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Biotechnological Applications of Green Synthesized Silver Nanoparticles

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Abstract

Silver and its compound have been widely used since from ancient time for the treatment of bacteria and wound infections especially in patients of serious burns. The use of silver compounds has been deteriorated due to emergence of new therapeutic agents. In the past decade nanotechnology has acquired pace due to its ability of modifying metals ions into their nano range, which dramatically changes their chemical, physical and optical properties. Silver nanoparticles have been proved a potential antimicrobial agent. Recently, the use of silver nanoparticles (AgNPs) has been greatly enhanced, due to the development of antibiotic resistance against several pathogenic bacteria. The silver nanoparticles have been widely employed in biomedical industry as coatings in dressings, in medicinal devices and in the form of nanogels in cosmetics and lotions, etc. There are well established protocols for the preparation of silver nanoparticles can be broadly classified into physical, chemical and biological protocols. The physical and chemical processes often involve high temperatures/pressure for the reaction and the use of hazardous chemicals. Therefore the research in synthesis of nanoparticles by biological methods is gaining importance. Plant extracts are considered cost-effective, environment friendly and efficient alternative for the large-scale synthesis of nanoparticles. In the present review, we critically assess the role of plants in synthesis of silver nanoparticles and their biomedical applications.

Keywords: Biosynthesis; Plant assisted synthesis; Silver nanoparticles; Biomedical; Metal nanoparticles

Introduction

Nanotechnology is the science which deals in materials in the range of 1 to 100 nm. Nanomaterials have great importance as the physico-chemical properties of the metal is changed as it reaches the nano size, their properties are different as compared to the bulk metal. These nanomaterials have multiple applications in various fields such as electronics, cosmetics, coatings, packaging, and biotechnology. Due to their optical properties the colloidal solution of metal nanomaterials is transparent, thus they are useful in cosmetics, coatings, and packaging. Among metal nanoparticles, silver nanoparticle has wide application in industry and medicine due to its antibacterial, antifungal, larvicidial and anti-parasitic characters. Because of their wide applications beneficial to humans there is a need to develop rapid and reliable experimental protocols for the synthesis of silver nanoparticles. Different types of nanoparticles such as Ag, Au, Pt and Pd have been synthesized in the recent past by chemical, physical and biological methods. The chemical methods are the most popular but the use of toxic chemicals during synthesis produces toxic by-products [1]. The physical methods require large amount of energy to maintain high pressure and temperature required for the reaction [2]. Thus the chemical and physical methods have their own limitations; these are considered expensive and unsuitable for sustainable ecosystem [3]. The synthesis of silver nanomaterials using biological entities is gaining momentum as; biological methods are providing, nontoxic and environmentally acceptable "green chemistry" procedures.

The physical and morphological features of metal nanoparticles are greatly affected by the solvents and reducing agents used. The variation in size, shape and morphology influenced the applications of the nanoparticles. The morphology of silver nanoparticles is determined by reducing precursor. These reducing and/or stabilizing precursor can be induced by bacteria, fungi, yeasts, algae, or plants [4,5] as a whole or their products. The interaction of these biomolecules has been exploited earlier also in various applications such as recovery of metal/metals, bioremediation, bioleaching and bio-mineralization [6]. However, still the mechanism of synthesis of nanoparticles using biomolecules is yet to be explored and hence needs much more experimentations.

Synthesis of metal nanoparticles acquires special attention due to its specificity and environment friendly approach. Whether the microorganisms or the plants are being employed, it is the biomolecules present in them which is responsible for the biosynthetic mechanism. These biomolecules may be carbohydrates, lipids, DNA and enzymes/proteins or a combination of two or more.

Plant in AgNPs synthesis-A green approach

The use of plant and plant extract in nanoparticle synthesis is considered advantageous over microbial based system because it reduces the elaborate process of maintaining cell cultures. The particle size growth can also be controlled by altering synthesis conditions like pH, reductant concentration, temperature, mixing ratio of the reactants etc. The plant based synthesis can be carried out either extracellularly or intracellularly. Intracellular synthesis takes place inside the plant whereas the extracellular synthesis occurs *in vitro*. The studies reveals that extracellular synthesis using plant extracts has been considered better as compared to intracellular synthesis [5] because it eliminates the extraction and purification procedures. Biosynthesis of AgNPs by plant extracts such as neem [4], *Chenopodium album* [7], *Allium cepa* [8], *Eucalyptus hybrid* [9], Cycas [10], *Tribulus terrestris* [11] etc. have been reported. Recent examples of plants reported in literature for AgNPs synthesis are cited in Table 1. Till date, lot of papers has been published in this area which describes the mechanism and role of active biomolecules in synthesis [12]. These studies suggested that presence of phytochemicals in plant extracts are the key component in reduction and stabilization of silver ions [12]. The phytochemicals

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Name of Organism	Plant parts Extract	Size (nm)	Reference
Sorghum bicolor	Bran	10	[71]
Vitex negundo	Leaf	10-30	[72]
Garlic	Leaf	4-7	[13]
Boerhaavia diffusa	Leaf	25	[73]
Ocimum sanctum	Leaf	5-7	[23]
Medicago sativa	Leaf	20–40	[74]
Jatropha curcas	Latex	10–20	[75]
Cinnamomum camphora	Leaf	55–80	[76]
Capsicum annuum	Leaf	15–20	[77]
Allium cepa	Extract	30-34	[8]
Azadirachta indica	Leaf	50–100	[4]
Pelargonium graveolens	Leaf	16–40	[24]
Aloe vera	Leaf	15–15.6	[78]
Emblica officinalis	Fruit	15–25	[79]
Saraca indica	Flower	12-14	[80]
Carica papaya	Fruit	60-80	[81]
Artemisia annua	Leaf	7-27	[82]
Trapa bispinosa	Peel	10-15	[83]
Brassica juncea	Leaf	~50	[84]
Gliricidia sepium	Leaf	10–50	[85]
Euphorbia hirta	Leaf and bark	40-50	[86]
Argemone mexicana	Leaf	30	[87]
Boswellia Ovalifoliolata	Bark and leaf	30-40	[88]
Cycas circinalis	Leaf	2–6	[10]
Acalypha indica	Leaf	20-30	[15]
Nerium indicum	Leaf	29	[89]
Bacopa monniera	Leaf	15–120	[90]
Rhizophora apiculata	Leaf	13–19	[91]
Nicotiana tobaccum	Leaf	8	[92]
Memecylonedule	Leaf	10–45	[93]
Bauhinia variegata L.	Leaf	43–145	[94]
Ficus benghalensis	Leaf	16	[95]
Murraya koenigii	Leaf	10–25	[18]
Dalbergia sissoo	Leaf	5–55	[96]
Ipomea carnea	Leaf	30–130	[97]
Phyllanthus maderaspatensis	Leaf	59–76	[98]
Santalum album	Leaf	80–200	[99]
Syzgium cumini	Leaf	100–160	[100]
Eucalyptus hybrida	Leaf	20-50	[9]

Table 1: Synthesis of silver nanoparticles mediated by plants.

which are responsible for reduction are terpenoids, flavonoids, ketones, aldehydes, amides, and carboxylic acids. The water soluble metabolites such as flavones, organic acids, and quinones are solely responsible for the bioreduction ions. Some researchers have reported that a keto-enol transition of anthraquinone is responsible for formation of AgNPs. It has been also observed that mesophytes contain three types of benzoquinones: cyperoquinone, dietchequinone, and remirin which might be responsible for reduction of ions and formation of AgNPs. The mechanism of reduction of silver ions depends upon the phytochemical present in the plants, this is diagrammatically represented in Figure 1.

Effect of concentration of reducing precursor

The synthesis of metal nanoparticles are greatly affected by the concentration of reducing and stabilising precursor. White et al. shows that the as the concentration of garlic extract varies, the nanoparticle synthesis is also varies. It was also reported that higher concentration of garlic extract lead to generation of polydispersed AgNPs [13]. Song and Kim also reported that average particle size can be controlled in biosynthesis of nanoparticles using five plants leaf extract [1]. Khalil et al. showed the concentration variation of olive leaf extract [14]. They demonstrated that increase in concentration of leaf extract results in blue shift and absorbance peak become more sharpened. This blue shift indicated the reduction in mean diameter of silver nanoparticles. Krishnaraj et al. reported that synthesis of AgNPs is more at 20% *A. Indica* (Neem) leaves extract than 40% [15]. The increased number of biomolecule results in agglomeration which reduces the absorption in UV-Vis spectroscopy.

Effect of silver ion concentration

Surface Plasmon resonance (SPR) spectra for AgNPs are obtained at around 400 to 480 nm with brown to yellow colour. Silver ion concentration play major role in biosynthesis of AgNPs. Several researchers have demonstrated the impact of concentration of silver ion on biosynthesis of AgNPs. Youmie Park et al. reported variation

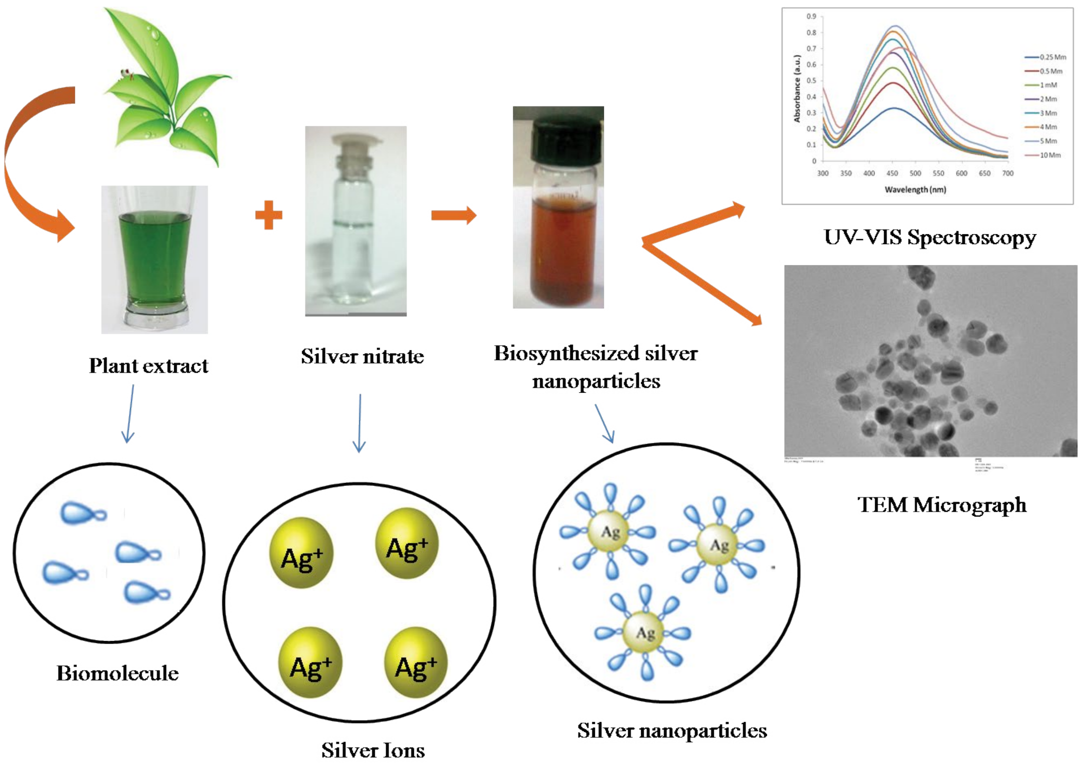

Figure 1: Diagrammatic representation of reduction of silver ions by biomolecules of plant extract.

of concentration of $AgNO_3$ from 0.25 mM to 1.0 mM results in increase in absorbance and the peak become more sharpened [16]. It was demonstrated by Dubey et al. that absorbance increases with the increase of metal ion concentration from 1 mM to 3 mM which may results in larger particle size of AgNPs [17]. Christensen et al. [18] kept *Murraya koenigii* leaf extract quantity constant (1 ml) and varied the concentration of silver nitrate i.e., 10^{-3} M in ratios of 1:20, 1:25, 1:50, 1:100, 1:200. The best synthesis was observed at the ratio of 1:20 beyond that the synthesis reduces which may be due to number biomolecules in 1 ml of extract which are sufficient enough for reduction of 20 ml of silver nitrate. But as the concentration of precursor is increased, a lesser number of biomolecules is available for reduction and capping thereby reducing the synthesis of AgNPs.

Effect of reaction temperature

The SPR spectra greatly vary with reaction temperature. When reaction temperature increases the absorbance peak decreases with increase in reaction rate which may results in smaller sized nanoparticles [19]. The temperature enhances the rate of reduction which results in decreased reaction time. The change in temperature may lead to blue shift in wavelength. Aparajita et al. showed that when temperature changes from 10 to 50°C the λ_{max} has been decreased from 433 to 397 nm. The change in λ_{max} may be due to localization of surface plasmon resonance of AgNPs. Therefore rise in temperature may lead to smaller size AgNPs. The rise in temperature also increases the kinetic energy of molecules which increases the consumption of silver ions, thus leaving the less possibility for particle size growth and uniform size AgNps are formed [20].

Effect of pH

The pH value of reaction also plays an important role in the formation of AgNPs [21]. The change in pH may lead to change in charge of natural phytochemicals present in an extract. This charge change influenced the adherence of silver ions to biomolecules and may affects the reduction of silver ions to AgNPs. Due to positive charge on silver ion the negative ionizable groups attached to silver ions. The reports show that the pH is also a determining factor of shape, size, production rate and stability of nanoparticles. Zeta potential data reveals about the surface charge and stability of silver nanoparticles. AgNPs generally show low zeta potential at strongly acidic pH and high zeta potential at alkaline pH [17].

Effect of reaction time

The exposure time of reducing agents to metal ions is also responsible for synthesis of nanoparticles. It has been observed that nanoparticle synthesis is increased when the reaction/incubation time of silver with the reductant is increased [15,22] Khatoon et al. shows that surface plasmon peak of AgNPs has been increased from zero to 30 min after that become constant which indicates that synthesis has been completed [23].

Mechanism of formation of silver nanoparticles

Silver ions are reduced by the various plant metabolites including terpenoids, polyhydroxyphenols, carbohydrates, alkaloids, phenolic compounds, and proteins etc. Fourier transform infrared spectroscopy (FTIR) spectroscopy of biosynthesized AgNPs has been used to demonstrate that biomolecules present in extract are responsible for synthesis of nanoparticles. One of the biomolecule which majorly participate is terpenoids. Terpenoids are also known as isoprene, a naturally occurring organic compounds in plants, they contain five-carbon isoprene units. It has been explored by some researchers that *Geranium* leaf extract contain terpenoids, which act as major player in biosynthesis of AgNPs [24]. *Cinnamomum zeylanicum* (cinnamon) extracts contains eugenol which might be responsible for the reduction silver nitrate to AgNPs [25]. On the basis of FTIR spectroscopy data, it have been proposed that the deprotonation of the hydroxyl ion of eugenol lead to formation of resonance stabilized structures which can further oxidised, by reducting metal ions into its nano range [25]. Another major class of plant metabolite is flavonoids. Falvonoids are group of polyphenolic compounds containing 15 carbon atoms and are water soluble. Flavonoids can be classified into: isoflavonoids, bioflavonoids and neoflavonoids, which can act as chelating and reducing agents for metal ions. The functional group present in flavonoids are solely responsible for nanoparticle formation. The transition of flavonoids from the enol to the keto may lead to reduction of metal ions to form nanoparticles [5]. Ahmad et al. that *Ocimum basilicum* (sweet basil) extract contains of flavonoids, eugenol and polyphenols that play key role in the formation of AgNPs from silver ions by tautomerization of enol to keto form [26]. Several studies have been shows that flavonoids can act as chelating agents for example quercetin is a flavonoid which can chelate at three positions involving the carbonyl and hydroxyls at the C3 and C5 positions and the catechol group at the C3' and C4' site [5]. This helps in understanding that flavonoids are involved in initiation of nanoparticle formation (nucleation) and further aggregation, in addition to the bioreduction stage. For example, *Lawsonia inermis* a good source of apiin (apigenin glycoside) was used for the biosynthesis of quasi-spherical AgNPs having average diameter of 21–30 nm [27]. It has been observed from FTIR spectroscopy that a carbonyl group of apiin has been attached to the nanoparticles, which shows that might be the sugars present in plant extracts are participating in the reduction and stabilization of metal ions into nanoparticles. Glucose a linear monosaccharides having free aldehydic group can directly act as reducing agents whereas fructose which contains keto-group can act as antioxidants if tautomeric transitions occurs from ketone to an aldehyde [5]. It has been reported that when glucose was used as a reducing agent the nanoparticles with different morphologies were observed whereas with fructose only monodispersed nanoparticles were observed. It has been postulated that aldehydic group of carbohydrate get oxidized into a carboxylic group via the nucleophilic addition of OH-, which ultimately lead to reduction of metal ions and synthesis of nanoparticles [5].

There are three main phases which included in the plant mediated synthesis. Initial phase also known as activation phase during which metal ions get reduced and the reduced metal atoms get nucleated; another is the growth phase in which spontaneous aggregation of small adjacent nanoparticles occurs to form particles of a larger diameter, which are thermodynamically more stable; last phase is the termination phase which determines the final shape of the nanoparticles [5,28]. Increase in the growth phase, lead to aggregation of nanoparticles into nanotubes, nanorods and nanotriangles etc. [5]. In the termination phase, nanoparticles undergo conformational change which is thermodynamically stable, which confirms the role of plant extract to stabilize metal nanoparticles.

Applications of Silver Nanoparticles

Some of the biomedical applications of AgNPs are highlighted in Figure 2.

Antibacterial

There is a demand for an alternative antibacterial treatment due to the development of antibiotic resistance among bacteria [29]. The AgNPs exhibit excellent bactericidal action against both Gram-positive and Gram-negative bacteria [30]. The antimicrobial activity of AgNPs is may be due to either (i) formation of pores in the cell wall, which ultimately leads to leakage of cellular content or (ii) the silver ion penetrate through ion channels does not damage the cell membranes; rather denatures the ribosome and inhibits the expression of enzymes and thiol containing proteins essential for the production of ATP and DNA thus resulting in cell death [31,32]. AgNPs plays a vital role in the respiratory chain by affecting the function of membrane-bound enzymes.

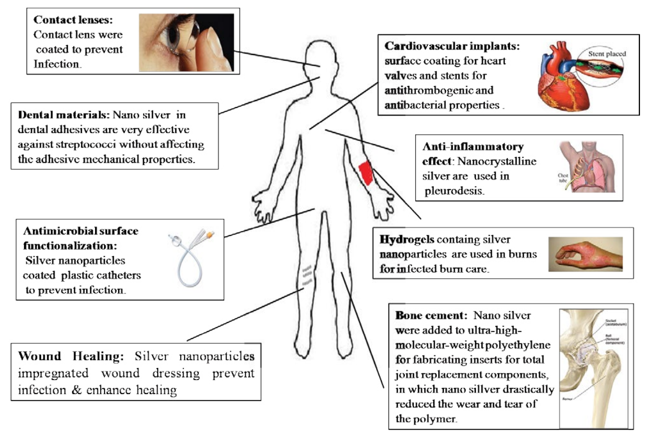

Figure 2: Biomedical applications of silver nanoparticles.

Antifungal

In recent past, extreme fungal infections have contributed in a significant manner to the increasing incidence of a particular disease and mortality of immune-compromised patients [33]. One of the most common pathogens responsible for fungal infections is *Candida* species. It often causes nosocomial infection with an associated mortality rate of up to 40% [34]. Kim et al. demonstrated the antifungal activity of silver nano formulation on a total of 44 antifungal stratins of six fungal species [35]. The literarture revealed that AgNPs are effective against *C. glabrata*, *C. albicans*, *C. krusei*, *C. parapsilosis* and *T. mentagrophytes* effectively. Recently studies showed that the Tulsi (*Ocimum sanctum L.*) mediated AgNPs exhibited antifungal activity against a opportunistic human fungal pathogen [23]. Hence AgNPs is considered as potent and a fast-acting fungicide against broad spectrum of common fungi including *Aspergillus, Candida* and *Saccharomyces*.

Antiviral

The cytoprotective properties of silver is well known and has been employed for the prevention of HIV interaction to the host cells [36]. AgNPs can also be used to prevent infection after surgery and acting as anti-HIV-1 agents [37]. Therefore AgNPs interaction with microorganisms and viruses is another flourishing field of research. The studies reported that AgNPs interact with HIV-1 by binding preferentially to gp120 glycoprotein knobs [38]. This sort of interaction of AgNPs specifically inhibits the binding of virus to host cells [38].

Medical devices

Wound dressing: AgNPs find tremendous use in topical ointments as well as creams used to prevent wounds, burns and infections

[39]. AgNPs are extensively used in medical devices and implants. Additionally they are also added to consumer products such as colloidal silver gel and silver-embedded fabrics which are now used in sporting equipment [40]. Silver coated biomedical devices [41], implants [42], textile fibres [43] are employed for the treatment of wounds or burns and glass windows and other surfaces to maintain sanitization and hygienically conditions. Metallic AgNPs are effective microbicidal so they have received significant consideration in multiple products ranging from paints to textiles.

Catheters: The plastic catheters are coated by bioactive AgNPs. The researchers have developed a coating method which yielded a thin (~100 nm) layer of nanoparticles of silver on the surface of the catheters. The nanoparticles coated catheters are biocompatible as they are non-toxic and have tendency to release specific and sustained release of silver at the implantation site [41]. The infection risk is highly reduced in these catheters due to significant *in vitro* antimicrobial activity by the inhibition of biofilm formation using *Escherichia coli, Enterococcus, Staphylococcus aureus, coagulase-negative staphylococci, Pseudomonas aeruginosa* and *Candida albicans* [44].

Bone cement: AgNPs with additive poly(methyl methacrylate) (PMMA) has been used as a bone cement [45]. Such bone cements are anitibacterial due to presence of AgNPs. Bone cement is the material which are employed by orthopaedician for annexing prostheses like hip and knee replacement surgery. The joint replacement surgery have high infection rates i.e., approximately 1.0–4.0% [46]. Therefore clinicians are switching over another type of bone cements which greatly reduce the rate of infection to 0.4% and 1.8%. The use of antibiotics is limited due to development of bacterial resistance. It has been demonstrated that nano silver -PMMA bone cement decreases the incidence of resistance by the versatile mode of action, and has also known for its antibacterial activity and low cytotoxicity [47]. These bone cements are known to have effective antibacterial agents against methicillin-resistant *S. epidermidis* and *S. aureus* and showed retarded biofilm growth [45]. The biocompatibility of these bone cement were demonstrated against mouse fibroblasts or human osteoblasts having very low cytotoxicity, suggesting good biocompatibility [45].

Tumor

Reactive oxygen species (ROS) can cause damage to cellular components such as proteins lipids and DNA and eventually lead to death of the cell. It has been found that AgNPs can induce cell death and oxidative stress in skin carcinoma cells and in human fibrosarcoma [47]. AgNPs is also known to induce a p53-mediated apoptotic pathway through which majority of the chemotherapeutic drugs triggers apoptosis [47]. Antiproliferative property of piperidine from *Piper nigram* against HEp2 cancer cell line has also been studied [48]. Small dose of AgNPs reduced by extracts of *Piper longum* can effectively show cytotoxic effect on HEp-2 cell line, thus indicating that AgNPs can also be used for anti-cancerous drug preparations [49].

Water purification

The AgNPs can be employed for purification in water filtering apparatus which may be due to its enhanced antimicrobial nature [50]. An overview for treatment of waste water using AgNPs is shown in Figure 3. Silver nanotechnology can be used in water purification systems as world health organization (WHO) approved [51]. Preventing the growth of harmful microorganisms by modifying or coating the surfaces with antimicrobial agents has received much consideration for application in biomedical devices and health as well as in the food and hygiene industries. Antimicrobial coatings should possess antibacterial efficacy, ease of fabrication along with low toxicity. Silver and silver containing surfaces have been widely used as antimicrobial coatings [50,51]. But continuous exposure of these agents might leads to the increased occurrence of resistance to treatment.

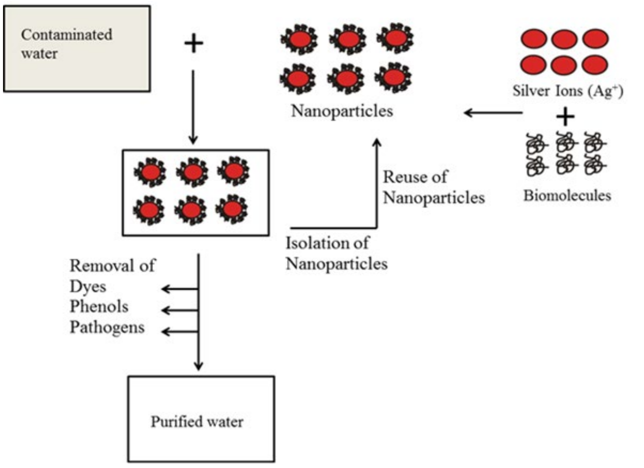

Figure 3: Schematic representation of plant assisted silver nanoparticles in removing water contaminants.

Catalytic activity

The catalytic activity of AgNPs is size dependent. The researchers have investigated the reduction of Methylene Blue (MB) by NaBH4 using catalytic activity of the synthesized AgNPs from the plant *Guggulutiktham Kashayam* [52]. Edison and Sethuraman had studied the enhanced catalytic activity on the reduction of benzyl chloride by *Acacia nilotica* pod mediated AgNPs modified glassy carbon electrode as compared to those of glassy carbon and metallic silver electrode [53]. The photocatalytic degradation of methyl orange by *Ulva lactuca* mediated AgNPs were studied spectrophotometrically under visible light illumination [54]. The degradation of methylene blue by AgNPs using *Gloriosa superba* extract were also reported [55]. Waghmode et. al. synthesized AgNPs using *Triticum aestivum* extract and reported that AgNPs are excellent nano catalyst in reduction of hydrogen peroxide [56]. The plant extract mediated AgNPs are also been employed for degradation of 4-nitrophenol (4-NP) to 4-aminophenol (4-AP) [57].

Antimicrobial nanopaints

The production of nanofibre embedded with AgNPs are gaining interest. These polymeric nanocomposites are highly stable. They can withstand high temperature i.e., up to 200°C by resisting oxidation and aggregation, which enhances their application in production of silver nanoparticle embedded homogeneous paints [58].

Biosensors

The plasmonic properties AgNPs are greatly depend on its size, shape and dielectric medium that surrounds it [59]. Therefore this dependency may lead to applicability of AgNPs in biosensing. As it known that the refractive index of biomolecules is higher than the buffer solutions [60]. The adherence of these biomolecules on the surface of AgNPs increases the refractive index and shifting the silver extinction (absorption and scattering) spectrum. Biosensors containing plasmonic nanomaterials (local surface plasmon resonance-LSPR) are advantageous over commercial thin, plasmonic, continuous films (surface plasmon resonance-SPR) [61]. The LSPR biosensors are less sensitive to bulk refractive index change thereby minimising errors and have better spatial resolution than the SPR ones [62]. The different shaped AgNPs are incorporated in biosensors for sensing the different interactions. Haes and Van fabricated triangular AgNPs by nanosphere lithography and coated on glass substrate. These surface coated nano biosensor was used to detect interactions between biomolecules, such as biotin-streptavidin [60] and two biomolecules related to Alzheimer's disease [63]. The cubical [64] or rhombohedral [65] silver nanoparticles were also used for sensing of protein interactions. Lately, the reports are available for AgNPs based biosensors in cancer detection [66]. The researcher have also demonstrated the use of silica-coated nanosilver as biosensors for the detection of bovine serum albumin (BSA) [67].

Bioimaging

The AgNPs due to its plasmonic properties can be detected by numerous optical microscopy techniques and are advantageous over commonly used fluorescent organic dyes that decompose during imaging (photobleaching). As AgNPs are photostable thus they can used as biological probes to monitor continuously dynamic events for an extended period of time [68]. Lee et al. demonstrated the real time study of AgNPs to monitor early embryonic developement with time. The unique plasmonic properties of such small metallic nanoparticles also encourages its employment in therapeutic tool. There are two ways by which AgNPs are employed in bioimaging: by incubation of AgNPs with cells in order to determine physical interactions and uptake, or to functionalization of biomolecule on the surface of AgNPs thus increasing specificity for cell membrane. The former is easier as the latter needs a specific biofunctionalization molecule [68]. The impact of AgNPs were examined in neuroblastoma cells under dark-field illumination [69]. AgNPs attached on iron oxide nanoparticles were incubated with macrophages for their easy detection by two-photon imaging after their cell uptake [69-99].

Conclusion

The mechanism and synthesis of AgNPs using plants has described in detail, their biotechnological applications and mechanism of cellular uptake needs to be strengthened. The process of synthesis using plant or plant extracts is considered economical, eco-friendly and can be easily scaled up. The bio-molecules present in plants reduce the silver ions into nano size. The varied bio-molecules present within the plants catalyze the reduction of silver into nano and give unique property to them. Because of its ability to kill diverse microorganisms it offers an attractive alternative to conventional antibiotics thus paving the way for the development of new-generation antibiotics. Since the synthesis of AgNPs is economical, it can be used in a wide variety of applications such as industrial appliances like bandage, food and water storage, biomedical fields, pharmaceutical and wastewater treatment in a low price. Analyzing the exact mechanism of synthesis and controlling the shape and size of the silver nanoparticle, will broaden the scope of study.

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References

1. Song JY, Kim BS (2009) Rapid biological synthesis of silver nanoparticles using plant leaf extracts. Bioprocess Biosyst Eng 32: 79-84.
2. Rajasekharreddy P, Rani PU, Sreedhar B (2010) Qualitative assessment of silver and gold nanoparticle synthesis in various plants: A photobiological approach. J Nanopart Res 12: 1711-1721.
3. Kumar V, Yadav SK (2009) Plant-mediated synthesis of silver and gold nanoparticles and their applications. J Chem Technol Biotechnol 84: 151-157.
4. Tripathy A, Raichur AM, Chandrasekaran N, Prathna TC, Mukherjee A (2010) Process variables in biomimetic synthesis of silver nanoparticles by aqueous extract of Azadirachta indica (Neem) leaves. J Nanopart Res 12: 237-246.
5. Makarov VV, Love AJ, Sinitsyna OV, Makarova SS, Yaminsky IV, et al. (2014) "Green" nanotechnologies: Synthesis of metal nanoparticles using plants. Acta naturae 6: 35.
6. Banerjee P, Sau S, Das P, Mukhopadhyay A (2014) Green synthesis of silver-nanocomposite for treatment of textile dye. Nanosci Technol 1: 1-6.
7. Dwivedi AD, Gopal K (2010) Biosynthesis of silver and gold nanoparticles using Chenopodium album leaf extract. Colloids Surf A Physicochem Eng Asp 369: 27-33.
8. Saxena A, Tripathi RM, Singh RP (2010) Biological synthesis of silver nanoparticles by using onion (Allium cepa) extract and their antibacterial activity. Dig J Nanomater Bios 5: 427-432.
9. Dubey M, Bhadauria S, Kushwah BS (2009) Green synthesis of nanosilver particles from extract of Eucalyptus hybrida (safeda) leaf. Dig J Nanomater Bios 4: 537-543.
10. Jha AK, Prasad K (2010) Green synthesis of silver nanoparticles using Cycas leaf. Int J Green Nanotechnol Phys Chem 1: 110-117.
11. Gopinath V, MubarakAli D, Priyadarshini S, Priyadharsshini NM, Thajuddin N, et al. (2012) Biosynthesis of silver nanoparticles from Tribulus terrestris and its antimicrobial activity: A novel biological approach. Colloids Surf B Biointerfaces 96: 69-74.
12. Parashar UK, Kumar V, Bera T, Saxena PS, Nath G, et al. (2011) Study of mechanism of enhanced antibacterial activity by green synthesis of silver nanoparticles. Nanotechnol 22: 1-13.
13. Von White G, Kerscher P, Brown RM, Morella JD, McAllister W, et al. (2012) Green synthesis of robust, biocompatible silver nanoparticles using garlic extract. J Nanomat 2012: 55-67.
14. Khalil MMH, Ismail EH, El-Baghdady KZ, Mohamed D (2014) Green synthesis of silver nanoparticles using olive leaf extract and its antibacterial activity. Arabian J Chem 7: 1131-1139.
15. Krishnaraj C, Jagan EG, Rajasekar S, Selvakumar P, Kalaichelvan PT, et al. (2010) Synthesis of silver nanoparticles using Acalypha indica leaf extracts and its antibacterial activity against water borne pathogens. Colloids Surf B Biointerfaces 76: 50-56.
16. Park Y (2014) New paradigm shift for the green synthesis of antibacterial silver nanoparticles utilizing plant extracts. Toxicol Res 30: 169-178.
17. Dubey SP, Lahtinen M, Sillanpaa M (2010) Tansy fruit mediated greener synthesis of silver and gold nanoparticles. Process Biochem 45: 1075-1071.
18. Christensen L, Vivekanandhan S, Misra M, Mohanty AK (2011) Biosynthesis of silver nanoparticles using Murraya koenigii (curry leaf): an investigation on the effect of broth concentration in reduction mechanism and particle size. Adv Mater Letters 2: 429-434.
19. Ibrahim HMM (2015) Green synthesis and characterization of silver nanoparticles using banana peel extract and their antimicrobial activity against representative microorganisms. J Radiat Res Appl Sci 8: 265-275.
20. Verma A, Mehata MS (2016) Controllable synthesis of silver nanoparticles using Neem leaves and their antimicrobial activity. J Radiat Res Appl Sci 9: 109-115.
21. Gan PP, Li SFY (2012) Potential of plant as a biological factory to synthesize gold and silver nanoparticles and their applications. Rev Environ Sci Biotechnol 11: 169-206.
22. Darroudi M, Ahmad MB, Abdullah AH, Ibrahim NA (2011) Green synthesis and characterization of gelatin-based and sugar-reduced silver nanoparticles. Int J Nanomedicine 6: 569-574.
23. Khatoon N, Mishra A, Alam H, Manzoor N, Sardar M (2015) Biosynthesis, characterization, and antifungal activity of the silver nanoparticles against pathogenic candida species. BioNanoSc 5: 65-74.
24. Shankar SS, Ahmad A, Sastry M (2003) Geranium leaf assisted biosynthesis of silver nanoparticles. Biotechnol Prog 19: 1627-1631.
25. Sathishkumar M, Sneha K, Won SW, Cho CW, Kim S, et al. (2009) Cinnamon zeylanicum bark extract and powder mediated green synthesis of nano-

crystalline silver particles and its bactericidal activity. Colloids Surf B Biointerfaces 73: 332-338.

26. Ahmad N, Sharma S, Alam MK, Singh VN, Shamsi SF, et al. (2010) Rapid synthesis of silver nanoparticles using dried medicinal plant of basil. Colloids Surf B Biointerfaces 81: 81-86.
27. Kasthuri J, Veerapandian S, Rajendiran N (2009) Biological synthesis of silver and gold nanoparticles using apiin as reducing agent. Colloids Surf B Biointerfaces 68: 55-60.
28. Si S, Mandal TK (2007) Tryptophan-based peptides to synthesize gold and silver nanoparticles: a mechanistic and kinetic study. Chem Eur J 13: 3160-3168.
29. Sharma VK, Yngard RA, Lin Y (2009) Silver nanoparticles: green synthesis and their antimicrobial activities. Adv Colloid Interface Sci 145: 83-96.
30. Stoimenov PK, Klinger RL, Marchin GL, Klabunde KJ (2002) Metal oxide nanoparticles as bactericidal agents. Langmuir 18: 6679-6686.
31. Sondi I, Salopek-Sondi B (2004) Silver nanoparticles as antimicrobial agent: a case study on E. coli as a model for Gram-negative bacteria. J Colloid Interface Sci 275: 177-182.
32. Pal S, Tak YK, Song JM (2007) Does the antibacterial activity of silver nanoparticles depend on the shape of the nanoparticle? A study of the gram-negative bacterium Escherichia coli. Appl Environ Microbiol 73: 1712-1720.
33. Martin GS, Mannino DM, Eaton S, Moss M (2003) The epidemiology of sepsis in the United States from 1979 through 2000. N Engl J Med 348: 1546-1554.
34. Panacek A, Kolar M, Vecerova R, Prucek R, Soukupova J, et al. (2009) Antifungal activity of silver nanoparticles against Candida spp. Biomaterials 30: 6333-6340.
35. Kim JS, Kuk E, Yu KN, Kim JH, Park SJ, et al. (2007) Antimicrobial effects of silver nanoparticles. Nanomedicine 3: 95-101.
36. Sun RWY, Chen R, Chung NPY, Ho CM, Lin CLS, et al. (2005) Silver nanoparticles fabricated in Hepes buffer exhibit cytoprotective activities toward HIV-1 infected cells. Chem Comm 2005: 5059-5061.
37. Elechiguerra JL, Burt JL, Morones JR, Camacho-Bragado A, Gao X, et al. (2005) Interaction of silver nanoparticles with HIV-1. J Nanobiotechnol 3: 1-10.
38. Lara HH, Ayala-Nunez NV, Ixtepan-Turrent L, Rodriguez-Padilla C (2010) Mode of antiviral action of silver nanoparticles against HIV-1. J Nanobiotechnol 8: 1-10.
39. Becker RO (1999) Silver ions in the treatment of local infections. Metal-based drugs 6: 311.
40. Silver S (2003) Bacterial silver resistance: molecular biology and uses and misuses of silver compounds. FEMS Microbiol Rev 27: 341-353.
41. Rupp ME, Fitzgerald T, Marion N, Helget V, Puumala S, et al. (2004) Effect of silver-coated urinary catheters: efficacy, cost-effectiveness, and antimicrobial resistance. Am J Infect Control 32: 445-450.
42. Furno F, Morley KS, Wong B, Sharp BL, Arnold PL, et al. (2004) Silver nanoparticles and polymeric medical devices: a new approach to prevention of infection? J Antimicrob Chemo 54: 1019-1024.
43. Duran N, Marcato PD, De Souza GIH, Alves OL, Esposito E (2007) Antibacterial effect of silver nanoparticles produced by fungal process on textile fabrics and their effluent treatment. J Biomed Nanotechnol 3: 203-208.
44. Roe D, Karandikar B, Bonn-Savage N, Gibbins B, Roullet JB (2008) Antimicrobial surface functionalization of plastic catheters by silver nanoparticles. J Antimicrob Chemo 61: 869-876.
45. Alt V, Bechert T, Steinrucke P, Wagener M, Seidel P, et al. (2004) An in vitro assessment of the antibacterial properties and cytotoxicity of nanoparticulate silver bone cement. Biomaterials 25: 4383-4391.
46. Albers CE, Hofstetter W, Siebenrock KA, Landmann R, Klenke FM (2013) In vitro cytotoxicity of silver nanoparticles on osteoblasts and osteoclasts at antibacterial concentrations. Nanotoxicol 7: 30-36.
47. Premkumar T, Lee Y, Geckeler KE (2010) Macrocycles as a tool: A facile and one pot synthesis of silver nanoparticles using cucurbituril designed for cancer therapeutics. Chem-A Eur J 16: 11563-11566.
48. Reshmi SK, Sathya E, Suganya Devi P (2010) Isolation of piperdine from Piper nigrum and its antiproliferative activity. J Pharm Pharm Sci.
49. Jacob SJP, Finub JS, Narayanan A (2012) Synthesis of silver nanoparticles using Piper longum leaf extracts and its cytotoxic activity against Hep-2 cell line. Colloids Surf B Biointerfaces 91: 212-214.
50. Jain P, Pradeep T (2005) Potential of silver nanoparticles coated polyurethane foam as an antibacterial water filter. Biotechnol Bioengg 90: 59-63.
51. Pedahzur R, Lev O, Fattal B, Shuval HI (1995) The interaction of silver ions and hydrogen peroxide in the inactivation of E. coli: a preliminary evaluation of a new long acting residual drinking water disinfectant. Water Sci Technol 31: 123-129.
52. Suvith VS, Philip D (2014) Catalytic degradation of methylene blue using biosynthesized gold and silver nanoparticles. Spectrochim Acta Mol Biomol Spectrosc 118: 526-532.
53. Jebakumar Immanuel Edison TN, Sethuraman MG (2013) Electrocatalytic reduction of benzyl chloride by green synthesized silver nanoparticles using pod extract of Acacia nilotica. ACS Sustainable Chem Eng 1: 1326-1332.
54. Kumar P, Govindaraju M, Senthamilselvi S, Premkumar K (2013) Photocatalytic degradation of methyl orange dye using silver (Ag) nanoparticles synthesized from Ulva lactuca. Colloids Surf B Biointerfaces103: 658-661.
55. Ashokkumar S, Ravi S, Velmurugan S (2013) Green synthesis of silver nanoparticles from Gloriosa superba L. leaf extract and their catalytic activity. Spectrochim Acta A Mol Biomol Spectrosc 115: 388-392.
56. Waghmode S, Chavan P, Kalyankar V, Dagade (2013) Synthesis of silver nanoparticles using Triticum aestivum and its effect on peroxide catalytic activity and toxicology. J Chem 2013: 1-6.
57. Gangula A, Podila R, Karanam L, Janardhana C, Rao AM (2011) Catalytic reduction of 4-nitrophenol using biogenic gold and silver nanoparticles derived from Breynia rhamnoides. Langmuir 27: 15268-15274.
58. Walton M (2010) Antimicrobial nanosilver coating for commercial applications. Adv Coat Surface Technol 23: 5-6.
59. Kreibig U, Vollmer M (2013) Optical properties of metal clusters. Springer Science & Business Media.
60. Haes AJ, Van Duyne RP (2002) A nanoscale optical biosensor: sensitivity and selectivity of an approach based on the localized surface plasmon resonance spectroscopy of triangular silver nanoparticles. J Am Chem Soc 124: 10596-10704.
61. Zhang JZ, Noguez C (2008) Plasmonic optical properties and applications of metal nanostructures. Plasmonics 3: 127-150.
62. Anker JN, Hall WP, Lyandres O, Shah NC, Zhao J, et al. (2008) Biosensing with plasmonic nanosensors. Nat Mater 7: 442-453.
63. Haes AJ, Hall WP, Chang L, Klein WL, Van Duyne RP (2004) A localized surface plasmon resonance biosensor: First steps toward an assay for Alzheimer's disease. Nano Lett 4: 1029-1034.
64. Galush WJ, Shelby SA, Mulvihill MJ, Tao A, Yang P (2009) A nanocube plasmonic sensor for molecular binding on membrane surfaces. Nano Lett 9: 2077-2082.
65. Zhu S, Li F, Du C, Fu Y (2008) A localized surface plasmon resonance nanosensor based on rhombic Ag nanoparticle array. Sens Actuators B Chem 134: 193-198.
66. Zhou W, Ma Y, Yang H, Ding Y, Luo X (2011) A label-free biosensor based on silver nanoparticles array for clinical detection of serum p53 in head and neck squamous cell carcinoma. Int J Nanomed 6: 381-386.
67. Sotiriou GA, Sannomiya T, Teleki A, Krumeich F, Voros J, et al. (2010) Non-toxic dry coated nanosilver for plasmonic biosensors. Adv Funct Mater 20: 4250-4257.
68. Lee KJ, Nallathamby PD, Browning LM, Osgood CJ, Xu XHN (2007) In vivo imaging of transport and biocompatibility of single silver nanoparticles in early development of zebrafish embryos. ACS Nano 1: 133-143.
69. Schrand AM, Braydich-Stolle LK, Schlager JJ, Dai L, Hussain SM (2008) Can silver nanoparticles be useful as potential biological labels? Nanotechnology 19: 235104.
70. Njagi EC, Huang H, Stafford L, Genuino H, Galindo HM, et al. (2010) Biosynthesis of iron and silver nanoparticles at room temperature using aqueous sorghum bran extracts. Langmuir 27: 264-271.
71. Zargar M, Hamid AA, Bakar FA, Shamsudin MN, Shameli K (2011) Green

synthesis and antibacterial effect of silver nanoparticles using Vitex negundo L. Molecules 16: 6667-6676.

72. Vijay Kumar PPN, Pammi SVN, Kollu P, Satyanarayana KVV, Shameem U (214) Green synthesis and characterization of silver nanoparticles using Boerhaavia diffusa plant extract and their anti bacterial activity. Ind Crops Prod 52: 562-566.
73. Lukman AI, Gong B, Marjo CE, Roessner U, Harris AT (2011) Facile synthesis, stabilization, and anti-bacterial performance of discrete Ag nanoparticles using Medicago sativa seed exudates. J Colloid Interface Sc 353: 433-444.
74. Bar H, Bhui DK, Sahoo GP, Sarkar P, De SP, et al. (2009) Green synthesis of silver nanoparticles using latex of Jatropha curcas. Colloids Surf A Physicochem Eng Asp 339: 134-139.
75. Huang J, Li Q, Sun D, Lu Y, Su Y, et al. (2007) Biosynthesis of silver and gold nanoparticles by novel sundried Cinnamomum camphora leaf. Nanotechnology 18: 105104.
76. Li S, Shen Y, Xie A, Yu X, Qiu L, et al. (2007) Green synthesis of silver nanoparticles using Capsicum annuum L. extract. Green Chem 9: 852-858.
77. Chandran SP, Chaudhary M, Pasricha R, Ahmad A, Sastry M (2006) Synthesis of gold nanotriangles and silver nanoparticles using Aloevera plant extract. Biotechnol Progr 22: 577-583.
78. Ankamwar B, Damle C, Ahmad A, Sastry M (2005) Biosynthesis of gold and silver nanoparticles using Emblica officinalis fruit extract, their phase transfer and transmetallation in an organic solution. J Nanosci Nanotechnol 5: 1665-1671.
79. Vidhu VK, Philip D (2014) Spectroscopic, microscopic and catalytic properties of silver nanoparticles synthesized using Saraca indica flower. Spectrochim Acta Mol Biomol Spectrosc 117: 102-108.
80. Jain D, Daima HK, Kachhwaha S, Kothari SL (2009) Synthesis of plant-mediated silver nanoparticles using papaya fruit extract and evaluation of their antimicrobial activities. Dig J Nanomater Bios 4: 557-563.
81. Khatoon N, Ahmad R, Sardar M (2015) Robust and fluorescent silver nanoparticles using Artemisia annua: Biosynthesis, characterization and antibacterial activity. Biochem Eng J 102: 91-97.
82. Pandey S, Mewada A, Thakur M, Shinde S, Shah R (2013) Rapid biosynthesis of silver nanoparticles by exploiting the reducing potential of Trapa bispinosa peel extract. J Nanosci 9: 1-10.
83. Harris AT, Bali R (2008) On the formation and extent of uptake of silver nanoparticles by live plants. J Nanopart Res 10: 691-695.
84. Rout RW, Lakkakula JR, Kolekar NS, Mendhulkar VD, Kashid SB (2009) Phytosynthesis of silver nanoparticle using Gliricidia sepium (Jacq.). Curr Nanosci 5: 117-122.
85. Elumalai EK, Prasad T, Viviyan TS (2010) Extracellular synthesis of silver nanoparticles using leaves of Euphorbia hirta and their antibacterial activities. J Pharm Sci Res 2: 549-554.
86. Singh A, Jain D, Upadhyay MK, Khandelwal N, Verma HN (2010) Green synthesis of silver nanoparticles using Argemone mexicana leaf extract and evaluation of their antimicrobial activities. Dig J Nanomater Bios 5: 483-489.
87. Ankanna S, Prasad T, Elumalai EK, Savithramma N (2010) Production of biogenic silver nanoparticles using Boswellia ovalifoliolata stem bark. Dig J Nanomater Biostruct 5: 369-372.
88. Priya MM, Selvi BK, Paul JAJ (2011) Green synthesis of silver nanoparticles from the leaf extracts of Euphorbia hirta and Nerium indicum. Dig J Nanomater Biosturct 6: 869-877.
89. Krishnaraj C, Jagan EG, Ramachandran R, Abirami SM, Mohan N, et al. (2012) Effect of biologically synthesized silver nanoparticles on Bacopa monnieri (Linn.) Wettst plant growth metabolism. Process Biochem 47: 651-658.
90. Antony JJ, Sivalingam P, Siva D, Kamalakkannan S, Anbarasu K, et al. (2011) Comparative evaluation of antibacterial activity of silver nanoparticles synthesized using Rhizophora apiculata and glucose. Colloids Surf B Biointerfaces 88: 134-140.
91. Prasad KS, Pathak D, Patel A, Dalwadi P, Prasad R, et al. (2011) Biogenic synthesis of silver nanoparticles using Nicotiana tobaccum leaf extract and study of their antibacterial effect. Afr J Biotechnol 10: 8122-8130.
92. Elavazhagan T, Arunachalam KD (2011) Memecylon edule leaf extract mediated green synthesis of silver and gold nanoparticles. Int J Nanomedicine 6: 1265-1278.
93. Kumar V, Yadav SK (2012) Synthesis of different-sized silver nanoparticles by simply varying reaction conditions with leaf extracts of Bauhinia variegata L. IET Nanobiotechnol 6: 1-8.
94. Saxena A, Tripathi RM, Zafar F, Singh P (2012) Green synthesis of silver nanoparticles using aqueous solution of Ficus benghalensis leaf extract and characterization of their antibacterial activity. Mater Lett 67: 91-94.
95. Singh C, Baboota RK, Naik PK, Singh H (2012) Biocompatible synthesis of silver and gold nanoparticles using leaf extract of Dalbergia sissoo. Adv Mater Lett 3: 279-285.
96. Daniel SCGK, Banu BN, Harshiny M, Nehru K, Ganesh PS, et al. (2014) Ipomea carnea-based silver nanoparticle synthesis for antibacterial activity against selected human pathogens. J Exp Nanosci 9: 197-209.
97. Annamalai A, Christina VLP, Christina V, Lakshmi PTV (2014) Green synthesis and characterisation of Ag NPs using aqueous extract of Phyllanthus maderaspatensis L. J Exp Nanosci 9: 113-119.
98. Swamy VS, Prasad R (2012) Green synthesis of silver nanoparticles from the leaf extract of Santalum album and its antimicrobial activity. J Optoelec Biomed Mat 4: 53-59.
99. Kumar V, Yadav SC, Yadav SK (2010) Syzygium cumini leaf and seed extract mediated biosynthesis of silver nanoparticles and their characterization. J Chem Technol Biotechnol 85: 1301-1309.