles take more attention due to their unique size-dependent properties and applications [2]. Nanoparticles have great potential in the management of various diseases, prominently in infection also in diabetes, and that they are stable under harsh process conditions [3]. Nanoparticles used for all the aforesaid purposes, the metallic nanoparticles considered as a most promising tool, as they contain remarkable antibacterial properties ascribed to their large surface area to volume ratio, which attracts researchers ascribed to the growing microbial resistance against metal ions, antibiotics, and the development of their resistant strains [4]. Iron oxide nanoparticles are broadly used as a catalyst, solar power conversion, environmental protection, sensors, have biomedical applications, tissue repair, magnetic storage medium, and drug delivery. The synthesis of iron nanoparticles has more concern to the scientific community due to their broad range of applications. These iron nanoparticles are being successfully utilized in the diagnosis and treatment also [5], [6]. Iron oxide nanoparticles having excellent properties to get rid of various water pollutants used as an adsorbent in wastewater treatment [7].

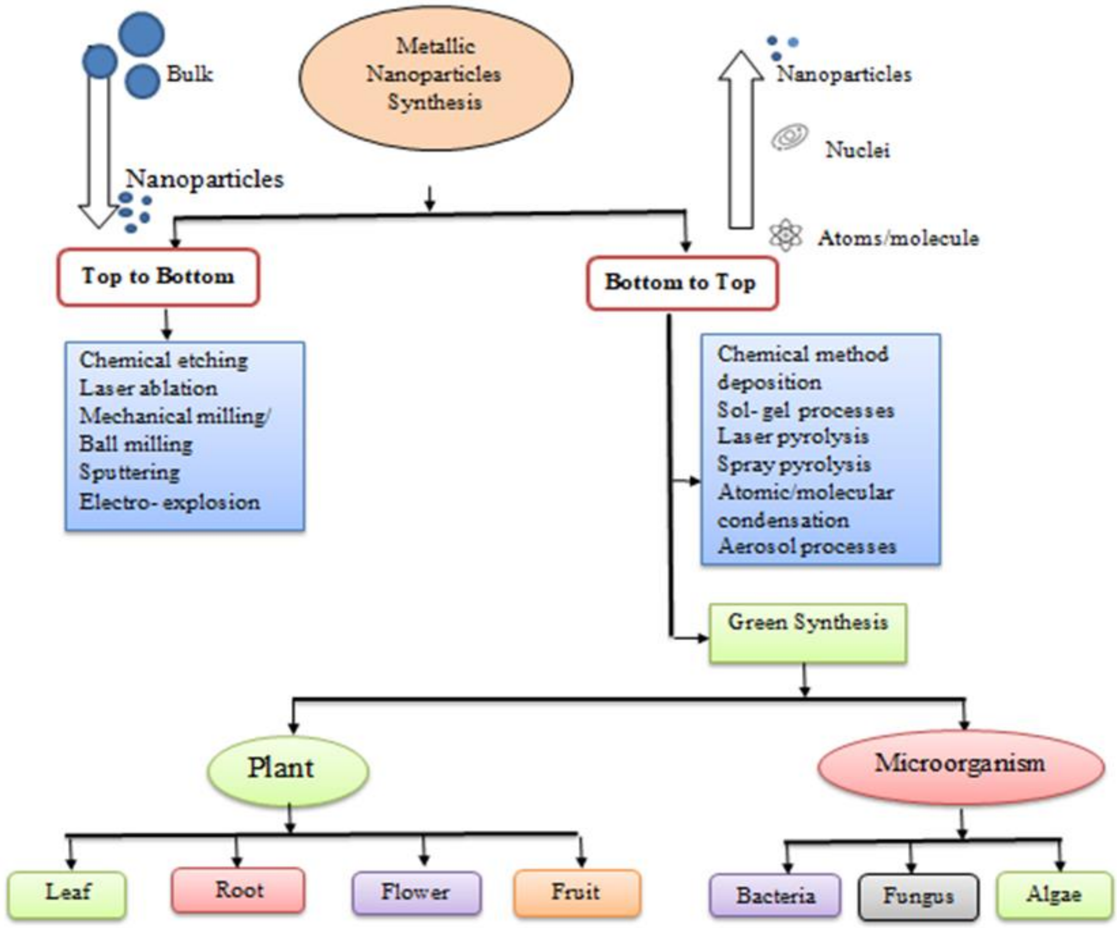

Figure 1 Different synthesis approaches available for the preparation of Iron nanoparticles

A huge number of physical, chemical, biological, and hybrid methods are currently available to synthesize various kinds of nanoparticles. Green nanotechnology has attracted a lot of attention and includes a huge range of processes that reduce or eliminate toxic substances to revive the environment [8]. Green synthesis of nanoparticles has been used because they're environmentally friendly, non-toxic, and use safe reagents. Green synthesis of metal nanoparticles using extracts from whole-plant or different parts of a plant is the most potent process of synthesis at an affordable cost. The components present within the plant extract are liable for the shrinkage of metal ions whereas water-soluble heterocyclic components can stabilize the nanoparticles formed. Thus, the synthesis of metal nanoparticles utilizing inactivated plant tissue, plant extracts, exudates, and other parts of living plants may be a modern choice for the assembly of nanoparticles over conventional methods [9].

Generally, two approaches are immersed in the syntheses of iron nanoparticles, either from the ''top to bottom'' path or a ''bottom to up'' path (Fig. 1). In bottom to top path, nanoparticles are often synthesized using chemical and biological methods by self-assembly of atoms to new nuclei which grow into a particle of nanoscale as shown in (Fig. 1). In the bottom to top path, the chemical reduction is that the most relevant scheme for syntheses of iron nanoparticles. The massive advantage of this method is, a huge number of nanoparticles can be synthesized in a short period.

The antimicrobial activity more effective of metallic nanoparticles depends on its parameters are;

- The material utilized for the synthesis of the metallic nanoparticle;
- Their particle size.

Accordingly, microbial resistance to antimicrobial drugs has turned to increase and therefore a possible threat to public health.

In the top to bottom approach, some bulk material breaks down into fine particles by size reduction with various lithographic techniques, e.g. grinding, milling, sputtering, and thermal/laser ablation. (Figs.1). In the case of top to bottom approach, nanoparticles are generally synthesized by evaporation–condensation using a tube furnace atmospheric air pressure. Fe, Au, PbS, and fullerene nanoparticles have previously been produced by utilizing the evaporation condensation technique. The formation of iron nanoparticles using a tube furnace has numerous drawbacks because it covered a huge space and munches an excellent deal of energy while raising the environmental temperature around the source material, and it also entails too much time to succeed thermal stability [8].

1.1. Different Methods used for Synthesis of Nanoparticles

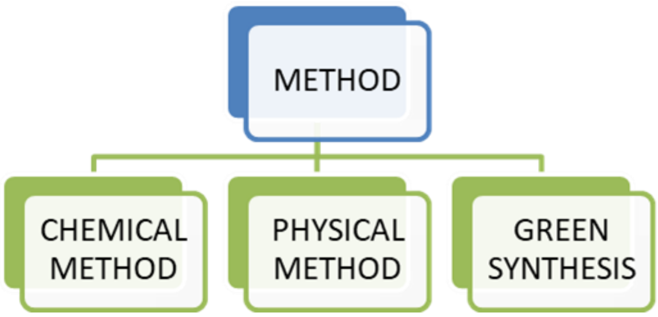

Figure1. Methods used for synthesis of nanoparticles

1.1.1. Chemical Method

Chemical methods include precipitation, oxidation or reduction, formation of an insoluble gas followed by tripping, and other chemical reactions that involve interchanging or sharing of electrons among atoms.

1.1.2. Physical Method

It's a bottom-up approach to synthesize nanostructured materials, which involves two basic steps. The primary step is that the evaporation of the material and thus the second step involves a rapidly controlled condensation to form the required particle size. This method provides an environmentally friendly way of synthesizing nanoparticles.

1.1.3. Green Synthesis

Green synthesis is utilized for environmentally compatible materials like bacteria, fungi, and plants within the synthesis of a nanoparticle. Green synthesis is concentrated on the formation of metal and metal oxide nanoparticles [10]. The development of green syntheses over chemical and physical methods is environment-friendly, cost-effective, and simply scaled up for large-scale syntheses of nanoparticles relative to bacteria /fungi or plant-mediated synthesis, there'll be no need to utilize high temperature, pressure, energy, and toxic chemicals [11].

In green synthesis there are two methods involve which are as follows:

- Plant Mediated Biosynthesis: Plants have the potential to compile certain amounts of heavy metals in their diverse parts. Therefore, biosynthesis techniques employing plant extracts have gained increased consideration as simple, efficient, cost-effective, and feasible methods also magnificent alternative means to standard preparation methods for nanoparticles production. Plants have metabolites (like carbohydrates, proteins, and coenzyme) with are responsible for the bio reduction of nanoparticles [12].
- Microbe-Mediated Biosynthesis: Synthetic pathways of nanoparticles by microbes may involve compounding of basic cell biochemistry, the transport of ionic metals both in and out of cells, mechanism of resistance of microbes to toxic metals, and activated metal-binding sites, ion accumulation metallic intracellular.

1.2. Procedure for green synthesized iron nanoparticles

The simplest platform for synthesized iron nanoparticles, as they're free from toxic chemicals also providing natural capping agents for the stabilization of iron nanoparticles.

- The preparing plant extract of its parts, the whole plant or desired a part of plant rinsed with deionized water to get rid of possible mud and dust, and were dried at normal surrounding temperature.
- Leaf aqueous extract is often prepared by boiling dried leaves in deionized water. Dried leaves and water are usually utilized in a ratio of 2–10:100, respectively. The boiling should be done under reflux to avert evaporation.
- After cooling at normal temperature, the solution gets separated by filtration, and leaf microparticles can be eliminated by centrifugation.

Plant metabolites such as flavones, terpenoids, sugar, ketones, proteins, amino acids, polyphenols, and carboxylic acids could act as green bio reduction and stabilizing agents for the production of NPs.

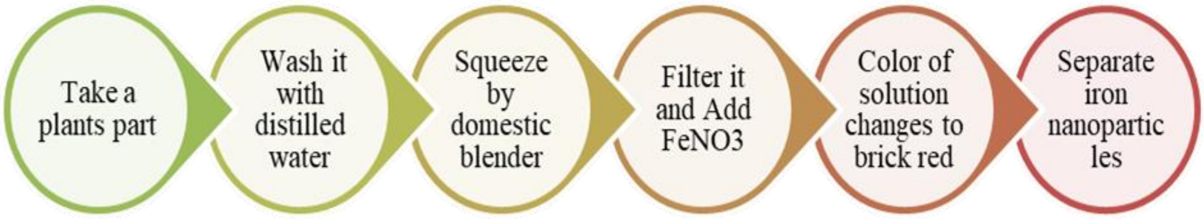

Figure 2. Protocol for the synthesis of iron nanoparticles using plant extract

Table 1 Green synthesis of iron nanoparticles from various plant extract

Plant	Part	Size (nm)	Shape	Uses	Test Microorganism	Ref.
Apple	Peel	2-6	Spherical	Antimicrobial	*P. aerugenosa, S. aureus B. cereus and S. typhii*	[13], [39]
Azadirachtaindica indica (Neem)	Leaves	50-100	Spherical	Antioxidant	*Streptococcus mutans*	[14]
Carica Papaya	Leaves	25-50	Spherical	Malaria and typhoid fever, antimicrobial activity	*Staphylococcus aureus, streptococcus faecalis, Escherichia coli and Proteus mirabilis.*	[15], [41]
Camellia Sinensis (green tea)	Leaves	10-100	Spherical	Antimicrobial		[16], [40]
Couroupita Guianensis	Fruit	10-20	Spherical	Antibacterial, cytotoxicity	*S. aureus, E. coli, S. typhi, K. penumoniae*	[17]
Datura inoxia	Leaves	16-40	Spherical	Antimicrobial		[18]

Eucalyptus	Leaves	40	Spherical	Antimicrobial activity	*Escherichia coli,*	[19]
Eucalyptus robusta Sm	Leaves	8	Spherical	Antimicrobial activity, antibacterial, and antioxidant	*Escherichia coli, Staphylococcus aureus, Pseudomonas aeruginosa, Bacillus subtilis*	[20]
Eucalyptus maculate	Leaves	8	Spherical	Antimicrobial activity	*Staphylococcus aureus, bacilluscereus, Enterococcus faecalis, Alicyclobacillus acidoterrestris, Propionibacterium acnes, Escherichia coli,*	[21]
Gardenia jasminoides	Leaves	32	Spherical	Antibacterial, antimicrobial	*Escherichia coli, Salmonella enterica, Proteus mirabilis, and Staphylococcus aureus*	[22]
Gooseberry	Leaves	10	Spherical	Biosensors.		[23]
Glycosmis mauritiana	Leaves	100	Spherical	Antibacterial	*Bacillus cereus, B. subtilis, Enterococcus faecalis, Escherichia coli, Klebsiella pneumonia*	[24]
Lawsonia Inermis	Leaves	21	Spherical	Antibacterial, antimicrobial	*Escherichia coli, Salmonella enterica, Proteus mirabilis, and Staphylococcus aureus*	[22], [40]
Lagenaria Siceraria	Leaves	30-100	Spherical	Antimicrobial, tissue repair, hyperthermia, drug delivery and in cell separation, antioxidant,	*Escherichia coli, Staphylococcus aureus,*	[8]
Leucas Aspera	Leaves	10 – 80	Spherical	Antibacterial, Antioxidant, chronic rheumatism, psoriasis, chronic skin eruptions	*Escherichia coli, Pseudomonas aeruginosa, Salmonella enterica, Shigella flexneri, Staphlococcusaureus, Vibrio choler, Bacillus cereus, Proteus mirabilis, Klebsiella sp*	[25], [42]
Mimosa pudica	Root	60–80	Spherical	Antimicrobial	*Escherichia coli*	[26],
Moringa Oleifera	Leaves	10-90	Spherical	Antibacterial, antimicrobial activity	*S. aureus, P. aeruginosa, E. coli, Shigella, Salmonella typhi, and P. multocida*	[27],
Murraya koenigii	Leaves	~59	Spherical	Fermentation process	*Clostridium acetobutylicum*	[28]
Musa ornate	Flower	43.69	Spherical	Antibacterial, antimicrobial	*Staphylococcus aureus, Streptococcus agalactiae, Escherichia coli, and Salmonella enteric*	[29]
Nelumbo nucifera	Leaves	25–80	Spherical, triangular	Malaria, A. subpictus and C. quinquefasciatus		[30]
Passiflora Foetida	Leaves	10-16	Spherical	Antibacterial	*Klebsiella pneumonia, Pseudomonas aeruginosa,*	[31]

					Staphylococcus aureus, Bacillus cereus, Escherichia coli	
Rosmarinus officinalis	Leaves	100	Spherical	Antioxidant, Cytotoxicity effect estimation on cancer cell lines, anti-proliferative activity, anti-inflammatory, antibacterial, antiviral, antidiabetic		[32]
Sargassum muticum	Seaweed powder	18 ± 4	Spherical	Antimicrobial	*Escherichia coli, Staphylococcus aureus*	[33]
Sorghum Bran	Leaves	10	Spherical	Antibacterial, antimicrobial activity, antioxidant		[34]
Tridax Procumbens	Leaves		Spherical	Antibacterial, antimicrobial activity	*Pseudomonas aeruginosa*	[35]
Withania Coagulans	Berries	18	Spherical	Antibacterial, antimicrobial activity	*S.aureus, P. aeuroginosa*	[36]
Withania Somnifera	Fruit Coat (Calx)		Spherical	Antibacterial, antimicrobial activity	*Proteus merabilis, Klebsiella pnemoniae, Agerobacterium tumefaciens*	[37], [38]

1.3. Green synthesis of iron nanoparticles from several research worker using plant extracts

The utilize of plants as a production assembly of iron nanoparticles has illuminated, due to its quick, biodegradable, non-pathogenic, economical protocol and providing a single-step technique for the biosynthetic processes. Many researchers have applied a green synthesis process for the preparation of iron nanoparticles via plant, leaf extract to further explore their application. A huge number of plants are reported to facilitate silver nanoparticle syntheses are mentioned in (Table 1) and it briefly expressed in the presented review.

The green synthesis of iron nanoparticles with a dimension of 2- 6 nm was observed using *Apple* aqueous extract [13]. The extracellular iron nanoparticles syntheses by aqueous leaf extract validate a rapid, simple, economical process like chemical and microbial methods. These iron nanoparticles exhibit antimicrobial activity against *P.aerugenosa, S.aureus, B.cereus,* and *S. typhi. Azadirachta indica (Neem)* was also utilized for the synthesis of iron nanoparticles to gauge its antioxidant activity [14]. *Carica Papaya* plant extract was used as an antimicrobial agent and also utilize to treat malaria and typhoid. XRD and TEM analysis revealed average particle size is 25-50nm of iron nanoparticles having a face-centered cubic (*FCC)* structure with a spherical shape. These nanoparticles were tested for antimicrobial activity against four microbial pathogens, viz, *Staphylococcus aureus*, *Streptococcus faecalis*, *Escherichia coli,* and *Proteus mirabilis* [15].

This nanoparticle was found to possess a crystalline structure with face-centered cubic geometric as studied by the XRD method. By using *Camellia Sinensis* (green tea) as a capping agent, 10-100 nm iron nanoparticles where are synthesized crystalline structure and spherical shape [16]. The edible fruit body extract of the plant *Couroupita guianens is* used to synthesized iron nanoparticles having a spherical shape with size during a range of 10-20 nm were achieved using this extract with antibacterial, cytotoxicity property observed [17]. An iron nanoparticle of size 8nm was synthesized using extract of the tree *Eucalyptus robusta Sm*, it showed significant antimicrobial, antibacterial antioxidant activity against bacterial pathogen, viz. *Escherichia coli, Staphylococcus aureus, Pseudomonas aeruginosa, Bacillus subtilis* [20].

A stable and spherical shaped iron nanoparticle was synthesized using extract of *Datura inoxia.* These nanoparticles show high antimicrobial activity [18]. *Gardenia jasminoides* leaves were wont to prepare the iron nanoparticles and different techniques were employed to characterize these nanoparticles. Transmission Electron Microscopy (TEM) analysis showed that these nanoparticles were spherical and uniformly distributed having a size of 32nm, functionalized with biomolecules that have hydroxyl, amide group these stabilizing functional group as shown by FTIR spectroscopy techniques [22].

In a recent report, these nanoparticles are synthesized on irradiation using an aqueous mixture of *Gooseberry* leaf extract [25]. *Lawsonia inermis* (commonly referred to as Henna) a native to East Africa, Pakistan to India, and cultivated in other tropical and subtropical countries showed strong antimicrobial and antibacterial effects against *Escherichia coli, Salmonella enterica, Proteus mirabilis, and Staphylococcus aureus* [24].

1.4. Characterization of iron nanoparticles

After the synthesis of iron nanoparticles, the characterization of their physicochemical properties is often provided through several sophisticated techniques (Table 2). In the next sections, the main target of the techniques is utilized to investigate the shape, size, size distribution, structure dimension, etc.

Table 2 Characterization techniques used to evaluate iron nanoparticles.

Techniques	**Evaluation**	**References**
Scanning tunnelling microscopy	Shape heterogeneity	[54]
Infrared spectroscopy (IR)	Nature of surface functionalization	[44]
Mass spectroscopy	Molecular weight	[53]
Nuclear magnetic resonance spectroscopy (NMR)	Longitudinal and transverse relaxivity; Structure conformation	[45]
Superconducting quantum interference device (SQUID); Vibrating sample magnetometry (VSM)	Magnetic properties	[46], [47]
Fluorescence correlation spectroscopy	Dimension, binding kinetics of Hydrodynamic	[53]
Electron microscopy (transmission, TEM; scanning, SEM)	Morphology, crystallinity, size distribution, composition	[48]
Surface-enhanced Raman scattering	Size distribution, electronic characteristics	[53]
X-ray diffraction (XRD)	Crystal structure, size	[43]
Dynamic light scattering (DLS)	Hydrodynamic diameter	[49]
Circular dichroism	Thermal constancy	[53]
Zeta potential measurement	Surface charge	[50], [51]
Thermal analysis (differential scanning calorimetry, thermogravimetric analysis, etc.)	Surface coverage, thermal stability, nature of surface functionalization, carrier-drug interaction	[52]
Small-angle X-ray scattering	Size and size navigation	[53]
Atomic force microscopy	Shape heterogeneity	[53]

2. Conclusion

The benefit of the synthesis of iron nanoparticles using plant extracts is that it is economical, energy-efficient, cost-efficient; protecting human health and the environment leading to leaser waste and safer products. The synthesis of nanoparticles employing plants can be favorable over other biological entities which can reduce cost as well as time. The use of plant extract for synthesis can form an immense impact in the coming decades. Still, there is a need for an economical and environmentally friendly route to find natural constituents to form iron nanoparticles that have not yet been studied.

Compliance with ethical standards

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Disclosure of conflict of interest

No conflict of interest.

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