Review Article

Biological Routes for the Synthesis of Silver Nanoparticles

Arthi C*, Hikku G S**

*UG Student, **Assistant Professor, Medical Bionanotechnology, Faculty of Allied Health Sciences, Chettinad Academy of Research and Education, Kelambakkam – 603103, Tamilnadu, India.

Ms. Arthi C is a B.Sc. III-year student, Department of Medical Bionanotechnology, Faculty of Allied Health Sciences, Chettinad Academy of Research and Education, Kelambakkam - 603103, Tamilnadu. Her area of interest is Nano-medicine and Targeted Drug delivery.

Corresponding author - Hikku G S (gshikku@gmail.com)

Chettinad Health City Medical Journal 2021; 10(1): 42 - 48

DOI: https://doi.org/10.36503/chcmj10(1)-07

Abstract

Silver nanoparticles (AgNPs) play a vital role in nano-science and technologyfield owing to their unique physical and chemical properties such as optical, electrical, thermal, high electrical conductivity, and biological properties. The AgNps are usually synthesized through chemical and biological processes. The major drawback of using chemical techniques is the waste generated during preparation is very high which is toxic, hazardousand causes environmental pollution.To overcome these drawbacks green synthesis/biological routes are most preferred. The ultimate aim of green synthesis is to prepare AgNps with minimal waste in a sustainable process to ensuresafety through theeco-friendly and relatively non-toxic process. There are two major practices to prepare AgNps via green synthesis such as micro-organism based synthesis and plant extract mediated synthesis where plant extract mediated synthesis are widely used owing to its low toxicity, facile technique, time effective, tunable preparation techniques, etc. which are discussed elaborately in this review.

Keywords: Silver nanoparticles, green synthesis, micro-organism mediated synthesis, plant extract mediated synthesis.

Overview

Silver nanoparticle (Ag Nps) has a wide range of applications in the field of nano-science due to their high catalytic activity, high chemical stability, good conductivity; andstable physio-chemical properties.[1] Silver is well known for its anti-microbial activity forthe past few generations. Likewise, AgNps also poses enhanced anti-microbial activity owing to their capability to attach on to the microbial membrane and generate oxidative stress which leads to cellular disruption.[2] This characteristic of AgNps is widely used in the food industry, textile industry and many other processes to eradicate the influence of microbes for spreading infectious diseases. For these applications, AgNps are prepared through various methods and technologiessuch as physical vapor deposition, ball milling, wet chemical synthesis, sol gel synthesis, sono-chemical synthesis, etc.of which bottom-up approaches are widely preferred. For bottom-up approach, there are some common requirements which are i) solvent, ii) reducing agent, and iii) stabilizing agents. The solvent is chosen in such a way that the precursor salt, reducing agent and stabilizing should be readily dissolved. The reducing agent is a compound thathas excess electrons (e-) to be shared or termed as e-donorsthat donate its excess e-to Ag+ ions. The reducing power of reducing agent determines the degree of reduction of Ag+to Ago.[3] The stabilizing agent is also called as capping agent/surfactant whichcontrols the growth rate of Ag Nps and prevents aggregation by promoting Brownian motion.[4] Usually, chemical compounds such as hydrazine hydrate, polyvinyl pyrrolidone, sodium citrate, polyvinyl alcohol, etc. are used as reducing and stabilizing agents for wet chemical synthesis. Even though, these chemicals don't pose acute toxicity, when continuously discarded into the environment can lead to ecotoxicity. To overcome such drawbacks, green synthesis technique is introduced where Ag Nps are prepared using eco-friendly methods.Green synthesis followsthe principles behind the green chemistry i.e., the principles to reduce and control the hazardous waste enteringour environment. Green synthesis concentrates on all the three important parameters such assolvent medium,

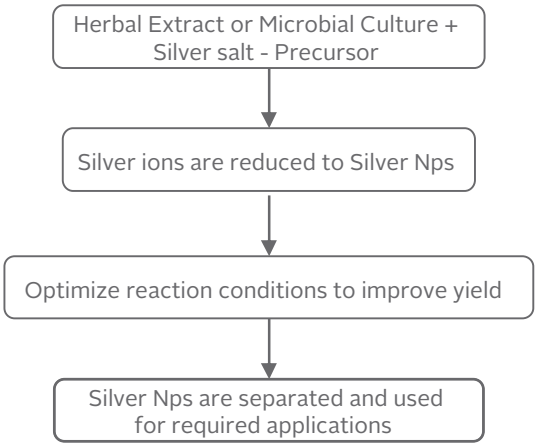

Figure 1: Flow chart explaining the synthesis of Ag Nps through biological route

reducing agent, and stabilizing agents to be non-toxic materials.Green synthesis of Ag Nps is carried out majorly by two processes i.e. micro-organism-basedsynthesis and plant extract- based synthesis.

Microorganism based synthesis

Microorganismsboth unicellular and multi-cellular have a tendency to nucleate and grow inorganic materials inside their cellular structure. The primary process that takes placeis that metallic ions like Ag+ ions are captured on the surface of the microbe'scell membrane, get slowly penetrated into the cellular structure by establishing electrostatic interactions between Ag+ ions and negatively charged cell wall.[5] Thus, once these metallic ions penetrate to the cell, reduction of ions occurs owing to the presence of biological moieties like sugar, proteins, etc.[6] that are natural reducing agents where nucleation and crystal growth happens. Most of the biological metabolism reaction inside the cell induces bio-reduction to form Ag Nps.[7] However, the full process of Ag Nps growth inside the microbe's cell is still under study. For example, Guangquanetal. synthesized the Ag Nps by reducing Ag+ions from the culture supernatantsof Aspergillus terreus. The nicotinamide adenine dinucleotide present is the cell act as the reducing agent and causes enzymatic reaction process for this biosynthesis.[8] Here, the culture is maintained in water and therefore, acts as a solvent. In another study, Sable et al. reported that during microorganism-based synthesis, proteins and peptides from the culture media acts as the capping agent.[9] Some examples of microorganism-based synthesis of Ag Nps are listed in Table 1.

The microorganism-based synthesis of Ag Nps poses major advantage of low toxicity compared to chemically synthesized counterpart and they have wide applications such as antimicrobial agents, biomedical device coatings, drug-delivery carriers, imaging probes, and diagnostic and optoelectronic platforms.[20] However, some major drawbacks set back the commercial potentiality of the microorganism-based synthesis technique. The bacterial culture preparation is a tedious process that requiresa hygienic environment.[21] maintainin-gaseptic condition involve sophisticated instru-ments. Also, after the preparation process, the culture has to be treated before discarding.[22] Further, the preparation of microbial culture is time-consuming where it takes 1 to several days depending on the microbe strain, growth, and media.[23]

Sl. No.	Size	Microorganism used	Application
1	10 nm[10]	*Gluconobacter roseus*	Antiplatelet activity
2	34-90 nm[11]	*Phanerochaete chrysosporium*	Antibacterial activity
3	20-100 nm[12]	*Candida utilis*	Antimicrobial activity
4	27.5 nm[13]	Pseudomonas aeruginosa	Antibacterial property
5	8-12 nm[14]	*Acinetobacter calcoaceticus*	Antibacterial property
6	20-30 nm[15]	*Streptomyces hygroscopicus*	Antibacterial property
7	10 nm[16]	*Sclerotinia sclerotiorum*	Antibacterial property
8	6-13 nm[17]	psychrophilic bacteria	Antibacterial property
9	41-68 nm[18]	*Bacillus brevis*	Antibacterial property
10	10-50 nm[19]	*Stenotrophomonas*	Antimicrobial activity

Table 1: Table1Microorganism based AgNps synthesis

Plantextract-based synthesis

In the plant extract-based synthesis method, the bio-molecules that are present in plants are extracted and used as reducing and capping agent. The reduction of Ag+to Agocan be achieved more rapidly without any sophisticated instruments.[24] It overcomes the drawbacks of microorganism-based synthesis such as difficulty in growth, maintaining culture, slow growth process, etc.[25] Here, the extract is obtained from the plant leaf, stem, or roots and mixed with silver precursor solution to obtain Ag Nps. The plant extracts withholdphytochemicals thattend to reduce the Ag+ ion much faster than the microbes. The phytochemicals include flavones, sugar, ketones, aldehydes, carbohydrates, proteins, etc. all acts as reducing agent.[26] The formation of Ag Nps through plant extract-based synthesis undergoes three phases

Activation phase

In the activation phase, the bio-reduction of Ag+ ions to Ago occurs which leads to the nucleation process of the reduced metal atoms. The degree of bio-reduction depends on the reducing power of phytochemicals.[27] Some plant extract readily reduces the ions but, in some reactions, some activation energy is required to start the reaction that solely depends on the concentration of plant extract and type of phytochemicals present.[28]

Growth phase

The growth phase of Nps is mainly due to a phenomenon known as Ostwald ripening. In the aqueous solution containing nucleated particles, the smaller particles tend to re-deposited over larger particles for reducing the overall surface energy influenced by thermodynamics [Fig. 2]. Thus, the ripening of smaller particles occurs.[29]

Termination phase

In this phase, the plant extract stabilizes the metal Nps growth by the favorable conformation of size, shape and morphological character and minimizes the Gibbs free energy.[30] The plant extract also acts as a capping agent which declines the aggregation of Nps and maintains the morphological characters of Nps.The bio-capping agents are negatively charged thus they get trapped on the positively charged surface of AgNps.[31]

Most preferably two types of solvents are used to extract phytochemicals from plant parts. The first one is the use of ethanol termed as ethanolic extract and the latter is aqueous extract where water is used as a solvent. The type of solvent determines the type of phytochemicals in the extract. In a study reported by Azwanida et. al. stated that ethanolic extract of Psidium guajava L. leaves is rich in alkaloids, saponins, carbohydrates, tannins and flavonoids whereas the water display similar constituents with the exception of alkaloids.[32]

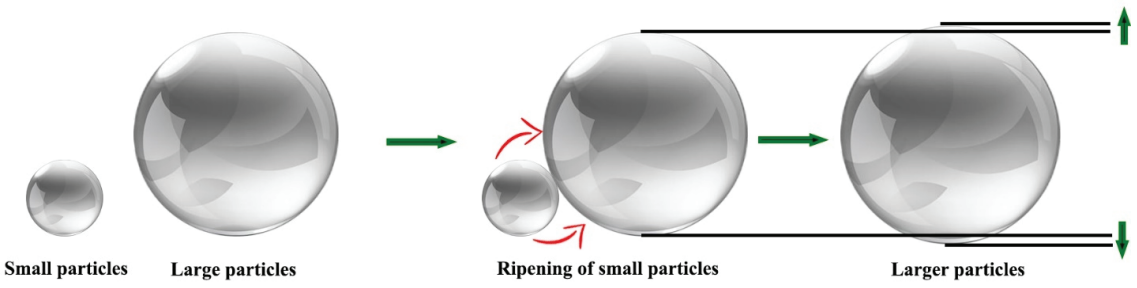

Figure 2: Schematic representing the Ostwald ripening process

Sl. No.	Size and shape	Plant used	Aqueous/ ethanolic extract	Application
1.	Spherical shape; 20-30 nm3[3]	*Cissusquadrangularis* (whole plant is used)	Aqueous extract	Antibacterial activity
2.	Spherical shape; 20-44 nm[34]	*Prosopis cineraria* (leaf extract)	Ethanolic extract	Antibacterial activity
3.	15 nm[35]	*Skimmialaureola* (leaf extract)	Ethanolic extract	Biomedical application
4.	11-16 nm[36]	*Tanacetum vulgare* (leaf extract)	Ethanolic extract	Antibacterial activity and sensor

to be followed...

Sl. No.	Size and shape	Plant used	Aqueous/ ethanolic extract	Application
5.	55-80 nm[37]	*Tinospora CordifoliaMiers* (leaf extract)	Ethanolic extract	Pediculocidal and larvicidal
6.	28-68 nm[38]	*Citrus sinensis* (Orange peel extract)	Aqueous extract	Antimicrobial
7.	30-50 nm[39]	*Chenopodium murale* (leaf extract)	Ethanolic extract	Antibacterial activity
8.	10-60 nm[40]	*Morindacitrifolia* (leaf extract)	Ethanolic extract	Inhibiting human pathogens
9.	Spherical shape; 5-30 nm[41]	*Melia azedarach* (bark extract)	Aqueous extract	Antimicrobial
11.	40-60 nm[43]	*Anacardium occidentale* (leaf extract)	Aqueous extract	Detection of Cr
12.	Polygon shape; 100-150 nm &hexagon shape; 10-20 nm[44]	*Dendropanaxmorbifera* (leaf extract)	Ethanolic extract	Anticancer
13.	Spherical shape; 6-8 nm[45]	*Tamarindus indica* (fruit extract)	Ethanolic extract and few Aqueous groups	Antibacterial activity
14.	2-115 nm[46]	*Erythrina suberosa* (leaf extract)	Aqueous extract	Antimicrobial, antioxidant and cytotoxicity
15.	4-35 nm[47]	*Albiziaadianthifolia* (leaf extract)	Aqueous extract	Anticancer
16.	Irregular shape; 10.78 nm[48]	*Artocarpusheterophyllum* (seed extract)	Aqueous extract	Antibacterial activity
17.	22 nm[49]	*Rhinacanthusnasutus* (leaf extract)	Aqueous extract	Antimicrobial
18.	20-30 nm[50]	*Ziziphus jujuba* (leaf extract)	Ethanolic extract	Antimicrobial
19.	6.45 nm[51]	*Coriandrum sativum* (leaf extract)	Ethanolic extract	Biomedicine
20.	15.5 nm[52]	*Momordica cymbalaria* (fruit extract)	Ethanolic extract	Antimicrobial

Table 2:

Therefore, depending upon the type of phytochemical required, the solvent is chosen.There is muchliterature that dealt with the synthesis of Ag Nps using both ethanolic and aqueous extract of different plant parts. Some of the data are summarized in Table 2.

Thus, Table 1 depictsthat different part of the plant extract is used to synthesis AgNps, which is of aqueous or ethanolic extract. Each plant has its own activation phase and growth phase which keenly depends on the phytochemicals that are present in the extract[28,29] and therefore, the size of the resultant Ag Nps varies upon the particle interaction during nucleation phase.[53] It is also clear that we can optimize the size of Ag Nps by controlling the precursor concentration, temperature, pH, the amount of reducing and stabilizing factors.[54]

Advantages of using plant extract-based synthesis

The major advantages of using plant extract-based green synthesis are facile, non-toxicity, time consumption is low, high stability, and cost-efficient. The Nps produced via this process enhances the biocompatible characteristicsand can be used for in-vivostudies also because they all are produced from natural reducing agents and they are non-toxic when compared to chemically synthesized Nps.[55-57] The better biocompatible nature of Ag Nps synthesized using green synthesis is due to the slow ionic

release facilitated by the presence of natural capping agent.

Summary

Overall, this review explains that the biological process of preparation AgNps is more efficient and produces low pollutants than conventional chemical techniques. The plant extract-based synthesis provides more practical feasibility than microbe assisted synthesis of Ag Nps due to various factors such as low cost, eco-friendly, no sophisticated environment required, time-efficient, etc.Further, the biocompatibility of Ag Nps synthesized through plant extract mediated synthesis promotes selective toxicity towards microbesfacilitating in vivo study.

Acknowledgments

The authors would like to thank the Management of Chettinad Academy of Research and Education, Kelambakkam for providing facilities to complete this review paper.

References

1. Rajput N. Methods of preparation of nanoparticles-a review. International Journal of Advances in Engineering & Technology 2015; 7: 1806.
2. Sun Q, Cai X, Li J, Zheng M, Chen Z, Yu CP. Green synthesis of silver nanoparticles using tea leaf extract and evaluation of their stability and antibacterial activity. Colloids and Surfaces A: Physicochemical and Engineering aspects 2014; 444: 226-31.
3. Raveendran P, Fu J, Wallen SL. Completely "green" synthesis and stabilization of metal nanoparticles. Journal of the American Chemical Society 2003; 125: 13940-1.
4. Pang C, Jung JY, Kang YT. Aggregation based model for heat conduction mechanism in nanofluids. International Journal of Heat and Mass Transfer 2014; 72: 392-9.
5. Dror-Ehre A, Mamane H, Belenkova T, Markovich G, Adin A. Silver nanoparticle–E. coli colloidal interaction in water and effect on E. coli survival. Journal of Colloid and Interface Science 2009; 339: 521-6.
6. Singh J, Dutta T, Kim KH, Rawat M, Samddar P, Kumar P. 'Green'synthesis of metals and their oxide nanoparticles: applications for environmental remediation. Journal of Nanobiotechnology 2018; 16: 84.
7. Iravani S. Green synthesis of metal nanoparticles using plants. Green Chemistry 2011; 13: 2638-50.
8. Li G, He D, Qian Y, Guan B, Gao S, Cui Y, Yokoyama K, Wang L. Fungus-mediated green synthesis of silver nanoparticles using Aspergillus terreus. International Journal of Molecular Sciences 2012; 13: 466-76.
9. Sable SV, Kawade S, Ranade S, Joshi S. Bioreduction mechanism of silver nanoparticles. Materials Science and Engineering: C 2020; 107: 110299.
10. Krishnaraj RN, Berchmans S. In vitro antiplatelet activity of silver nanoparticles synthesized using the microorganism Gluconobacter roseus: an AFM-based study. RSC advances 2013;3:8953-9.
11. Saravanan M, Arokiyaraj S, Lakshmi T, Pugazhendhi A. Synthesis of silver nanoparticles from Phenerochaete chrysosporium (MTCC-787) and their antibacterial activity against human pathogenic bacteria. Microbial pathogenesis 2018;117:68-72.
12. Waghmare SR, Mulla MN, Marathe SR, Sonawane KD. Ecofriendly production of silver nanoparticles using Candida utilis and its mechanistic action against pathogenic microorganisms. 3 Biotech 2015;5:33-8.
13. Busi S, Rajkumari J, Ranjan B, Karuganti S. Green rapid biogenic synthesis of bioactive silver nanoparticles (AgNPs) using Pseudomonas aeruginosa. IET nanobiotechnology 2014;8: 267-74.
14. Singh R, Wagh P, Wadhwani S, Gaidhani S, Kumbhar A, Bellare J, Chopade BA. Synthesis, optimization, and characterization of silver nanoparticles from Acinetobacter calcoaceticus and their enhanced antibacterial activity when combined with antibiotics. International journal of nanomedicine 2013;8:4277.
15. Sadhasivam S, Shanmugam P, Yun K. Biosynthesis of silver nanoparticles by Streptomyces hygroscopicus and antimicrobial activity against medically important pathogenic microorganisms. Colloids and Surfaces B: Biointerfaces 2010;81:358-62.
16. Saxena J, Sharma PK, Sharma MM, Singh A. Process optimization for green synthesis of silver nanoparticles by Sclerotinia sclerotiorum MTCC 8785 and evaluation of its antibacterial properties. SpringerPlus 2016;5:1-0.
17. Shivaji S, Madhu S, Singh S. Extracellular synthesis of antibacterial silver nanoparticles using psychrophilic bacteria. Process Biochemistry 2011;46:1800-7.
18. Saravanan M, Barik SK, MubarakAli D, Prakash P, Pugazhendhi A. Synthesis of silver nanoparticles from Bacillus brevis (NCIM 2533) and their antibacterial activity against pathogenic bacteria. Microbial pathogenesis 2018;116:221-6.
19. Malhotra A, Dolma K, Kaur N, Rathore YS, Mayilraj S, Choudhury AR. Biosynthesis of gold and silver nanoparticles using a novel marine strain of Stenotrophomonas. Bioresource technology 2013;142:727-31.
20. Lee SH, Jun BH. Silver Nanoparticles: Synthesis and application for nanomedicine. International Journal of Molecular Sciences 2019; 20: 865.

21. Duponnois R, Garbaye J. Mycorrhization helper bacteria associated with the Douglas fir-Laccarialaccata symbiosis: effects in aseptic and in glasshouse conditions. In: Annales des Sciences Forestières.EDP Sciences; 1991; pp. 239-251.

22. Ozanne G, Huot R, Montpetit C. Influence of packaging and processing conditions on the decontamination of laboratory biomedical waste by steam sterilization. Applied and Environmental Microbiology1993; 59: 4335-7.

23. Lagier JC, Edouard S, Pagnier I, Mediannikov O, Drancourt M, Raoult D. Current and past strategies for bacterial culture in clinical microbiology. Clinical Microbiology Reviews 2015; 28: 208-36.

24. Mittal AK, Chisti Y, Banerjee UC. Synthesis of metallic nanoparticles using plant extracts. Biotechnology Advances 2013; 31: 346-56.

25. Srikar SK, Giri DD, Pal DB, Mishra PK, Upadhyay SN. Green synthesis of silver nanoparticles: a review. Green and Sustainable Chemistry 2016; 6: 34.

26. Puri B, Hall A. Phytochemical dictionary: a handbook of bioactive compounds from plants. CRC press; 1998.

27. Dauthal P, Mukhopadhyay M. Biofabrication, characterization, and possible bio-reduction mechanism of platinum nanoparticles mediated by agro-industrial waste and their catalytic activity. Journal of Industrial and Engineering Chemistry 2015; 22: 185-91.

28. Yong P, Rowson NA, Farr JP, Harris IR, Macaskie LE. Bioreduction and biocrystallization of palladium by Desulfovibriodesulfuricans NCIMB 8307. Biotechnology and Bioengineering 2002; 80: 369-79.

29. Liu B, Hu X. Hollow Micro-and Nanomaterials: Synthesis and Applications. In: Advanced Nanomaterials for Pollutant Sensing and Environmental Catalysis. Elsevier; 2020; pp. 1-38

30. Makarov VV, Love AJ, Sinitsyna OV, Makarova SS, Yaminsky IV, Taliansky ME, Kalinina NO. "Green" nanotechnologies: synthesis of metal nanoparticles using plants. Acta Naturae 2014;6: 35-44

31. Yallappa S, Manjanna J. Biological evaluation of silver nanoparticles obtained from T. arjuna bark extract as both reducing and capping agent. Journal of Cluster Science 2014; 25: 1449-62.

32. Azwanida NN. A review on the extraction methods use in medicinal plants, principle, strength and limitation. Med Aromat Plants 2015; 4: 2167-0412.

33. Valli JS, Vaseeharan B. Biosynthesis of silver nanoparticles by Cissusquadrangularis extracts. Materials Letters 2012; 82: 171-3.

34. Jinu U, Gomathi M, Saiqa I, Geetha N, Benelli G, Venkatachalam P. Green engineered biomolecule-capped silver and copper nanohybrids using Prosopis cineraria leaf extract: enhanced antibacterial activity against microbial pathogens of public health relevance and cytotoxicity on human breast cancer cells (MCF-7). Microbial pathogenesis 2017; 105: 86-95.

35. Ahmed MJ, Murtaza G, Mehmood A, Bhatti TM. Green synthesis of silver nanoparticles using leaves extract of Skimmialaureola: characterization and antibacterial activity. Materials Letters 2015; 153: 10-3.

36. Dubey SP, Lahtinen M, Sillanpää M. Tansy fruit mediated greener synthesis of silver and gold nanoparticles. Process Biochemistry 2010; 45: 1065-71.

37. Jayaseelan C, Rahuman AA, Rajakumar G, Kirthi AV, Santhoshkumar T, Marimuthu S, Bagavan A, Kamaraj C, Zahir AA, Elango G. Synthesis of pediculocidal and larvicidal silver nanoparticles by leaf extract from heartleaf moonseed plant, TinosporacordifoliaMiers. Parasitology Research 2011; 109: 185-94.

38. de Barros CH, Cruz GC, Mayrink W, Tasic L. Bio-based synthesis of silver nanoparticles from orange waste: effects of distinct biomolecule coatings on size, morphology, and antimicrobial activity. Nanotechnology, Science and Applications 2018; 11: 1-14.

39. Abdel-Aziz MS, Shaheen MS, El-Nekeety AA, Abdel-Wahhab MA. Antioxidant and antibacterial activity of silver nanoparticles biosynthesized using Chenopodium murale leaf extract. Journal of Saudi Chemical Society 2014; 18: 356-63.

40. Sathishkumar G, Gobinath C, Karpagam K, Hemamalini V, Premkumar K, Sivaramakrishnan S. Phyto-synthesis of silver nanoscale particles using Morindacitrifolia L. and its inhibitory activity against human pathogens. Colloids and Surfaces B: Biointerfaces 2012; 95: 235-40.

41. Pani A, Lee JH, Yun SI. Autoclave mediated one-pot-one-minute synthesis of AgNPs and Au–Ag nanocomposite from Melia azedarach bark extract with antimicrobial activity against food pathogens. Chemistry Central Journal 2016; 10: 15.

42. Vaseeharan B, Ramasamy P, Chen JC. Antibacterial activity of silver nanoparticles (AgNps) synthesized by tea leaf extracts against pathogenic Vibrio harveyi and its protective efficacy on juvenile Feneropenaeus indicus. Letters in Applied Microbiology 2010; 50: 352-6.

43. Balavigneswaran CK, Kumar TS, Packiaraj RM, Prakash S. Rapid detection of Cr (VI) by AgNPs probe produced by Anacardium occidentale fresh leaf extracts. Applied Nanoscience 2014; 4: 367-78.

44. Wang C, Mathiyalagan R, Kim YJ, Castro-Aceituno V, Singh P, Ahn S, Wang D, Yang DC. Rapid green synthesis of silver and gold nanoparticles using Dendropanaxmorbifera leaf extract and their anticancer activities. International Journal of Nanomedicine 2016; 11: 3691.

45. Jayaprakash N, Vijaya JJ, Kaviyarasu K, Kombaiah K, Kennedy LJ, Ramalingam RJ, Munusamy MA, Al-Lohedan HA. Green synthesis of Ag nanoparticles using Tamarind fruit extract for the antibacterial studies. Journal of Photochemistry and Photobiology B: Biology 2017; 169: 178-85.

46. Mohanta YK, Panda SK, Jayabalan R, Sharma N, Bastia AK, Mohanta TK. Antimicrobial, antioxidant and cytotoxic activity of silver nanoparticles synthesized by leaf extract of Erythrina suberosa (Roxb.). Frontiers in Molecular Biosciences 2017; 4: 14.

47. Gengan RM, Anand K, Phulukdaree A, Chuturgoon A. A549 lung cell line activity of biosynthesized silver nanoparticles using Albiziaadianthifolia leaf. Colloids and Surfaces B: Biointerfaces 2013; 105: 87-91.

48. Jagtap UB, Bapat VA. Green synthesis of silver nanoparticles using Artocarpusheterophyllus Lam. seed extract and its antibacterial activity. Industrial crops and products 2013; 46: 132-7.

49. Pasupuleti VR, Prasad TN, Shiekh RA, Balam SK, Narasimhulu G, Reddy CS, Ab Rahman I, Gan SH. Biogenic silver nanoparticles using Rhinacanthusnasutus leaf extract: synthesis, spectral analysis, and antimicrobial studies. International Journal of Nanomedicine 2013; 8: 3355.

50. Gavade NL, Kadam AN, Suwarnkar MB, Ghodake VP, Garadkar KM. Biogenic synthesis of multi-applicative silver nanoparticles by using Ziziphus Jujuba leaf extract. Spectrochimica Acta Part A: Molecular and Biomolecular Spectroscopy 2015; 136: 953-60.

51. Khan MZ, Tareq FK, Hossen MA, Roki MN. Green synthesis and characterization of silver nanoparticles using Coriandrum sativum leaf extract. Journal of Engineering Science and Technology 2018; 13: 158-66.

52. Swamy MK, Akhtar MS, Mohanty SK, Sinniah UR. Synthesis and characterization of silver nanoparticles using fruit extract of Momordica cymbalaria and assessment of their in vitro antimicrobial, antioxidant and cytotoxicity activities. Spectrochimica Acta Part A: Molecular and Biomolecular Spectroscopy 2015; 151: 939-44.

53. Karatoprak GŞ, Aydin G, Altinsoy B, Altinkaynak C, Koşar M, Ocsoy I. The Effect of Pelargonium endlicherianumFenzl. root extracts on formation of nanoparticles and their antimicrobial activities. Enzyme and microbial technology 2017; 97: 21-6.

54. Zhang XF, Liu ZG, Shen W, Gurunathan S. Silver nanoparticles: synthesis, characterization, properties, applications, and therapeutic approaches. International journal of molecular sciences 2016; 17: 1534.

55. Sharma VK, Yngard RA, Lin Y. Silver nanoparticles: green synthesis and their antimicrobial activities. Advances in colloid and interface science 2009; 145: 83-96.

56. Devatha CP, Thalla AK. Green synthesis of nanomaterials. In: Synthesis of Inorganic Nanomaterials.Woodhead Publishing; 2018; pp. 169-184

57. Shah M, Fawcett D, Sharma S, Tripathy SK, Poinern GE. Green synthesis of metallic nanoparticles via biological entities. Materials 2015; 8: 7278-308.