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Review Paper

Plants as Green Source towards Synthesis of Nanoparticles

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Abstract

The recent development and implementation of new technologies have led to new era, the nano-revolution which unfolds role of plants in bio and green synthesis of nanoparticles which seem to have drawn quite an unequivocal attention with a view of synthesizing stable nanoparticles. Although nanoparticles can be synthesized through array of conventional methods biological route of synthesizing are good competent over the physical and chemical techniques. Green principle route of synthesizing have emerged as alternative to overcome the limitation of conventional methods among which plant and microorganisms are majorly exploited. Employing plants towards synthesis of nanoparticles are emerging as advantageous compared to microbes with the presence of broad variability of bio-molecules in plants can act as capping and reducing agents and thus increases the rate of reduction and stabilization of nanoparticles. Biological synthesized nanoparticles have upsurge applications in various sectors. Hence the present study envisions on biosynthesis of nanoparticles from plants which are emerging as nanofactories.

Keywords: Plants, nanoparticles, biosynthesis, biomolecules.

Introduction

The emergence of nanotechnology has provided an extensive research in recent years by intersecting with various other branches of science and forming impact on all forms of life[1]. The concept of nanotechnology was first begun with lecture delivered by Richard Feynman in 1959[2]. Nanotechnology is a field of science which deals with production, manipulation and use of materials ranging in nanometers. In nanotechnology nanoparticles research is an important aspect due to its innumerable applications. Nanoparticles have expressed significant advances owing to wide range of applications in the field of bio-medical, sensors, antimicrobials, catalysts, electronics, optical fibers, agricultural, bio-labeling and in other areas[3] (figure-1).

Nanoparticles Synthesis

Arrays of conventional methods have been employed in synthesis of nanoparticles. But these conventional methods are bound with various limitations such as expensive, generation of hazardous toxic chemicals etc., which has upsurge the researchers to develop safe, eco-friendly alternative approaches in synthesis of nanoparticles among which biological systems have been focused and exploited as a preferred green principle process for synthesis of nanoparticles. Undoubtedly, biological systems have a unique ability for production of precise shape and controlled structures. Methods employed for the synthesis of nanoparticles are broadly classified under two processes such as “Top-down” process and “Bottom-up” process (figure-2).

Top-down approach: Bulk material is broken down into particles at nanoscale with various lithographic techniques e.g.: grinding, milling etc. Bottom-up approach: Atoms self-assemble to new nuclei which grow into a particle of nanoscale. With the advent of advance technologies and improved scientific knowledge have paved a way for research and development in the field of herbal and medicinal plant biology towards intersection of nanotechnology. One such interference is employing plants in synthesis of nanoparticles. The possibilities of employing plants in the deliberate synthesis of nanoparticles have burgeoning interest as an important source towards reliable and environmentally benign method of metallic nanoparticles synthesis and its characterization (figure-3).

The present review emphasizes reported plant resources for the synthesis of different nanoparticles. Plants are known to possess various therapeutic compounds which are being exploited since ancient time as a traditional medicine. Due its huge diversity plants have been explored constantly for wide range of applications in the field of pharmaceutical, agricultural, industrial etc. Recent reports of plants towards production of nanoparticles is said to have advantages such as easily available, safe to handle and broad range of biomolecules such as alkaloids, terpenoids, phenols, flavanoids, tannins, quinines etc. are known to mediate synthesis of nanoparticles. Plants reported to mediate nanoparticles synthesis are mentioned in the table-1 which is discussed briefly in this present review.

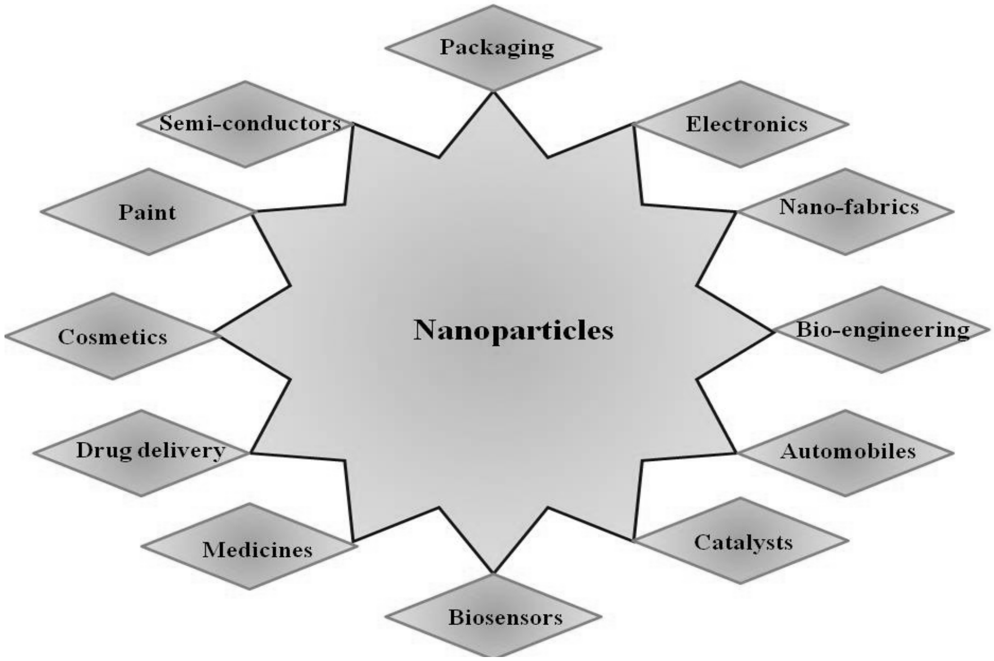

Figure-1
Overview applications of nanoparticles

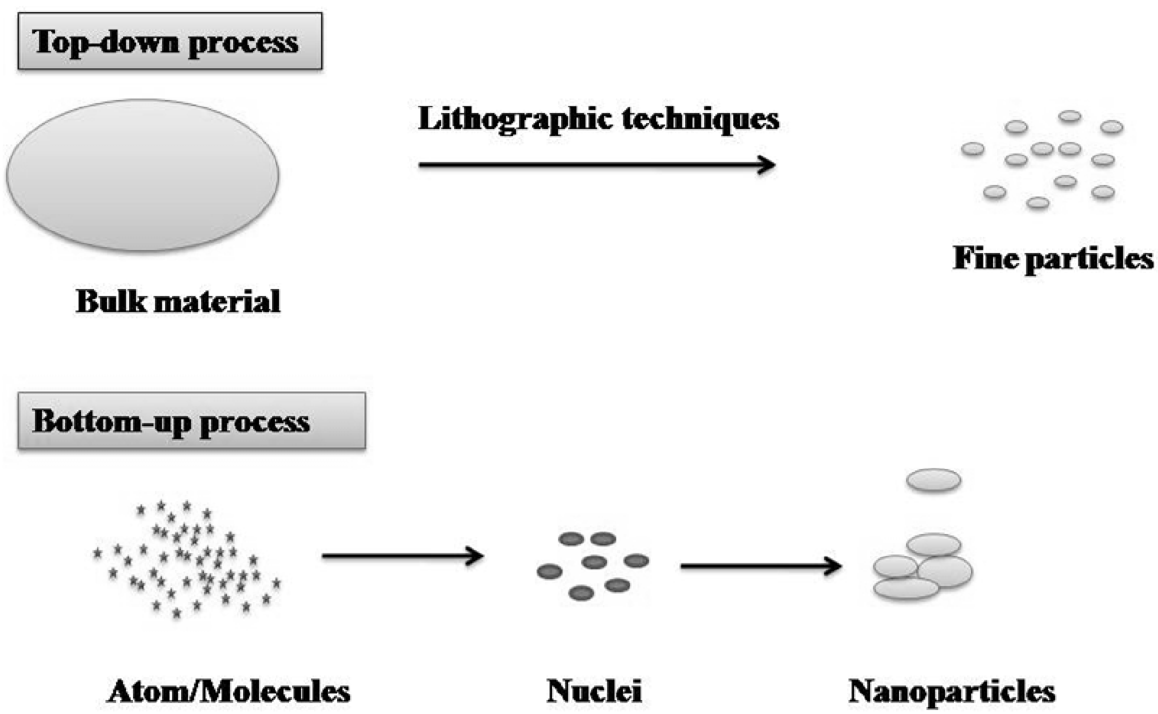

Figure-2
Protocols employed for the synthesis of nanoparticles

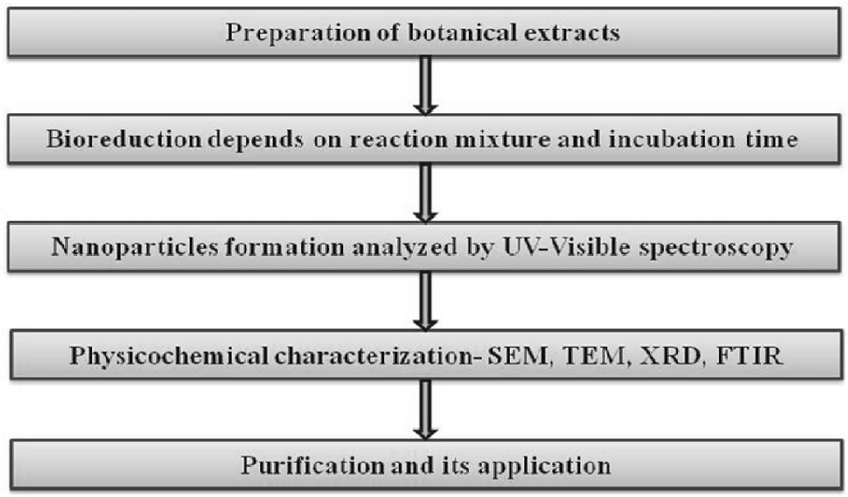

Figure-3
Steps involved in the biosynthesis of nanoparticles

Fabrication of different Nanoparticles using Plants

Platinum nanoparticles were synthesized using leaf extract of *Diopyros kaki*. The synthesized platinum nanoparticles were characterized resulting in 2 to 12nm in size FTIR analysis revealed that the formation of platinum nanoparticles was due to the biomolecules present in the extract but not an enzyme-mediated process[4]. The synthesis of iron and silver nanoparticles were studied using the aqueous bran extract of *Sorghum*. The synthesized silver nanoparticles were crystalline in nature with an average diameter of 10nm in size and face-centered cubic shaped whereas the iron nanoparticles were amorphous in nature with a 50nm average diameter size[5]. Biological synthesis of gold nanoparticles using *Nyctanthes arbortristis* ethanolic flower extract was evaluated resulting in synthesis of spherical shaped gold nanoparticles with size 19.8 ± 5.0 nm[6]. The phytosynthesis of titanium dioxide nanoparticles using *Nyctanthes* leaf extract resulted in formation of titanium dioxide nanoparticles which was analyzed by SEM and PSA resulting in the size ranging from 100 to 150nm[7]. The synthesis of selenium (α-Se)/protein composites using *Capsicum annuum* L. extract resulted with the increased concentration of *Capsicum annuum* leaf extract with a low pH increases the α-Se/protein composites size and thickness of the shell[8]. Similarly synthesis of zinc oxide using *Calotropis procera* latex revealed zinc nanoparticles which was analyzed by TEM and SEM that revealed the particles size ranging 5-40nm and spherical shaped respectively[9]. The aqueous leaves extract of the *Sorbus aucuparia* were used as reducing agent for the synthesis of silver and gold nanoparticles. The formation of silver and gold nanoparticles were characterized by transmission electron microscopy (TEM), UV-Vis spectroscopy, X-ray diffraction (XRD), energy dispersive X-ray (EDX) and Fourier transform infrared spectroscopy (FTIR). The concentration of residual silver and gold ions was measured by Inductively Coupled Plasma (ICP) spectroscopy. The synthesized nanoparticles were spherical, triangular and hexagonal in shape with an average size of 16 and 18nm for silver and gold respectively[10]. Similar study conferring green synthesis of silver nanoparticles using weed *Argemone maxicana* leaf extract was reported which was monitored by UV–Vis absorption spectroscopy, FTIR, XRD and SEM. X-ray diffraction and characterized by SEM analysis resulted in the average particle size of 30 nm[11]. Plant mediated silver nanoparticles using the sea weed *Padina tetrastromatica* leaf extract upon evaluation resulted in silver nanoparticles formation which was confirmed by analytical techniques. Fourier Transform Infra-Red (FT-IR) spectroscopy analysis revealed that bimolecular compounds were capped with nano-silver are responsible for reduction of silver ions[12].

Probable mechanism involved in the fabrication of nanoparticles in plants

The synthesis of irregular shape of gold nanoparticles from the extracellular aqueous dried clove buds (*Syzygium aromaticum*) was reported and FTIR characterization revealed that the freely water soluble flavonoids of clove buds are responsible for bioreduction of gold ions[13]. Similarly, crude ethyl-acetate extract of *Ulva fasciata*, was evaluated for nanoparticles synthesis resulted in polydispersed nanoparticles with size ranging from 28- 41nm. The study also revealed the presence of 1-(hydroxymethyl)- 2,5,5,8a- tetramethyl decahydro-2-napthalenol as reducing agent and hexadecanoic acid was found to be a stabilizing agent. The biological synthesis of nanoparticle was evaluated for antimicrobial study against *Xanthomonas campestris* Pv. *malvacearum* with zone of inhibition ranging 14.00±0.58 mm and minimum inhibitory concentration was 40.00±5.77µg/ml[14]. The synthesis of antimicrobial silver nanoparticles using tissue culture-derived callus and leaf of the saltmarsh plant, *Sesuvium portulacastrum* L. was studied. The callus extract was able to produce silver nanoparticles, better than leaf extract. The synthesis was confirmed by using X-ray diffraction spectrum. TEM resulted in the formation of silver nanoparticles with a spherical shaped and the size ranging from 5-20nm. Fourier transform infrared (FTIR) spectroscopy revealed the presence of proteins, flavones and terpenoids which were responsible for the stabilization of the silver nanoparticles. The synthesized silver nanoparticles showed significant activity against clinical strains of bacteria than the fungi[15]. When aqueous leaf extract of M*emecylon edule* (Melastomataceae) was evaluated for the production of silver and gold nanoparticles by challenging silver nitrate and chloroauric acid resulted in rapid gold and silver nanoparticles formation where the gold nanoparticles ranging in the size of 20-50nm with varied shapes such as triangular, circular, and hexagonal. The silver nanoparticles were predominantly square with uniform size range 50-90 nm. The study also revealed the presence of saponin in aqueous extract was responsible for the mass production of silver and gold nanoparticles[16]. The rapid synthesis of silver, gold and bimetallic alloy gold/silver nanoparticles was investigated from the *Swietenia mahogany* leaf towards synthesis of nanoparticles which was monitored by UV–visible spectroscopic. TEM images showed the formation of bimetallic Au/Ag alloy nanoparticles and resulted that various polyhydroxy limonoids present in the *Mahogany* leaf were responsible for the reduction and stabilization of silver and gold nanoparticles[17]. The aqueous extract of rose petals was used for the study of biosynthesis of gold nanoparticles displayed gold nanoparticles upon characterized by UV–VIS spectroscopy, FT-IR spectroscopy, X-ray diffraction and energy dispersive X-ray spectroscopy. FT-IR spectroscopy revealed the presence of biomolecules that have primary amine group (–NH2), carbonyl group, –OH groups and other stabilizing functional groups that are responsible for the stabilization of gold nanoparticles. X-ray diffraction pattern showed high purity and face centered cubic structure of gold nanoparticles. The size of gold nanoparticles was determined by Dynamic light scattering technique and it was found to be about 10 nm[18]. The bio fabrication of gold nanoparticles resulted to depend on different parameters like temperature and pH effects on its synthesis using the aqueous extract of *Macrotyloma uniflorum*. Biosynthesized nanoparticles were recorded by UV–visible spectroscopy, transmission electron microscopy (TEM), X-ray diffraction (XRD) and FTIR analysis. The high crystallinity with fcc phase of nanoparticles was analyzed by HRTEM images, SAED and XRD patterns. The size of the nanoparticles was ranging from 14-17nm and FTIR spectrum resulted the presence of different functional groups present in the bio-molecule capping the nanoparticles[19].

Applications of plant mediated synthesised Nanoparticles

Bio-fabricated nanoparticles employed for Biological Assays: Rapid synthesize of silver nanoparticles using leaf extract of *Acalypha indica* was evaluated against the water borne bacterial pathogens. Silver nanoparticles characterization was recorded from UV–Vis spectrum, scanning electron microscopy (SEM), X-ray diffraction (XRD) and energy dispersive spectroscopy (EDS) and resulted in the formation of 20-30nm particle size of nanoparticles. The antibacterial activity of synthesized silver nanoparticles showed effective inhibitory activity against *Escherichia coli* and *Vibrio cholera* with MIC ranging 10µg/ml[67]. Silver nanoparticles from *Ocimum tenuiflorum*, *Solanum tricobatum*, *Syzygium cumini*, *Centella asiatica* and *Citrus sinensis* were tested against *Staphylococcus aureus*, *Pseudomonas aeruginosa*, *Escherichia coli* and *Klebsiella pneumonia*. *O. tenuiflorum* extracts found significant activity against *S. aureus* (30mm) and *E. coli* (30mm) respectively[68]. The copper nanoparticles using plant leaf extract of *Magnolia*. Electron microscopy analysis revealed the size of copper nanoparticles of about 40 to 100 nm upon evaluation resulted in antibacterial activity against *Escherichia coli* and observed significant activity against the test pathogen[69]. Similarly copper nanoparticles using leaf extract of *Tridax procumbens* where the water soluble carbohydrates were responsible for the reduction of copper ions and also showed significant activity against *Escherichia coli*[64]. The photosynthesized silver nanoparticles using different plant parts (leaves, bark and root) of *Avicenna marina* mangrove plant showed the maximum silver nanoparticles formation than the bark and root extract. The synthesized nanoparticles displayed maximum zone of inhibition against *E. coli* (18.40 ± 0.97 mm) and minimum inhibition with *S. aureus* (10.87 ± 1.33 mm). The MIC and MBC values ranged from 6.25 and 50.0 µg ml^{-1} between the selected test bacteria[70]. Silver nanoparticles were synthesized by using papaya fruit as reducing as well as capping agent. The production of nanoparticles was monitored by using UV–Vis absorption spectroscopy and was characterized by FTIR, XRD and SEM. X-ray diffraction and SEM analysis showed the average particle size of 15 nm as well as revealed their cubic structure. Synthesized nanoparticles were evaluated for antimicrobial activity against multi-drug resistant human pathogens[28]. Antimicrobial activity of silver nanoparticles synthesized from *Psidium guajava* was evaluated against human pathogens. The synthesized silver nanoparticles showed significant antimicrobial activity against *Escherichia coli*, *Bacillus cereus* and *Candida tropicalis*[71]. Silver nanoparticles by using the rhizome extract of *Dioscorea batatas* and were characterized by UV-Vis spectrophotometer, SEM, FTIR, XRD, and EDX. Upon antimicrobial evaluation resulted activity against gram positive (*B. subtilis* and *S. aureus*), gram negative (*E. coli*), and fungi (*S. cerivisae* and *C. albicans*) [72]. The synthesis of silver nanoparticles using *Cassia auriculata* leaf extract was and evaluated for antimicrobial activity against *E.coli*, *Serratia marcescens*, *Bacillus subtilis*, *Aspergillus niger* and *Aspergillus flavus*. Fungi showed significant activity followed by the test bacteria[73]. Biosynthesized silver nanoparticles using stem bark extracts of *Boswellia* and *Shorea*; and leaf extract of *Svensonia* was evaluated against panel of pathogenic microorganism viz., *Proteus, Pseudomonas, Klebsiella, Bacillus* and *E.coli* species of bacteria and *Aspergillus, Fusarium, Curvularia* and *Rhizopus* species of fungi. Silver nanoparticles synthesized from bark extracts of *Boswellia ovalifoliolata* and *Shorea tumbuggaia* showed significant activity against *Klebsiella* and *Aspergillus*; and *Pseudomonas* and *Fusarium* species respectively whereas the leaf extract of *Svensonia hyderobadensis* inhibited the growth of *Pseudomonas* and *Rhizopus* species[74]. The formation of silver nanoparticles using stem extract of *Svensonia hyderobadensis* (Walp.) Mold. were tested against bacteria such as *Proteus, Pseudomonas, Klebsiella, Bacillus* and *E.coli* and fungi- *Aspergillus, Fusarium, Curvularia* and *Rhizopus* species. The antimicrobial activity of silver nanoparticles showed significant activity against *Pseudomonas*, *Curvularia* and *Fusarium and* moderate activity against *E. coli, Klebsiella, Bacillus*, *Proteus*, *Aspergillus flavus* and *Aspergillus niger*[75]. The preparation of silver nanoparticles using the aqueous leaf extract of *Citrus limon* were tested against *Fusarium oxysporum* and *Alternaria brassicicola* and also the formed nanoparticles were used in the treatment of fabrics against antifungal activity[76]. The synthesized nanoparticles using *Euphorbia prostrate* were evaluated as an eco-friendly alternative for pesticidal activity against the adult of *Sitophilus oryzae*[77]. When leaf extract of *Euphorbia hirta* L. was used for the production of silver nanoparticles and were evaluated for antifungal activity against the *Candida albicans*, *C. kefyr*, *A. niger* [78].

Table-1
Representing plant reported synthesis of nanoparticles

Sl. No	Plant	Biomolecules involved	Nanoparticle	Size	References
1	*Allium cepa* L.	Vitamin C	Au	~100 nm	Parida et al. [20]
2	*Allium sativum* L.	Sucrose and fructose	Ag	4 .4 ± 1.5nm	White II et al. [21]
3	*Achyranthus aspera* L.	Polyols	Ag	20-30nm	Daniel et al. [22]
4	*Anacardium occidentale* L.	Polyols and proteins	Au, Ag, Au-Ag alloy and Au core-Ag shell	-	Sheny et al. [23]
5	*Andrographis paniculata* Nees.	Hydroxyflavones catechins	Ag	28nm	Sulochana et al. [24]
6	*Astragalus gummifer* Labill.	Proteins	Ag	13.1±1.0 nm	Kora et al. [25]
7	*Azadirachta indica* A. Juss.	Salanin, Nimbin, Azadirone and Azadirachtins	Au	2-100nm	Thirumurugan et al. [26]
8	*Camellia sinensis* L.	Polyphenolic compounds	Au	25 nm	Boruah et al. [27]
9	*Carica papaya* L.	hydroxyflavones and catechins.	Ag	15nm	Jain et al. [28]
10	*Centella asiatica* L.	Terpenoid, flavonoid	Ag	-	Palaniselvam et al. [29]
11	*Chenopodium album* L.	Oxalic acid	Ag Au	12nm,10 nm	Dwivedi and Gopal [30]
12	*Coleus aromaticus* Lour.	Flavonoids	Ag	40–50 nm.	Vanaja and Annadurai [31]
13	*Cinnamomum zeylanicum* Blume.	Terpenoids	Pd	15 to 20 nm	Sathishkumar et al. [32]
14	*Cinnamomum camphora* L.	Polyols, heterocyclic components	Pd	3.2to 6.0 nm	Xin et al. [33]
15	*Citrullus colocynthis* L.	Polyphenols with aromatic ring and bound amide region	Ag	31nm	Satyavani et al. [34]
16	*Datura metel* L.	Plastohydroquinone or plastrocohydroquinol	Ag	16 to 40 nm	Kesharwani et al. [35]
17	*Desmodium triflorum* (L) DC.	Water-soluble antioxidative agents like ascorbic acids	Ag	5–20 nm	Ahmed et al. [36]
18	*Diopyros kaki*	Terpenoids and reducing sugars	Pt	2–12 nm	Song et al. 2010 [4]
19	*Dioscorea bulbifera* L.	Polyphenols or flavonoids	Ag	8–20 nm Average 75nm	Ghosh et al. [37]
20	*Dioscorea oppositifolia* L.	Polyphenols with aromatic ring and bound amide region	Ag	14nm	Maheswari et al. [38]

21	*Elettaria cardamomom* (L) Maton.	Alcohols, carboxylic, acids, ethers, esters and aliphatic amines	Ag	-	GnanaJobitha et al. [39]
22	*Gardenia jasminoides* Ellis.	Geniposide,chlorogenicacid, crocins and crocetin	Pd	3-5nm	Jia et al. [40]
23	*Glycyrrhiza Glabra* L.	Flavonoids, terpenoids, thiamine.	Ag	20 nm	Dinesh et al. [41]
24	*Hibiscus cannabinus* L.	Ascorbic acid	Ag	9 nm	Bindhu and Umadevi [42]
25	*Hydrilla verticilata* (L.f.) Royle.	Proteins	Ag	65.55 nm	Sable et al. [43]
26	*Jatropha curcas* L.	Curcacycline A (an octapeptide), Curcacycline B (a nonapeptide) Curcain (an enzyme)	ZnS Pb	10nm 10-12.5 nm	Hudlikar et al.[44] Joglekar et al. [45]
27	*Justicia gendarussa* L.	Polyphenol and flavonoid	Au	27 nm	Fazaludeena et al. [46]
28	*Lantana camara* L.	Carbohydrates, glycosides and flavonoids	Ag	12.55	Sivakumar et al. [47]
29	*Leonuri herba* L.	Polyphenols and hydroxyl groups	Ag	9.9 to 13.0 nm	A-Rang Im et al. [48]
30	*Macrotyloma uniflorum* (Lam) Verdc.	Functional groups	Au	14-17nm	Aromal et al. [19]
31	*Mentha piperita* L.	Menthol	Ag, Au	90nm, 150nm	Ali et al. [49]
32	*Mirabilis jalapa* L.	Polyols	Au	100nm	Vankar and Bajpai [50]
33	*Morinda pubescens* L.	Hydroxyflavones, catechins	Ag	25-50nm	Mary and Inbathamizh [51]
34	*Ocimum sanctum* L.	Phenolic and flavanoid compounds. Proteins Ascorbic acid, gallic acid, terpenoids,	Ag Ag Pt	~10 nm 4–30nm 23 nm	Ahmad et al. [52] Ramteke et al. [53] Soundarrajan et al.[54]
35	*Parthenium hysterophorus* L.	Hydroxyflavones and catechins	Ag	10nm	Ashok Kumar [55]
36	*Pedilanthus tithymaloides* (L) Poit.	Proteins and enzymes	Ag	15-30nm	Sundarayadivelan et al. [56]
37	*Piper betle* L.	Proteins	Ag	3-37 nm	Mallikarjuna et al. [57]
38	*Piper nigrum* L.	Proteins	Ag	5 - 50 nm	Garg [58]
39	*Plumeria rubra* L.	Proteins	Ag	32 -220 nm	Patil et al. [59]
40	*Sesuvium portulacastrum* L.	Proteins, flavones and terpenoids	Ag	5-20nm	Nabikhan et al. [15]
41	*Solanum xanthocarpum* L.	Phenolics, alkaloids and sugars	Ag	10 nm	Amin et al. [60]
42	*Sorghum* Moench.	Polyphenols	Ag , Fe	10nm, 50nm	Njagi et al. [5]
43	*Soybean (Glycine Max)* L.	Proteins and amino acids	Pd	~15 nm	Petla et al. [61]
44	*Swietenia mahogany* (L) Jacq.	Polyhydroxy limonoids	Ag, Au and bimetallic alloy Au-Ag	-	Mondala et al. [17]
45	*Syzygium aromaticum* (L) Merr. & Perr.	Flavonoids	Au	5-100 nm	Deshpande et al. [13]
46	*Terminalia catappa* L.	Hydrolysable tannins	Au	10-35nm	Ankamwar [62]
47	*Trianthema decandra* L.	Hydroxyflavones and catechins.	Ag	10-50nm	Geethalakshmi and Sarada [63]
48	*Tridax procumbens* L.	Water-soluble carbohydrates	Cuo_2	-	Gopalakrishnan et al. [64]
49	*Vitus vinifera* L.	Flavone and anthocyanins	Pb	661nm	Pavani et al. [65]
50	*Zingiber officinale* Rosc.	alkanoids, flavonoids	Ag Au	10nm	Singh et al. [66]

Note: Ag- Silver, Au- Gold, Pd- Palladium, Pt- Platinum, ZnS- Zinc Sulphide, Fe- Iron, Pb- Lead, CuO_2- Copper oxide

Silver nanoparticles by using *Musa paradisiaca* L. was recorded and tested for acaricidal and larvicidal activity. Results of SEM analysis showed that the formation of nanoparticles of rod shaped with a size of 60-150nm. The synthesized silver nanoparticles showed maximum activity with an LC50 value against *Haemaphysalis bispinosa* (1.87mg/l; 0.963) and larvae of hematophagous fly *Hippobosca maculata* (2.02mg/l; 0.976) and the fourth-instar larvae of malaria vector, *Anopheles stephensi* (1.39; 0.900 mg/l), Japanese encephalitis vector, *Culex tritaeniorhynchus* (1.63 mg/l; 0.951)[79]. When leaves of *Andrographis paniculata* was evaluated for synthesis of silver nanoparticles the obtained nanoparticles were characterized using UV-Vis (UV-visible spectroscopy), XRD (X-ray diffraction analysis), and SEM (scanning electron microscope) and was tested as anti-parasitic activity against *Plasmodium falciparum* resulted in IC50 values: 26±0.2% at 25µg/ml, 83±0.5% at 100µg/ml[80]. *Catharanthus roseus* Linn upon evaluation resulted in synthesis of silver nanoparticles with an average size of 35-55nm which showed significant anti plasmodial activity against *Plasmodium falciparum*[81]. The formation of silver nanoparticles using geraniol showed the uniform distribution of silver nanoparticles size and shape ranging from 1 to 10 nm with an average size of 6 nm. The synthesized nanoparticles also showed significant cytotoxicity by inhibiting >60% of cancer cell line (Fibrosarcoma-Wehi 164) growth. The significant inhibition of about 50% of cell death was observed at the concentration of 2.6µg/ml silver nanoparticles[82]. The efficacy of immune-restorative by using Ziziphus mauritiana leaves and chitosan nanoparticles as a carrier were investigated and the results showed that the plant loaded with the chitosan nanoparticles was suppressed the Swiss albino mice by injecting intra-peritoneal injection of hydrocortisone[83].

Bio-fabricated nanoparticles for physic-chemical applications: The extracellular synthesis of gold nanoparticles using *Barbated Skullcup* (BS) herb characterized by UV-Vis spectrum and Transmission electron microscopy (TEM) micrograph revealed well-dispersed and 5-30nm sized nanoparticles. They also showed that the modified gold nanoparticles on the glassy carbon electrode (GCE), that enhances the electronic transmission rate between the electrode and the *p*-nitrophenol[84]. Similarly, the plant mediated gold synthesis using *Sesbania* seedlings was investigated and characterized by TEM revealed the intracellular distribution of monodisperse nanospheres, due to the metal ions reduction by secondary metabolites present in cells. X-ray absorption showed a high degree of efficiency for the biotransformation of Au (III) into Au (0) by plant tissues. The catalytic function of the nanoparticles bearing bio-matrix directly reduced the aqueous 4-nitrophenol (4-NP)[85]. The synthesis of Indium oxide nanoparticles using *Aloe vera* plant were characterized by XRD and TEM analysis showed that the indium oxide nanoparticles were cubic with size ranging from 5-50nm. The morphology and size of indium oxide materials were affected by the calcinations temperature. The synthesized indium oxide nanoparticles showed a strong PL emission in the UV region. The strong emissions of indium oxide are attributed to the radioactive recombination of an electron occupying oxygen vacancies with a photo-excited hole[86].

Future Perspectives

Biologically synthesized nanoparticles are important aspect of nanotechnology, nanoparticles have unprecedented applications in various sectors. With the advent of the new technologies and improved scientific knowledge have paved the route towards employing biological entities in synthesis of nanoparticles among which employing plants for the synthesis of nanoparticles can be advantageous over other biological entities which can overcome the time consuming process of employing microbes and maintaining their culture which can lose their potential towards synthesis of nanoparticles during prospect. Wherein the plants and their product employed reliable with one step process towards production of nanoparticles at the same time harvesting of endangered species may pose a risk towards plant kingdom which forms a major challenge. Hence in this regard bio-template synthesis can form an immense impact in coming decades wherein biomolecules present in the plant responsible for mediating the nanoparticles production can be identified and employed in rapid single step protocol which can overcome the above said disadvantageous and can give a new facelift towards green principle nanoparticles production.

Conclusion

Biological synthesis of nanoparticles has upsurge in the field of nano-biotechnology to create novel materials that are eco-friendly, cost effective, stable nanoparticles with a great importance for wider applications in the areas of electronics, medicine and agriculture. During the current scenario nanotechnology motivates progress in all sphere of life, hence biosynthetic route of nanoparticles synthesis will emerge as safer and best alternative to conventional methods. Though various biological entities have been exploited for the production of nanoparticles, the use of plants for the facile robust synthesis of nanoparticles is a tremendous. Thus the present review envisions the importance of plant mediated nanoparticles productions by conferring the various literatures reported by far. With the huge plant diversity much more plant species are in way to be exploited and reported in future era towards rapid and single step protocol with green principle.

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