Green Synthesis of Silver Nanoparticles Involving Extract of Plants of Different Taxonomic Groups

Abstract

Silver nanoparticles are being used in numerous technologies and incorporated into a wide array of consumer products that take advantage of their desirable optical, conductive, and antibacterial properties. Silver nanoparticles have attained a special focus due to its antimicrobial property. Conventionally silver nanoparticles are synthesized by chemical method using chemicals as reducing agents which later on become accountable for various biological risks due to their general toxicity; engendering the serious concern to develop environment friendly processes. Thus, to solve the objective; principles of green chemistry have now become a torch for chemical technologist, biotechnologist and nanotechnologist worldwide in developing less hazardous chemicals. The present review explores the synthesis of silver nanoparticles through a natural and single step protocol preparatory method using the different plant products of different texa belonging to different families with green principles over the conventional ones.

Keywords: Green synthesis; Silver nanoparticles; Plants extract; Precursor

Review Article

Volume 5 Issue 2 - 2017

Deepika Gupta[1] and Pratima Chauhan[1,2]*

[1]Environmental Sciences, Department of Botany, University Of Allahabad, India

[2]Department of Physics, University Of Allahabad, India

***Corresponding author:** Pratima Chauhan, Department of Physics, University Of Allahabad, Allahabad, UP, 211002, India, Email: mangu167@yahoo.co.in

Received: December 31, 2016 | **Published:** March 08, 2017

Introduction

Nanotechnology today is regarded as a revolutionary technology which deals with the matter at nanoscale (1-100 nm). Within this size range all the properties (chemical, physical and biological) changes in fundamental ways of both individual atoms/molecules and their corresponding bulk. Novel applications of nanoparticles and nanomaterials are growing rapidly on various fronts due to their completely new or enhanced properties based on size, their distribution and morphology. Nanotechnology is emerging as the sixth revolutionary technology in the current era. It is now emerging and fast growing field of science which is being exploited over a wide range of disciplines such as physics, chemistry, biology, material science, electronics, medicine, energy, environment and health sectors. The nanoparticles used for all the aforesaid purposes, the metallic nanoparticles considered as the most promising as they contain remarkable antibacterial properties due to their large surface area to volume ratio. Amongst the all noble metal nanoparticles, silver nanoparticles are significant which has gained boundless interests because of their unique properties such as chemical stability, good conductivity, catalytic and most important antimicrobial and anti-inflammatory activities [1,2]. Silver's mode of action is presumed to be dependent on Ag+ ions, which strongly inhibit bacterial growth through suppression of respiratory enzyme and electron transport components and through interference with DNA functions [3].

Because of their wide range of applications Synthesis of silver nanoparticles is of much interest to the researcher. Generally, nanoparticles are prepared by a variety of chemical and physical methods which are quite expensive and potentially hazardous to the environment which involve use of toxic chemicals that are responsible for various biological risks. In the search of cheaper and eco-compatible pathways for nanoparticles, scientist used microorganism [4-11] and plant extracts [12-15]. Green synthesis of nanoparticles has proven to be better methods due to slower kinetics, offer better manipulation, control over crystal growth and their stabilization. Greener synthesis provides advancement over traditionally used nanoparticles synthesis methods i.e. chemical [16,17] and physical method as it is cost effective, easily scaled up, environment friendly [18] or large scale synthesis and in this method there is no need to use toxic chemicals. Green synthesis of nanoparticles is a bottom up approach where the main reaction occurring is reduction. Biogenic synthesis is useful not only because of its reduced environmental impact [19-21] compared with some of the physicochemical production methods, but also because it can be used to produce large quantities of nanoparticles that are free of contamination and have a well-defined size and morphology [22]. Biosynthetic routes can actually provide nanoparticles of a better defined size and morphology than some of the physicochemical methods of production [23]. The methods for obtaining nanoparticles using naturally occurring reagents such as vitamins, sugars, plant extracts, biodegradable polymers, and microorganism as reductants and capping agents could be considered attractive for nanotechnology. But among above mentioned reagents plant extract using leaf, root, stem, latex, resin, seed seems to be the best candidates and they are suitable for large scale "Green synthesis" of nanoparticles. The advancement of green syntheses over chemical and physical methods is: environment friendly, cost effective and easily scaled up for large scale syntheses of nanoparticles, furthermore there is no need to use high temperature, pressure, energy and toxic chemicals [24]. Although, among the various biological methods of silver nanoparticle synthesis, microbe mediated synthesis is not of industrial feasibility due to the requirements of highly aseptic conditions and their maintenance. Therefore; the use of plant extracts for this purpose is potentially advantageous over microorganisms due to the ease of improvement, the less biohazard and elaborate process of maintaining cell cultures [25].

Hence, a review is compiled describing the green syntheses of silver nanoparticles that provide advancement over conventional methods as it is cost effective and lesser or almost zero contaminations for the environment.

Green Synthesis of Silver Nps by Plants

A large number of plants are reported to facilitate silver nanoparticles syntheses are mentioned in Table 1 and are discussed briefly in the presented review.

Preparation of plant broth and biosynthesis of silver nanoparticles

The protocol for the nanoparticle syntheses involves: the collection of the part of plant of interest from the available sites then it's washing thoroughly with tap water to remove contamination followed by surface sterilization with double distilled water and air dried at room temperature. These clean and fresh sources are then powdered using domestic blender or cut it into very small pieces. And for the plant broth preparation, around 10-25g of the dried powder or finally chopped leaves were kept in a beaker and boiled with 100mL of deionised distilled water. The extract was filtered with Whatman filter paper No.1 further the filtrate was used as reducing source for the synthesis of silver nanoparticles.

Synthesis of silver nanoparticles was carried out by adding 10ml of leaf extract to 100ml of 1mM silver nitrate ($AgNO_3$) solution with continuous stirring at room temperature. Reduction of Ag^+ to Ag0 was confirmed by the colour change of solution from colourless to brown. Its formation was further confirmed by using UV-Visible spectroscopy.

Table1: Use of different plant parts extract in the synthesis of silver nanoparticles as a precursor.

S. No.	Latin Name	Family Name	Size and Shape	References
Leaves Extract				
1	*Azadirachta indica*	*Meliaceae*	spherical	[21]
2	*Aloe vera*	*Xanthorrhoeaceae*	12.2nm, spherical	[42]
3	*Argemone maxicana*	*Papaveraceae*	16-40nm, crystalline	[68]
4	*Tea*	*Theaceae*	20 to 90 nm.	[69]
5	*Citrullus colocynthis*	*Cucurbitaceae*	31nm	[49]
6	*Cassia auriculata*	*Caesalpiniaceae*	20-40nm	[70]
7	*Coleus aromaticus*	*Labiatae*	44nm	[51]
8	*Myrica nagi*	*Myricaceae*	50-69nm	[71]
9	*Diopyros kaki*	*Ebenaceae*	15-500nm, cubic	[45]
10	*Euphorbia hirta*	*Euphorbiaceae*	40-50nm, spherical	[72]
11	*Ginko biloba*	*Ginkgoaceae*	15-500nm, cubic	[45]
12	*Helianthus annus*	*Asteraceae*		[44]
13	*Hibiscus rosasinensis*	*Malvaceae*	13nm, spherical	[73]
14	*Magnolia kobus*	*Magnoliaceae*	15-500nm, cubic	[45]
15	*Mangifera indica*	*Anacardiaceae*	20nm, spherical, triangular, hexagonal	[74]
16	*Mentha piperita*	*Lamiaceae*	90nm, spherical	[76]
17	*Memecylon edule*	*Melastomataceae*	50-90nm, square	[77]
18	*Murraya keenigii*	*Rutaceae*	10nm,crystalline, spherical	[75]
19	*Nicotiana tobaccum*	*Solanaceae*	8nm, crystalline	[78]
20	*Ocimum tenuiflorum*	*Lamiaceae*	5-10nm, spherical	[26]
21	*Oryza sativa*	*Poaceae*		[44]

22	*Pelargonium graveolens*	*Geraniaceae*	16-40nm, crystalline	[41]
23	*Piper betle*	*Piperaceae*	3-37nm, spherical	[79]
24	*Platanus orientalis*	*Platanaceae*	15-500nm, cubic	[47]
25	*Pinus desiflora*	*Pinaceae*	15-500nm, cubic	[47]
26	*Rosa rugosa*	*Rosaceae*	30-60nm	[80]
27	*Saccharum officinarum*	*Poaceae*		[44]
28	*Sorghum bicolour*	*Poaceae*		[44]
Seed Extract				
1	*Jatropha curcas*	*Euphorbiaceae*	10-20nm, crystalline	[63]
2	*Medicago sativa*	*Fabaceae*	5-51nm, spherical	[65]
3	*Papaver somniferum*	*Papaveraceae*		[64]
4	*Nyctanthes arbor-tristis*	*Nyctanthes*	50 and 80 nm, spherical	[15]
Fruit Extract				
1	*Emblica officinalis*	*Euphorbiaceae*	10-20 nm	[38]
2	*Carica papaya*	*Caricaceae*	15nm, cubic	[12]
3	*Tanacetum vulgare*	*Asteraceae*	16nm, spherical	[80]
Fruit Peel Extract				
1	*Musa pudica*	*Musaceae*	20nm	[35]
2	*Annona squamosa*	*Annonaceae*	20-60nm, spherical	[36]
3	*Citrus sinensis*	*Rutaceae*	14-20nm, spherical	[81]
4	*Punica granatum*	*Punicaceae*	5+1.5 nm	[37]
Gum and Latex				
1	*Jatropha curcas*	*Euphorbiaceae*		[79]
2	*Euphorbia*	*Euphorbiaceae*	18nm	[26]
3	*Acacia*	*Mimosoideae*		[28]
4	*Boswellia serrata*	*Burseraceae*		[27]
5	*Peach gum*	*Rosaceae*	23.56±7.87 nm	[80]
Bark/ Stem Powder				
1	*Cinnamon zeylanicum*	*Lauraceae*	31-40nm, spherical	[60]
2	*Shorea tumbuggaia*	*Dipterocarpaceae*	Spherical	[61]
3	*Boswellia ovalifoliolata*	*Burseraceae*	Spherical	[61]
Tuber, Root, Rhizome				
1	*Curcuma longa*	*Zingiberaceae*	21-30nm, quasi-spherical, triangular	[58]
2	*Dioscorea bulbifera*	*Dioscoreaceae*	8-20 nm, spherical, triangular	[56]
3	*Ocimum sanctum*	*Lamiaceae*	5-10nm, spherical	[82]
4	*Zingiber offcinale*	*Zingiberaceae*	6-20nm, spherical	[82]

Coir Extract				
1	*Cocos nucifera*	*Arecaceae*	23+2nm	[55]
Flower Extract				
1	*Pandanus odorifer Forssk* (spath of male inflorescence)	*Pandanaceae*	24-55 nm, quasispherical	[66]
2	*Hibiscus sabdariffa* (flower)	*Malvaceae*		[67]

Plant latex and gum as medium

Synthesized the silver nanoparticles in one-step solvent free condition using *Euphorbiaceae* plant latex [26]. Around eight plant species were utilized for the synthesis of nanoparticles, out of which *Jatropha gossypifolia, Jatropha curcas,* and *Euphorbia milii* showed an average of 62 + 105 nm. The stem latex of *Boswellia serrrata* was successfully used to induce synthesis of silver nanoparticles [27]. It has been demonstrated that the plant based exudates gum such as *gum Acacia* can be utilized as a reducing and stabilizing agent for the silver nanoparticle biosynthesis [28]. *Gum kondagogu* biopolymer derived as exudates from the bark of *Cochlospermum gossypium* used as a template for the synthesis and stabilization of silver nanoparticles. The synthesis was carried out in aqueous medium without the requirement of any added chemical reducing agent by autoclaving. *Gum olibanum* is a naturally occurring gum-oleo-resin derived as exudates from the bark of *Boswellia serrata*, a native tree of India. Besides its use as incense, fumigant and multipurpose aromatic; it is also exploited in silver nanoparticle synthesis as reducing and capping agent. Typically the gum consists of volatile oil, water soluble gum (polysaccharides), lipophilic terpenes and insoluble matter. The polysaccharide is abundant in neutral sugars and composed of galactose, arabinose, xylose and d-glucuronic acid [29,30]. From the Raman spectrum of the nanoparticle solution it is confirmed that both amino and carboxylate groups of the gum are involved in the capping of the nanoparticles [27].

Fruit peel extracts as medium

Literature survey has shown that naturally available agricultural wastes have not been investigated for the synthesis of silver nanoparticles. A classical example of such an abundantly available natural material is the banana peel. Bananas are consumed all over the world. After consumption of the pulp, the peels are generally discarded. Beside a few applications of banana peels i.e. exploitation of their medicinal properties [31], in ethanol fermentation [32], as a substrate for generating fungal biomass [33], utilization as a biosorbent for heavy metal removal [34,35], utilizes banana peel for the synthesis of silver nanoparticles [36], employing peel extract of *Annona squamosa* for the synthesis of silver nanoparticles. Controlled growth of silver nanoparticles was formed in 4hr at room temperature (25^{0}C) and 60^{0}C. silver nanoparticles were irregular spherical in shape and the average particle size was about 35 ± 5 nm. The water soluble ketone and hydroxyl as functional group containing compounds are reported to be responsible for the reduction of silver ions [36]. The Pomegranate fruit extract is a rich source of highly potent antioxidants due to rich in phenolic compounds (mainly Ellagic acid) employed for the synthesis of silver nanoparticles. Ellagic acid an active constituent present in fruit peel has an easy electron loosing capacity which results in the formation of H+ radical, which reduces the size of silver to nano size. The morphological and crystalline phase study of the NPs showed that the average size of silver nanoparticles obtained from was 5 ± 1.5 nm [37].

Fruit extract as medium

On treating aqueous silver sulfate and chloroauric acid solutions with *Emblica Officinalis* fruit extract, rapid reduction of the silver and chloroaurate ions is observed leading to the formation of highly stable silver and gold nanoparticles in solution. Transmission Electron Microscopy analysis of the silver and gold nanoparticles indicated that they ranged in size from 10 to 20 nm and 15 to 25 nm respectively [38]. The fruit extract of papaya works as reducing as well as capping agent. Nanoparticles on characterization analysis showed the average particle size of 15 nm as well as revealed their cubic structure. C-O group of polyols such as hydroxyl flavones and catechins present in green unripe Papaya *(Carica papaya)* fruit are mainly responsible for the reduction of Ag ions, whereby they themselves get oxidized to unsaturated carbonyl groups [12].

Leaf extract as medium

The synthesis of quasi-spherical silver nanoparticles and triangular or spherical gold nanoparticles using sun dried *Cinnamomum camphora* leaf without addition of any protectors or accelerators [39]. They demonstrated that the polyol components and water soluble hydrocyclic compounds present in leaf were mainly responsible for reduction of silver ions or chloroaurate ions. [40] Reported the possibility of terpenoids from geranium leaf in the synthesis of nano-sized silver particles. [41] Reported the synthesis of highly stable and crystalline silver nanoparticles (16-40 nm) by exposing the aqueous geranium leaf extract to silver nitrate solution. Highly concentrated silver nanoparticles obtained from the aqueous leaf extract of *Azadirachta indica* [21]. Leela A & Song JY [42,43] reported the synthesis of silver nanoparticles from the leaf extracts of *Aloe vera* and Capsicum annum plants, respectively. Among the leaf extracts of plants, namely, *Helianthus annus*, *Basella alba*, *Oryza sativa*, *Saccharum officinarum*, *Sorghum bicolar*, *and Zea mays*, it is concluded that among all the tested plant extracts, *H. annus* exhibited the strongest potential for rapid reduction of silver ions [44]. Leaf extract of Pine, Persimmon, Ginkgo, Magnolia, and Platanus plants is used for the extracellular synthesis of silver nanoparticles [45]. Methanolic extract of *Eucalyptus* hybrid leaves is exploited in the extracellular biosynthesis of silver nanoparticles [46]. Similarly, Satyavani K [47] reported rapid synthesis (reaction time <30 min) of silver nanoparticles using *Acalypha indica* leaf extract and their antibacterial activity against water borne pathogens. Patil RS [48] Highlighted the possibility of tissue culture-derived callus extract from *Sesuvium portulacastrum* for the synthesis of antimicrobial silver nanoparticles. Similarly, [49] reported the synthesis of silver nanoparticles using the stem-derived callus extract of the bitter apple plant and illustrated their tremendous antibacterial activity. Very recently, bio-inspired synthesis of highly stabilized silver nanoparticles using *Ocimum tenuiflorum* as well as *Coleus aromaticus* have been reported by [31,50,51] respectively. Kulkarni AP [52] Synthesized silver nanoparticles with an average size of 35 nm using aqueous leaf extract of *Catharanthus roseus* and proven their activity against malaria parasite. SM Roopana [53] reported the synthesis of silver nanoparticles using *Piper longum* leaf extracts. The particles had a uniform spherical shape and ranged in size from about 18 to 41 nm. These nanoparticles were found to have a significant cytotoxic effect on HEp-2 cancer cells. In addition to the vast number of reports on angiospermic plants bryophytes are also utilized to synthesise silver nanoparticles. Recently Sougata Ghosh [54] reported synthesis of silver nanoparticles using the alcoholic extract of a *Riccia a bryophyte*.

Coconut coir as medium

Gole A [55] reported that the reduction of silver ions occurred when silver nitrate solution was treated with aqueous extract of *Cocus nucifera* coir at 60^{0}C, particle synthesised with range of the size as 23± 2 nm and face centred cubic silver nanoparticles obtained.

Tuber, rhizome and root extract as medium

Dioscorea bulbifera tuber extract is rich in flavonoid, phenolics, reducing sugars, starch, diosgenin, ascorbic acid, and citric acid [56]. Energy dispersive x-ray spectroscopy results confirmed the presence of significant amounts of silver with no contaminants and HRTEM images clearly show that the shape of silver nanoparticles were mostly spherical with dimensions of 75 nm. In *Curcuma longa* terpenoids are believed to play an important role in silver nanoparticle biosynthesis through the reduction of silver ions [40,57,58]. Ag-NPs with an average size of 6.30 ± 2.64 nm and spherical shapes were synthesized using aqueous tuber-powder extract of *C. Longa* [59].

Bark extract as medium

The compatibility of the bark and powder extracts of *Cinnamon zeylanicum* toward the formation of silver nanoparticles results that bark extract could produce a higher amount of silver nanoparticles compared to the powder extract. The resulting nanoparticles varied in shape and size but had strong antibacterial activity against the *Escherichia coli.* [60]. Savithramma N [59] Used bark extracts of *Boswellia ovalifoliolata* and *Shorea tumbuggaia* to synthesise silver nanoparticle.

Seed extract as medium

Joyita banerjee [60] reported the formation of crystalline silver nanoparticles using seed extract of *Syzygium cumuni*. Harekrishna Bar [61] reported that aqueous seed extract of *Jatropha curcas* can be used for both reducing silver ion to silver and stabilizing the particles during the growth process. They shows that size of the particles can be controlled within certain range from 15-50nm by varying the concentration of $AgNO_3$. Vijayaraghavan K [62] reported synthesis of silver nanoparticles by using seed extract of *Trachyspermum ammi* (ajwain) and *Papaver somniferum*. The extracts of both *T. ammi* and *P. somniferum* showed a maximum absorbance at 430 nm, as the reductant concentration increased the colour intensity also increased [60]. Audra I Lukman [63] reported that colloidal silver (Ag) nanoparticles were synthesized by reacting aqueous $AgNO_3$ with *Medicago sativa* seed exudates under non-photomediated conditions. Upon contact, rapid reduction of Ag^+ ions was observed in <1 min with Ag nanoparticle formation reaching 90% completion in <50 min. Effect of Ag ion concentration, quantity of exudates and pH on the particle size and shape were investigated. At $[Ag^+]$ = 0.01 M and 30°C, largely spherical nanoparticles with diameters in the range of 5-51 nm were generated, while flower-like particle clusters (mean size = 104 nm) were observed on treatment at higher Ag concentrations.

Flower extract as medium

The synthesis of silver nanoparticles using a broth prepared from the aromatic spath of male inflorescence of screw pine *Pandanus odorifer* (Forssk) [64]. Flower extract of *Hibiscus sabdariffa* extracellular synthesized silver nanoparticle of 25 nm [65].

Conclusion

As metal nanoparticles seems to fascinate for the future diverse industry due to their enriched chemical, electrical and physical properties. The development of immaculate protocols for the synthesis of highly monodisperse nanoparticles of various sizes, geometries and chemical composition is one of the most challenging obstructions in the field of nanotechnology. The use of toxic chemicals and non-polar solvents in synthesis leads to the inability to use nanoparticles in clinical fields. Therefore, development of clean, non-toxic, biocompatible and eco-friendly method for synthesis of nanoparticles deserves recognition. So there is need of eco friendly nanoparticles synthesis approach.

Massive numbers of plant species are available in nature, and many of them have huge potential for the production of nanomaterials. For the syntheses of nanoparticles employing plants 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. And the advantages of using plants for the synthesis of nanoparticles are that the plants are easily available and safe to handle and possess a large variety of active agents that can promote the reduction of silver ions. Most of the plant parts like leaves, roots, latex, bark, stem, and seeds are being used for nanoparticle synthesis. Green synthesis silver nanoparticles using plant extracts provides benefits over chemical and physical method as it is economical, energy efficient, cost effective; provide healthier work places and communities, protecting human health and environment leading to lesser waste and safer products. This eco-friendly method can potentially be used in various areas, including pharmaceuticals, cosmetics, foods, and medical applications. Hence in this regard; use of plant extract for synthesis can form an immense impact in coming decades.

Acknowledgment

Support from the University of Allahabad, University Grant Commission (UGC) is gratefully acknowledged.

References

1. Ahmad A, Mukherjee P, Senapati S, Mandal D, Khan MI, et al. (2003) Extracellular biosynthesis of silver nanoparticles using the fungus *Fusarium oxysporum*. Colloids Surf B Biointerfaces 28(4): 313-318.
2. Klaus Joerger T, Joerger R, Olsson E, Granqvist C (2001) Bacteria as workers in the living factory: metal accumulating bacteria and their potential for materials science. Trends Biotech 19(1): 15-20.
3. Li Y, Leung P, Yao L, Song Q W, Newton E (2006) Antimicrobial effect of surgical masks coated with nanoparticles. J Hosp Infect 62(1): 58-63.
4. Dhillon GS, Brar SK, Kaur S, Verma M (2012) Green approach for nanoparticle biosynthesis by fungi: current trends and applications. Crit Rev Biotechnol 32(1): 49-73.
5. Gericke M, Pinches A (2006) Biological synthesis of metal nanoparticles. Hydrometallurgy 83(1-4): 132-140.
6. Kaler A, Nankar R, Bhattacharyya MS, Banerjee UC (2011) Extracellular biosynthesis of silver nanoparticles using aqueous extract of Candida viswanathii. J Bionanosci 5: 53-58.
7. Korbekandi H, Iravani S, Abbasi S (2009) Production of nanoparticles using organisms. Crit Rev Biotechnol 29(4): 279-306.
8. Luangpipat T, Beattie IR, Chisti Y, Haverkamp RG (2012) Gold nanoparticles produced in a microalga. J Nanopart Res 13: 6439-6445.
9. Mohanpuria P, Rana NK, Yadav SK (2008) Biosynthesis of nanoparticles: technological concepts and future applications. J Nanopart Res 10(3): 507-517.
10. Sanghi R, Verma P (2010) Microbes as green and eco-friendly nanofactories. Green Chem Environ Sustainable 15: 315-339.
11. Sastry M, Ahmad A, Islam Khan M, Kumar R (2003) Biosynthesis of metal nanoparticles using fungi and actinomycete. Curr Sci 85: 162-170.
12. Jain D, Daima H Kumar, Kachhwaha S, Kothari SL (2009) Synthesis of plant-mediated silver nanoparticles using papaya fruit extract and evaluate one of their anti microbial activities. Digest Journal of Nanomaterials and Biostructures 4(4): 723-727.
13. Logeswari P, Silambarasan S Abraham J (2013) Ecofriendly synthesis of silver nanoparticles from commercially available plant powders and their antibacterial properties. Scientia Iranica F 20(3): 1049-1054.
14. Priya B, Mantosh S, Anirudha M, Papita D (2014) Leaf extract mediated green synthesis of silver nanoparticles from widely available Indian plants: synthesis, characterization, antimicrobial property and toxicity analysis. Bioresour Bioprocess 1:3
15. Shibani Basu, Priyankar Maji, Jhuma Ganguly (2015) Rapid green synthesis of silver nanoparticles by aqueous extract of seeds of *Nyctanthes arbor-tristis*. Appl Nanosci 6(1): 1-5.
16. Bhattacharya D, Gupta RK (2005) Nanotechnology and potential of microorganisms. Crit Rev biotechnol 25(4): 199-204.
17. Iravani S (2011) Green synthesis of metal nanoparticles using plants. Green Chem 13: 2638-2650.
18. Anastas PT, Zimmerman JB (2007) Green nanotechnology. Why we need a green nano award and how to make it happen. Washington DC: Woodrow Wilson International Center for Scholars, The pew charitable trusts, USA.
19. Dahl JA, Maddux BLS, Hutchison JE (2007) Toward greener nanosynthesis. Chem Rev 107: 2228-2269.
20. Shankar SS, Rai A, Ahmad A, Sastry M (2004) Rapid synthesis of Au, Ag, and bimetallic Au core–Ag shell nanoparticles using Neem (*Azadirachta indica*) leaf broth. J Colloid Interface Sci 275(2): 496-502.
21. Hutchison JE (2008) Greener nanoscience: a proactive approach to advancing applications and reducing implications of nanotechnology. ACS Nano 2(3): 395-402.
22. Raveendran P, Fu J, Wallen SL (2003) Completely “green” synthesis and stabilization of metal nanoparticles. J Am Chem Soc 125(46): 13940-13941.
23. Dhuper S, Panda D, Nayak PL (2012) Green Synthesis and Characterization of Zero Valent Iron Nanoparticles from the Leaf Extract of *Mangifera indica*, Nano Trends. J Nanotech App 13(2): 16-22.
24. Kalishwaralal K, Deepak V, Pandian RK, Kottaisamy Barathmani SM, Kartikeyan KS, et al. (2010) Biosynthesis of silver and gold nanoparticles using *Brevibacterium casei*. Colloids Surf B: Biointerfaces 77(2): 257-262.
25. Patil SV, Borase HP, Patil CD, Salunke BK (2012) Biosynthesis of silver nanoparticles using latex from few euphorbian plants and their antimicrobial potential. Appl Biochem Biotechnol 167(4): 776-790.
26. Mohan YM, Raju KM, Sambasivudu K, Singh S, Sreedhar B (2007) Preparation of Acacia-stabilized silver nanoparticles: A green approach. Journal of Applied Polymer Science 106(5): 3375-3381.
27. Kora AJ, Sashidhar RB, Arunachalam J (2012) Aqueous extract of gum olibanum (*Boswellia serrata*): A reductant And stabilizer for the biosynthesis of antibacterial silver Nanoparticle. Process Biochemistry 47: 1516-1520.
28. Shukla PK, Bhatnagar P, Yadav R (2005) *Boswellia serrata*: a gum-oleoresin yielding tree. Vaniki Sandesh 29: 23-26.
29. Sen AK, Das AK, Banerji N, Vignon MR (1992) Isolation and structure of a 4- O-methyl-glucuronoarabino-galactan from *Boswellia serrata* Carbohydrtes 223: 321-327.
30. HS Parmar, A Kar (2008) Medicinal values of fruit peels from *Citrus sinensis*, *Punica granatum*, and Musa paradisiacal with respect to alterations in tissue lipid per oxidation and serum concentration of glucose, insulin, and thyroid hormones. J Med Food 11(2): 376-381.

31. HK Tewari, SS Marwaha, K Rupal (1986) Ethanol from banana peels. Agric Wastes 16(2): 135-146.

32. JP Essien, EJ Akpan, EP Essien (2005) Studies on mould growth and biomass production using waste banana peel. Bioresour Technol 96(13): 1451-1456.

33. G Annadurai, RS Juang, DJ Lee (2003) Adsorption of heavy metals from water using banana and orange peels. Water Sci Technol 47(1): 185-190.

34. Bankar A, Joshi B, Kumar A, Zinjarde S (2010) Banana peel extract mediated novel route for the synthesis of silver nanoparticles. Colloids and Surfaces A: Physicochem Eng Aspects 368: 58-63.

35. Kumar R, Roopan SM, Prabhakarn A, Khanna VG, Chakroborty S (2012) Agricultural waste Annona squamosa peel extract: Biosynthesis of silver nanoparticles. Spectrochimica Acta Part A 90: 173-176.

36. Naheed Ahmad, Seema Sharma, Radheshyam Rai (2012) Rapid green synthesis of silver and gold nanoparticles using peels of *Punica granatum*. VBRI Press 3(5): 376-380.

37. Ankamwar, Balaprasad, Damle, Chinmay, Ahmad, et al. (2005) Biosynthesis of Gold and Silver Nanoparticles Using Emblica Officinalis Fruit Extract, Their Phase Transfer and Transmetallation in an Organic Solution. Journal of Nanoscience and Nanotechnology 5(10):1665-1671.

38. Huang J, Q Li, D Sun, Y Lu, Y Su, et al. (2007) Biosynthesis of silver and gold nanoparticles by novel sundried *Cinnanonum camphora* leaf. Nanotechnology 18(10): 104-105.

39. Shankar SS, Ahmad A, Sastry M (2003) Geranium leaf assisted biosynthesis of silver nanoparticles. Biotechnol Prog 19(6): 1627-1631.

40. Chandran SP, Minakshi Chaudhary, Renu Pasricha, Absar Ahmad, Murali Sastry (2006) Synthesis of gold nanotriangles and silver nanoparticles using *Aloe vera* plant extract. Biotechnology Progress 22(2): 577-583.

41. Shikuo Li, Yuhua Shen, Anjian Xie, Xuerong Yu, Lingguang Qiu, Li Zhang, et al. (2007) Green synthesis of silver nanoparticles using *Capsicum annuum L.* Extract. Green Chem 9: 852-858.

42. Leela A, Vivekanandan M (2008) Tapping the unexploited plant resources for the synthesis of silver nanoparticles Afr J Biotechnol 7(17): 3162-3165.

43. Song JY, Kim BS (2009) Rapid biological synthesis of silver nanoparticles using plant leaf extracts. Bioprocess Biosyst Eng 32(1): 79-84.

44. Dubey M, Bhadauria S, Kushwah BS (2009) Green synthesis of nanosilver particles from extract of *Eucalyptus hybrida* (Safeda) leaf Dig. J Nanomater Biostruct 4(3): 537-543.

45. Krishnaraj C, Jagan EG, Rajasekar S, Selvakumar P, Kalaichelvan PT (2010) Synthesis of silver nanoparticles using *Acalypha indica* leaf extracts and its antibacterial activity against water borne pathogens. Colloids Surf B 76(1): 50-56.

46. Nabikhan A, Kandasamy K, Raj A Alikunhi NM (2010) Synthesis of antimicrobial silver nanoparticles by callus and leaf extracts from salt marsh plant, *Sesuvium portulacastrum L.* Colloids Surf B 79(2): 489-493.

47. Satyavani K, Ramanathan T, Gurudeeban S (2011) Green synthesis of silver nanoparticles using stem dried callus extract of bitter apple (*Citrullus colocynthis*) Dig. J Nanomater Biostruct 6(3): 1019-1024.

48. Patil RS, Kokate MR, Kolekar SS (2012) Bioinspired synthesis of highly stabilized silver nanoparticles using *Ocimum tenuiflorum* leaf extract and their antibacterial activity Spectrochem Acta A 91: 234-238.

49. Vanaja M, Annadurai G (2012) Coleus aromaticus leaf extract mediated synthesis of silver nanoparticles and its bactericidal activity. Appl Nanosci 3(3): 217-223.

50. Ponarulselvam S, Panneerselvam C, Murugan K, Aarthi N, Kalimuthu K, et al. (2012) Synthesis of silver nanoparticles using leaves of *Catharanthus roseus* Linn. G. Don and their antiplasmodial activities Asian Pac. J Trop Biomed 2(7): 574-580.

51. Jacob S, Finub J, Narayanan A (2011) 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.

52. Kulkarni AP, Srivastava AA, Nagalgaon RK, Zunjarrao RS (2012) Phytofabrication of silver nanoparticles from a novel plant source and its application. Int J Biol Pharm Res 3(3): 417-421.

53. SM Roopana, Rohit G Madhumithaa, A Abdul Rahuman, C Kamaraj, A Bharathi, et al. (2013) Low-cost and eco-friendly phyto-synthesis of silver nanoparticles using *Cocos nucifera* coir extract and its larvicidal activity. Industrial Crops and Products 2(3): 631-635.

54. Sougata Ghosh, Sumersing Patil, Mehul Ahire, Rohini Kitture, Sangeeta Kale, et al. (2012) Synthesis of silver nanoparticles using *Dioscorea bulbifera* tuber extract and evaluation of its synergistic potential in combination with antimicrobial agents. Int J Nanomedicine 7: 483-496.

55. Gole A, CV Dash, V Ramachandran, AB Mandale, SR Sainkar, et al. (2001) Pepsin-gold colloid conjugates: preparation, characterization and enzyme activity. Langmuir 17(5): 1674-1679.

56. Muthuswamy Sathishkumar, Krishnamurthy Sneha, Yeoung-Sang Yun (2010) Immobilization of silver nanoparticles synthesized using *Curcuma longa* tuber powder and extract on cotton cloth for bactericidal activity. Bioresour Technol 101(20): 7958-7965.

57. Kamyar Shameli, Mansor Bin Ahmad, Ali Zamanian, Parvanh Sangpour, Parvaneh Shabanzadeh, et al. (2012) Green biosynthesis of silver nanoparticles using *Curcuma longa* tuber powder. Int J Nanomedicine 7: 5603-5610.

58. M Sathishkumar, K Sneha, SW Won, CW Cho, S Kim, 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(2): 332-338.

59. Savithramma N, Rao ML, Devi PS (2011) Evaluation of antibacterial efficacy of biologically synthesized silver nanoparticles using stem bark of *Boswellia ovalifoliolata Bal.* and Henry and *Shorea tumbuggaia Roxb*. J Biol Sci 11(1): 39-45.

60. Joyita banerjee, narendhirakannan RT (2011) Biosynthesis of silver nanoparticles from *Syzygium cumini* (l.) Seed extract and evaluation of their in vitro antioxidant activities. Digest Journal of nanomaterials and Biostructures 6(3): 961-968.

61. Harekrishna Bar, Dipak Kr Bhui, Gobinda P Sahoo, Priyanka Sarkar, Santanu Pyne, et al. (2009) Green synthesis of silver nanoparticles using seed extract of *Jatropha curcas*. Colloids and surfaces A: physicochem Eng Aspects 348: 212-216.

62. Vijayaraghavan K, Nalini SP, Prakash NU, Madhankumar D (2012) One step green synthesis of silver nano/microparticles using extracts of *Trachyspermum ammi* and *Papaver sominiferum*. Colloids Surf B Biointerfaces 94: 114-117.

63. Audra I Lukman, Bin Gong Christopher E Mario, Ute Roessner, Andrew T Harris (2011) Facile synthesis, stabilization, and anti-bacterial performance of discrete Ag nanoparticles using *Medicago sativa* seed exudates. J Colloid Interface Sci 353(2): 433-444.

64. Panda KK, Achary VMM, Krishnaveni R, Padhi BK, Sarangi SN, et al. (2011) In vitro biosynthesis and genotoxicity bioassay of silver nanoparticles using plants. Toxicol *In Vitro* 25(5): 1097-1105.

65. Singh A, Jain D, Upadhyay M K, Khandelwal N, Verma HN (2010) Green synthesis of silver nanoparticles using *Argemone maxicana* leaf extract and evaluation of their antimicrobial activities. Digest Journal of Nanomaterials and Biostructures 5(2): 483-489.

66. Qian Sun, Xiang Cai, Jiangwei Li, Min Zheng, Zuliang Chen, et al. (2014) Green synthesis of silver nanoparticles using tea leaf extract and evaluation of their stability and antibacterial activity. Colloids and Surfaces A Physicochem Eng Aspects 444: 226-231.

67. Udayasoorian C, Kumar KV, Jayabalakrishnan RM (2011) Extracellular synthesis of silver nanoparticles using leaf extracts of *Cassia auriculata* J Nanomater Biostruct 6(1): 279-283.

68. Preeti Panthari, Pranauv Balaji, Monika Joshi, Harsha Kharkwal (2014) Synthesis, Characterization and Evaluation of Antibacterial Efficacy, Antioxidant Potential of Silver nanoparticle using *Myrica nagi* leaf extract. International Journal of Phytomedicine 6(4).

69. Elumalai EK, Prasad TNVKV, Hemachandran J, Therasa SV, Thirumalai T, et al. (2010) Extracellular synthesis of silver nanoparticles using leaves of *Euphorbia hirta* and their antibacterial activities. J Pharma Sci Res 2(9): 549-554.

70. Philip D (2010) Green synthesis of gold and silver nanoparticles using *Hibiscus rosa-sinensis*. Physica E 42(5): 1417-1424.

71. Phillip D (2011) *Mangifera indica* leaf-assisted biosynthesis of well-dispersed silver nanoparticles. Spectrochim Acta Part A 78(1): 327-331.

72. Philip D, Unni C, Aromal SA, Vidhu VK (2011) *Murraya koenigii* leaf-assisted rapid green synthesis of silver and gold nanoparticles. Spectrochim Acta Part A 78(2): 899-904.

73. Ali DM, Thajuddin N, Jeganathan K, Gunasekhran M (2011) Plant extract mediated synthesis of silver and gold nanoparticles and its antimicrobial activity against clinically isolated pathogens. Colloids Surf B 85(2): 360-365.

74. Elavazhagan T, Arunachalam KD (2011) *Memecylon edule* leaf extract mediated green synthesis of silver and gold nanoparticles. Int J Nanomed 6: 1265-1278.

75. 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(41): 8122-8130.

76. Mallikarjuna K, Dillip GR, Narasimha G, Sushma NJ, Raju BDP (2012) Phytofabrication and characterization of silver nanoparticles from Piper betle broth. Res J Nanosci Nanotechnol 2(1): 17-23.

77. Dubey SP, Lahtinen M, Sillanpaa M (2010) Tansy fruit mediated greener synthesis of silver and gold nanoparticles Process Biochem 45(7): 1065-1071.

78. Kaviya S, Santhanalakshmi J, Viswanathan B, Muthumary J, Srinivasan K (2011) Biosynthesis of silver nanoparticles using *Citrus sinensis* peel extract and its antibacterial activity. Spectrochimica Acta A Mol Biomol Spectrosc 79(3): 594-598.

79. Joglekar S, Kodam K, Dhaygude M, Hudlikar M (2011) Novel route for rapid biosynthesis of lead nanoparticles using aqueous extract of *Jatropha curcas L. latex.* Mater Lett 65: 3170-172.

80. Ning Yang, Xiao-Feng Wei, Wei-Hong Li. Sunlight irradiation induced green synthesis of silver nanoparticles using peach gum polysaccharide and colorimetric sensing of H_2O_2. Materials Letters, Elsevier, Europe.

81. Ahmad N, Sharma S Alam, MK Singh, VN Shamsi, SF Mehta, et al. (2010) Rapid synthesis of silver nanoparticles using dried medicinal plant of basil. Colloids Surf B 81(1): 81-86.

82. Udayasoorian C, Kumar KV, Jayabalakrishnan RM (2011) Extracellular synthesis of silver nanoparticles using leaf extracts of *Cassia auriculata*. J Nanomater Biostruct 6: 279-283.