ISSN 2449-8955 European Journal of Biological Research Review Article

DOI: http://dx.doi.org/10.5281/zenodo.2617168

Biosynthesis of Silver Nanoparticle from Fungi, Algae and Bacteria

Indranil Singh

Amity Institute of Biotechnology, Amity University Madhya Pradesh, Gwalior, India

Correspondence: E-mail: adrasiner@gmail.com

Received: 13 December 2018; **Revised submission:** 20 February 2019; **Accepted:** 30 March 2019

ABSTRACT: Silver nanoparticles are today considered as the backbone of nanotechnology industries. Since time immemorial silver along with its compound and associated salts have been walking together with human civilization. Although the silver has been known from such a long time it has not been recently that fabrication of silver nanoparticle was to be a reality. It has some prominent as well as pronounced application in the field of medicine, agriculture etc. It has very favorable and significant antioxidant, antibacterial and antifungal properties. It has been found effective against many of bacteria's such as *Vibrio parahaemolyticus, Citrobacter koseri, Salmonella Typhii, Pseudomonas aeruginosa, Staphylococcus aureus* and even against few fungus species like *Candida albicans*. The mode of mechanism could be possible binding of silver ions with the biomolecules present in cells. It is believed that the whole system runs over the fact that it leads to the formation of free radical along with the production of ROS i.e. reactive oxygen species, which ultimately result in apoptotic condition and hence cell could no longer replicate. There is much more application ranging from food preservation, cosmetic etc. But the physical and chemical synthesis of Ag has been inefficient to meet the demands at the same time causing lots of damage to the environment. Hence it calls for a cleaner, efficient and eco-friendly process. That space has been traveled by biosynthesis of Ag nanoparticle from plant, algae, and bacteria etc. This review takes under consideration such efforts in the last few years.

Keywords: Silver nanoparticles; Algae; Bacteria; Fungi; Green synthesis; Toxicity mechanism.

1. INTRODUCTION

Nanoparticles unique properties are surface dependent that tends to vary with their shape, size, and morphology. These have a crucial say in into interaction of nanoparticles with plants, animal or microorganism [1-7]. The silver nanoparticle has a pronounced effect on bacteria and those of a wide number of microorganisms [8-11]. They are prepared through a variety of processes in order to study all its dimension of properties [12]. The silver nanoparticle can be synthesized from various methods ranging from physical, chemical and biological methods. In the biogenic formation of the nanoparticle, it is a microorganism; Fungi, Bacteria, yeast and various parts of plants in extract form are used in its production [13-15]. Hence formed particles properties greatly varies with our choice of solvent, how strong is the reducing agent and what is the temperature being subjected to metallic ion or compound to form nanoparticles [10, 11]. Of the entire nanoparticle formed Ag and Au hold the specific position. Silver beneficial aspect is known from quite a long time but it has not been used much before. Every year it is estimated that nearly 320 tons of silver nanoparticle are used in different applications [16, 17].

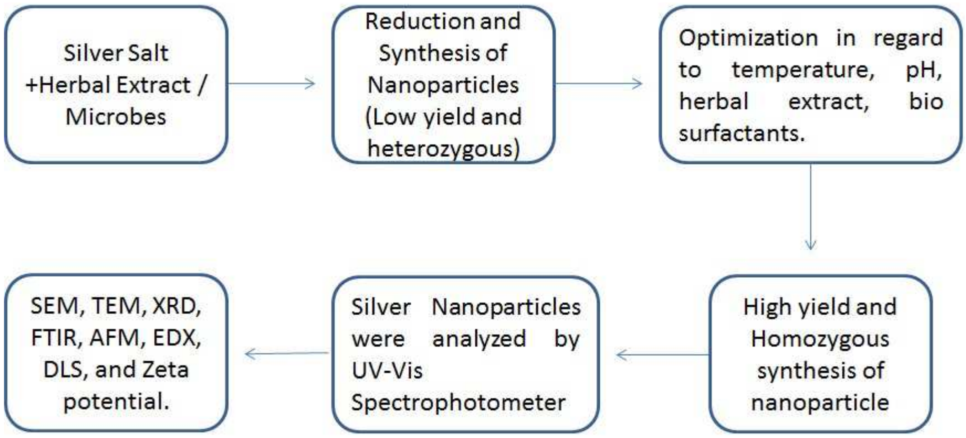

Figure 1. Biosynthesis of silver nanoparticle and their optimization techniques.

Owing to the unfavorable advancement like the development of multi-drug resistant bacteria, viruses because of various anthropogenic activities like pollution that is changing environmental condition and influencing organism to undergo mutation. Many metal salt and metal nanoparticle have been found to act as antimicrobial agents but yet silver has a prominent place in the series [18, 19]. The silver nanoparticle has been not only utilized as growth inhibitors for only bacteria's but has also been used in other cut and wounds to inhibit the microbial infection [20-22]. In a separate study, it has been found that water-soluble protein extracted from silkworms with a functional group like hydroxyl, amino or carboxyl group could even act as the potential reducing agent for reduction of the $AgNO_3$ solution. The antibacterial studies reveal that MIC for gram positive and negative bacteria falls under 0.001 and 0.008 mM [23-25].

2. SYNTHESIS AND CHARACTERIZATION OF SILVER NANOPARTICLE

We can broadly classify the whole method of metallic nanoparticle formation into two major approaches i.e. Bottom-up and top-down approach. The bottom-up method involves production of nanoparticles from atom and molecule involving agglomeration. At the same time, the top-down approach involves slicing or successive cutting in order to achieve the nano range of 1 to 100 nm [1]. The bottom-up approach is preferred over the top-down approach, involving a heterogeneous system and the uses of various reducing agent and enzyme. "Top-down" method is employed only when the sample is in bulk form, a further various method like physical ablations; cutting, sputtering, mechanical grinding etc. is used in order to gain a significant amount of size reduction. But it has a bigger loophole in form of surface structural defect leading to significant loss of properties. The silver nanoparticle can be formed from various methods ranging from the involvement of chemicals [26-29] to use of various physical break down processes [30-32] and application of biologic system [10, 11]. There is a number of chemical methods reported till date like pyrolysis, electrochemical, reduction through chemicals and irradiation [33].

The process of forming nanoparticle from solution requires a reducing and a capping agent or stabilizing agent. The role of reducing agent can be played with help of ascorbic acid, sodium citrate, a hydrazine compound, and alcohol etc. In a separate study, it has been achieved to form closely regulated silver NPs deposition over nanostructured SiO_2 [29]. At the same time physical method has quite a few benefits over chemical method like narrow size distribution and no such requirement of lethal and highly relative chemical with a fast processing time but only at the expanse of high energy. Examples of a method that could be employed are arc-discharge, [31] physical deposition method, [30] magnetron sputtering [32] and energy ball milling method [34].

In case of biological synthesis of nanoparticle plant and micro-organism has been used in place of reducing as well as a capping agent. Plants are found to be in possession of various fats, nucleic acid, pigment and secondary metabolites which have required the capability to reduce and form nanoparticles from the metallic compound and at the same time producing less toxic by-product. While in the case of microorganism it is the presence of the biologically active molecule, as well as enzymes, are responsible for reduction [1].

Table 1. List of different stabilizing/capping agent used in synthesis of nanoparticle from various strains of bacteria.

Strains of bacteria	Morphology	Stabilising agent	References
Pseudomonas aeruginosa BS-161R	15.1 ± 5.8 nm; spherical	Rhamnolipids	[35]
Brevibacterium casei MSA19	-	Biosurfactant	[36]
Bacillus cereus NK1	50-80 nm	URAK (a fibrinolytic enzyme)	[37]
Gluconacetobacter xylinum	5-40 nm	Cellulose	[38]
Streptomyces coelicolor	28-50 nm	Irregular Actinorhodin pigment	[39]
Bacillus subtilis MSBN	17-60 nm	Spherical Bioflocculant	[40]
Salmonella typhimurium	3-11 nm	Flagellin	[41]
Bacillus athrophaeus	5-30 nm	Polydispersed Spores	[42]
Lactobacillus rhamnosus GG ATCC 53103	2-15 nm; spherical, rodshaped and hexagonal	Exopolysaccharide	[43]
Nostoc commune	15-54 nm	spherical Extracellular	[44]
Pseudomonas aeruginosa	10-13 nm; spherical	Biosurfactant	[45]
Ochrobactrum rhizosphaerae	10 nm; spherical	Glycolipoprotein	[46]
Gordonia amicalis HS-11	5-25 nm; spherical	Glycolipid	[47]
Bacillus subtilis	-	Surfactin	[48]

3. NANOPARTICLES FROM BACTERIA

After the onset of green nanotechnology concept, a lot has been done in biosynthesis of Ag nanoparticles. For example, *Pseudomonas stutzeri* which were isolated from silver mine was found to produce nanoparticles of silver intracellular [49] on an addition to this various other bacteria has been used in order to produce AgNPs in both extracellular as well as intracellularly. *A. calcoaceticus, B. flexus, B. megaterium, B. amyloliquefaciens*, and *S. aureus* [50-53] Ag nanoparticle has found to be in the variety of shapes ranging from spherical to cuboidal, hexagonal and could be triangular in shape. Fabrication of nanoparticle could be done with cell help of aqueous cell-free extract, cells, and cultural supernatant. In a separate study, it has been found that rapid production of silver nanoparticle could be achieved by the involvement of a bacterial strain S-27, which belongs to *Bacilis flexus* group [53-56]. Das et al. has used *Bacillus strain* (CS11) to report biosynthesis of silver nanoparticle from 1 mM $AgNO_3$ and bacteria at 25^{o}C. This has yielded nanoparticle within 24 h with peak obtained at 450 nm and size ranging between 42 and 92 nm.

4. NANOPARTICLES FROM FUNGI

Fungi in preparation of silver nanoparticle have been used extensively [57-59]. Biosynthesis from both types of fungi i.e. pathogenic and the other one which is non- pathogenic in nature has been reported. It leads to the formation of particles either extracellular or intracellular or can be in both the condition. In other work, it has also resulted in silver nanoparticle stable in water [60, 61]. Syed et al. in his work has achieved the synthesis by using fungus *Humicola* sp. [62].

Owaidi et al. in his work reported that silver nanoparticle could be produced from yellow exotic oyster mushroom, with species *Pleurotus cornucopiae* var. *citrinopileatus*. In this procedure first of all basidiocarps are dried, powdered and boiled along with water after which the supernatant was then moved for freeze drying. The silver nanoparticle is then confirmed when the yellow color change to yellow-brownish color. The absorption peak is found to be at 420 and 450nm in UV-vis region. [63] Several fungi namely, *Aspergillus flavus, F. solani, Phytophthora infestans, A. fumigates, Phoma glomerate, Fusarium oxysporum, F. acuminatum, F. culmorum, Verticillium* sp., *Metarhizium anisopliae,* and *Trichoderma viride,* lead to the synthesis of the particle at both the location i.e. extracellular and intracellular.

Table 2. Silver nanoparticles synthesis with help of various microorganisms.

Microorganism	Morphology	Location	References
Acinetobacter calcoaceticus	8-12 nm; spherical	Extracellular	[64]
A. haemolyticus MMC8	4-40 nm	Extracellular	[65]
Aeromonas sp. SH10	6.4 nm	Intracellular	[66, 67]
Bordetella sp.	63-90 nm	Extracellular	[68]
Enterobacter aerogenes	25-35 nm; spherical	Extracellular	[69]
Escherichia coli	42.2-89.6 nm; spherical	Extracellular	[70]
Geobacter sulfurreducens	-	Extracellular	[71]
Gluconobacter roseus	10 nm	Extracellular	[72]
Idiomarina sp.	25 nm	Extracellular	[73]
Klebsiella pneumoniae	15-37 nm	Extracellular	[74]
Klebsiella pneumoniae	5-32 nm	Extracellular	[75]
Morganella sp.	10-40 nm; quasispherical	Extracellular	[76]
Proteus mirabilis	10-20 nm; spherical	Extracellular	[77]
Pseudomonas aeruginosa SM1	6.3 ± 4.9 nm; spherical	Intracellular	[78]
Pseudomonas aeruginosa SM1	8-24 nm; spherical	Extracellular	[79]
Pseudomonas aeruginosa SM1	5-25 nm; quasispherical	Intracellular	[80]

5. NANOPARTICLES FROM PLANTS

Plant extract collected from various sources ranging from leaves, barks, stem, shoot, root, seeds and their primary as well as the secondary metabolites can be utilized for the efficient biosynthesis [81]. Recently, in a work extract from the seed of plant species *Pongamia pinnata* have been reported for the green synthesis of the silver nanoparticle. Further, the nanoparticle confirmation was done by getting the absorption max at 439 nm. Karatoprak et al. in their work have reported biosynthesis of silver nanoparticle from the extract taken of plant *Pelargonium endlicherianum.* In another work, it has been established that gallic acid, apocynin along with quercetin acts as the potential reducing agent. In a yet another work Moldovan et al. has used the extract from the food of plant species *Sambucus nigra* in what is known as the phytomediated synthesis of silver nanoparticle [82].

Logaranjan et al. have reported that *Aloe vera* extract could be very useful in the creation of silver nanoparticle with highly restricted morphology and variation in shape and size of it. It shows absorption peak at 420 nm that confirmed the formation of silver nanoparticles. After irradiation done by microwave, silver nanoparticle in range of 5-50 nm could be found, flourishing octahedral geometry of itself.

Table 3. Synthesis of silver nanoparticles with the help of fungus.

Fungus species	Morphology	Location	References
Humicola sp.	5-25 nm; spherical	Extracellular	[83]
Macrophomina phaseolina	5-40 nm; spherical	Cell free extract	[84]
Penicillium brevicompactum	58.35 ± 17.88 nm	Cell free extract	[85]
P. nalgiovense AJ12	25 ± 2.8 nm	Cell free extract	[86]
Phaenerochaete chrysosporium	5-200 nm; pyramidal	-	[87]
Phoma glomerata	60-80 nm; spherical	-	[88]
Pleurotus ostreatus	< 40 nm; spherical	-	[89]
P. sajor-caju	30.5 ± 4.0 nm; spherical	Extracellular	[90]
Trichoderma asperellum	13-18 nm; nanocrystalline	Extracellular	[91]
T. reesei	5-50nm	Extracellular	[92]
T. viride	5-40 nm	Extracellular	[93]
T. viride	2-5 nm; spherical 40-65 nm; rectangular 50-100 nm; penta/hexagonal	Cell free extract	[94]

6. CYTOTOXICITY OF SILVER NANOPARTICLES

Cytotoxicity of any nanoparticles or nanomaterial is the function of their size, shape along with the stabilizing or capping agent and especially it is being affected by the pathogen in regard to which it is being studied. Biosynthesis is believed to have increased the toxicity of silver nanoparticle against pathogen when compared to their counterpart. The pathogen is found to be more prone to the silver nanoparticle as respect to other nanoparticles, because of its ionic state in which Ag NPs are present. At first Ag NPs will simply envelop the pathogen followed by them breaking through it and finally ending up as the inhibiting factor for various cellular constituents [95-99]. The cytotoxic effect being due to Ag ions that have been released or the Ag NPs is still a controversial position and thoughts are divided on both the option [100-103].

The cytotoxicity of silver nanoparticle has been owned to the fact that it leads to the production of ROS that as a result sees the reduction in glutathione level and the further increase in ROS level [104]. It has been established fact that silver nanoparticle is effective against a large number of the pathogen such as *Vibrio parahaemolyticus, Citrobacter koseri, Salmonella Typhii, Pseudomonas aeruginosa, Staphylococcus aureus* and even against few fungus species like Candida albicans. It is owned to fact that it possesses a larger surface area that is capable to penetrate through the cell membrane and further can attach to different intracellular location based on its size. Reduction in size is inverse proportional to its anti-bacterial efficiency. There have been many arguments for same but the most convincing one is the formation of free radical which has been backed by absorption at 336.33 in ESR (electron spin resonance) band of Ag NPs. Yet in another work, it has been argued that Ag^{+} get through cell wall being smaller in size and lead to its rupture further leading to denaturation of protein and finally its death [105-110].

7. CONCLUSION

Silver nanoparticle has established various applications in research and development as well as also in things related to commercial uses. It has been employed in the various fields from medicine, agriculture, biosensor and many more. It has been cytotoxic to both the gram positive and gram negative pathogen. It could be used to treat various infections and when coupled with an antibody could further result into active against many bacteria that has been coming up as drug-resistant bacteria. Ag NPs have been coupled with the polymer to act as the efficient drug delivery system which is expected to increase solubility, stability and also the distribution of the drug inside the body. Besides all the very good application of silver nanoparticle, we too have some disadvantage of it. The effect of these nanoparticles in long run is just a random guess and need to be studied.

Conflict of Interest: The author declares no conflict of interest.

REFERENCES

1. Husen A, Siddiqi KS. Phytosynthesis of nanoparticles: concept, controversy and application. Nano Res Lett. 2014; 9: 229.
2. Husen A, Siddiqi KS. Plants and microbes assisted selenium nanoparticles: characterization and application. J Nanobiotechnol. 2014; 12: 28.
3. Siddiqi KS, Husen A. Green synthesis, characterization and uses of palladium/ platinum nanoparticles. Nano Res Lett. 2016; 11: 482.
4. Husen A, Siddiqi KS. Carbon and fullerene nanomaterials in plant system. J Nanobiotechnol. 2014; 12: 16.
5. Siddiqi KS, Rahman A, Tajuddin Husen A. Biogenic fabrication of iron/iron oxide nanoparticles and their application. Nano Res Lett. 2016; 11: 498.
6. Siddiqi KS, Husen A. Recent advances in plant-mediated engineered gold nanoparticles and their application in biological system. J Trace Elements Med Biol. 2017; 40: 10-23.
7. Siddiqi KS, Husen A. Engineered gold nanoparticles and plant adaptation potential. Nano Res Lett. 2016; 11: 400.
8. Wei L, Lu J, Xu H, Patel A, Chen ZS, Chen G. Silver nanoparticles: synthesis, properties, and therapeutic applications. Drug Discov Today. 2015; 20: 595-601.
9. Lara HH, Garza-Trevino EN, Ixtepan-Turrent L, Singh DK. Silver nanoparticles are broad-spectrum bactericidal and virucidal compounds. J Nanobiotechnol. 2011; 9: 30.
10. Siddiqi KS, Husen A. Fabrication of metal nanoparticles from fungi and metal salts: scope and application. Nano Res Lett. 2016; 11: 98.
11. Siddiqi KS, Husen A. Fabrication of metal and metal oxide nanoparticles by algae and their toxic effects. Nano Res Lett. 2016; 11: 363.
12. Zaheer Z, Rafiuddin. Silver nanoparticles to self-assembled films: Green synthesis and characterization. Colloids Surf B Biointerfaces. 2012; 90: 48-52.
13. Lokina S, Stephen A, Kaviyarasan V, Arulvasu C, Narayanan V. Cytotoxicity and antimicrobial activities of green synthesized silver nanoparticles. Euro J Med Chem. 2014; 76: 256-263.
14. Saifuddin N, Wong CW, Yasumira AAN. Rapid biosynthesis of silver nanoparticles using culture supernatant of bacteria with microwave irradiation. e-J Chem. 2009; 6: 61-70.
15. Shahverdi AR, Minaeian S, Shahverdi HR, Jamalifar H, Nohi AA. Rapid synthesis of silver nanoparticles using culture supernatants of Enterobacteria: a novel biological approach. Process Biochem. 2007; 42: 919-923.
16. Ahamed M, AlSaalhi MS, Siddiqui MKJ. Silver nanoparticle applications and human health. Clin Chim Acta. 2010; 411: 1841-1848.
17. Chen X, Schluesener HJ. Nanosilver: a nanoproduct in medical application. Toxicol Lett. 2008; 176: 1-12.

18. Jones SA, Bowler PG, Walker M, Parsons D. Controlling wound bioburden with a novel silver-containing Hydrofiber dressing. Wound Repair Regen. 2004; 12: 288-294.
19. Silver S, Phung LT. Bacterial heavy metal resistance: new surprises. Annu Rev Microbiol. 1996; 50: 753-789.
20. Catauro M, Raucci MG, De Gaetano FD, Marotta A. Antibacterial and bioactive silver-containing Na_2O × CaO × $2SiO_2$ glass prepared by solgel method. J Mater Sci Mater Med. 2004; 15: 831-837.
21. Crabtree JH, Burchette RJ, Siddiqi RA, Huen IT, Handott LL, Fishman A. The efficacy of silver-ion implanted catheters in reducing peritonealdialysis-related infections. Perit Dial Int. 2003; 23: 368-374.
22. Das R, Gang S, Nath SS. Preparation and antibacterial activity of silver nanoparticles. J Biomater Nanobiotechnol. 2011; 2: 472-475.
23. Aramwit P, Bang N, Ratanavaraporn J, Ekgasit JS. Green synthesis of silk sericin-capped silver nanoparticles and their potent anti-bacterial activity. Nano Res Lett. 2014; 9: 79.
24. Vigneshwaran N, Nachane RP, Balasubramanya RH, Varadarajan PV. A novel one-pot ‘green’ synthesis of stable silver nanoparticles using soluble starch. Carbohydr Res. 2006; 341: 2012-2018.
25. Shin Y, Bae IT, Exarhos GJ. Green approach for self-assembly of platinum nanoparticles into nanowires in aqueous glucose solutions. Colloids Surf A. 2009; 348: 191-195.
26. Zhang Q, Li N, Goebl J, Lu Z, Yin Y. A systematic study of the synthesis of silver nanoplates: is citrate a “magic” reagent? J Am Chem Soc. 2011; 133: 18931-18939.
27. Roldán MV, Pellegri N, de Sanctis O. Electrochemical method for Ag-PEG nanoparticles synthesis. J Nanopart. 2013; 2013: 524150.
28. Sotiriou GA, Pratsinis SE. Antibacterial activity of nanosilver ions and particles. Environ Sci Technol. 2010; 44: 5649-5654.
29. Sotiriou GA, Teleki A, Camenzind A, Krumeich F, Meyer A, Panke S, Pratsinis SE. Nanosilver on nanostructured silica: antibacterial activityand Ag surface area. Chem Eng J. 2011; 170: 547-554.
30. Abou El-Nour KMM, Eftaiha A, Al-Warthan A, Ammar RAA. Synthesis and applications of silver nanoparticles. Arab J Chem. 2010; 3: 135-140.
31. Tien DC, Tseng KH, Liao CY, Huang JC, Tsung TT. Discovery of ionic silver in silver nanoparticle suspension fabricated by arc discharge method. J Alloys Compd. 2008; 463: 408-411.
32. Asanithi P, Chaiyakun S, Limsuwan P. Growth of silver nanoparticles by DC magnetron sputtering. J Nanomater. 2012; 2012: 963609.
33. Zhang W, Qiao X, Chen J. Synthesis of silver nanoparticles-effects of concerned parameters in water/oil microemulsion. Mater SciEng B. 2007; 142: 1-15.
34. Wright R, Zhang Q, Kirby P. Synthesis of silver nano particles and fabrication of aqueous Ag inks for inkjet printing. Mater Chem Phys. 2011; 129: 1075-1080.
35. Kumar CG, Mamidyala SK, Das B, Sridhar B, Devi GS, Karuna MS. Synthesis of biosurfactant-based silver nanoparticles with purified rhamnolipids isolated from *Pseudomonas aeruginosa* BS-161R. J Microbiol Biotechnol. 2010; 20: 1061-1068.
36. Kiran GS, Sabu A, Selvin J. Synthesis of silver nanoparticles by glycolipid biosurfactant produced from marine *Brevibacterium casei* MSA19. J Biotechnol. 2010; 148: 221-225.
37. Deepak V, Umamaheshwaran PS, Guhan K, Nanthini RA, Krithiga B, Jaithoon NMH, Gurunathan S. Synthesis of gold and silver nanoparticles using purified URAK. Coll Surf B Biointerface. 2011; 86: 353-358.

38. Liu C, Yang D, Wang Y, Shi J, Jiang Z. Fabrication of antimicrobial bacterial cellulose-Ag/AgCl nanocomposite using bacteria as versatile biofactory. J Nanopart Res. 2012; 14: 1084-1095.
39. Manikprabhu D, Lingappa K. Antibacterial activity of silver nanoparticles against methicillin-resistant *Staphylococcus aureus* synthesized using model *Streptomyces* sp. pigment by photo-irradiation method. J Pharm Res. 2013; 6: 255-260.
40. Sathiyanarayanan G, Kiran GS, Selvin J. Synthesis of silver nanoparticles by polysaccharide bioflocculant produced from marine *Bacillus subtilis* MSBN17. Coll Surf B Biointerface. 2013; 102: 13-20.
41. Gopinathan P, Ashok AM, Selvakumar R. Bacterial flagella as biotemplate for the synthesis of silver nanoparticle impregnated bionanomaterial. Appl Surf Sci. 2013; 276: 717-722.
42. Hosseini-Abari A, Emtiazi G, Ghasemi SM. Development of an ecofriendly approach for biogenesis of silver nanoparticles using spores of *Bacillus athrophaeus*. World J Microbiol Biotechnol. 2013; 29: 2359-2364.
43. Kanmani P, Lim ST. Synthesis and structural characterization of silver nanoparticles using bacterial exopolysaccharide and its antimicrobial activity against food and multidrug resistant pathogens. Process Biochem. 2013; 48: 1099-1106.
44. Morsy FM, Nafady NA, Abd-Alla MH, Elhady DA. Green synthesis of silver nanoparticles by water soluble fraction of the extracellular polysaccharides/ matrix of the cyanobacterium *Nostoc commune* and its application as a potent fungal surface sterilizing agent of seed crops. Univ J Microbiol Res. 2014; 2: 36-43.
45. Farias CBB, Silva AF, Rufino RD, Luna JM, Souza JEG, Sarubbo LA. Synthesis of silver nanoparticles using a biosurfactant produced in low-cost medium as stabilizing agent. Electro J Biotechnol. 2014; 17: 122-125.
46. Gahlawat G, Shikha S, Chaddha BS, Chaudhuri SR, Mayilraj S, Choudhury AR. Microbial glycolipoprotein-capped silver nanoparticles as emerging antibacterial agents against cholera. Micro Cell Fact. 2016; 15: 25.
47. Sowani H, Mohite P, Munot H, Shouche Y, Bapat T, Kumar AR, et al. Green synthesis of gold and silver nanoparticles by an actinomycete *Gordonia amicalis* HS-11: mechanistic aspects and biological application. Process Biochem. 2016; 51: 374-383.
48. Mendrek B, Chojniak J, Libera M, Trzebicka B, Bernat P, Paraszkiewicz K, Płaza G. Silver nanoparticles formed in bio- and chemical syntheses with biosurfactant as the stabilizing agent. J Disp Sci Technol. 2017; 38: 1647-1655.
49. Klaus T, Joerger R, Olsson E, Granqvist CG. Silver-based crystalline nanoparticles, microbially fabricated. Proc Natl Acad Sci USA. 1999; 96: 13611-13614.
50. Nanda A, Saravanan M. Biosynthesis of silver nanoparticles from *Staphylococcus aureus* and its antimicrobial activity against MRSA and MRSE. Nanomedicine. 2009; 5: 452-456.
51. Reddy AS, Chen CY, Chen CC, Jean JS, Chen HR, Tseng MJ, et al. Biological synthesis of gold and silver nanoparticles mediated by the bacteria *Bacillus subtilis*. J Nanosci Nanotechnol. 2010; 10: 6567-6574.
52. Shivaji S, Madhu S, Singh S. Extracellular synthesise of antibacterial silver nanoparticles using psychrophilic bacteria. Process Biochem. 2011; 49: 830-837.
53. Wei X, Luo M, Li W, Yang L, Liang X, Xu L, et al. Synthesis of silver nanoparticles by solar irradiation of cell-free *Bacillus amyloliquefaciens* extracts and $AgNO_3$. Bioresour Technol. 2012; 103: 273-278.

54. Saravanan M, Vemu AK, Barik SK. Rapid biosynthesis of silver nanoparticles from *Bacillus megaterium* (NCIM 2326) and their antibacterial activity on multi drug resistant clinical pathogens. Coll Surf B. 2011; 88: 325-331.
55. Priyadarshini S, Gopinath V, Meera Priyadharsshini N, Mubarak Ali D, Velusamy P. Synthesis of anisotropic silver nanoparticles using novel strain, *Bacillus flexus* and its biomedical application. Coll Surf B Biointerface. 2013; 102: 232-237.
56. Das VL, Thomas R, Varghese RT, Soniya EV, Mathew J, Radhakrishnan EK. Extracellular synthesis of silver nanoparticles by the *Bacillus* strain CS 11 isolated from industrialized area. 3. Biotech. 2014; 4: 121-126.
57. Durán N, Priscyla D, Marcato PD, Alves O, De Souza G, Esposito E. Mechanistic aspects of biosynthesis of silver nanoparticles by several *Fusarium oxysporum* strains. J Nanobiotechnol. 2005; 3: 1-7.
58. Ingle A, Gade A, Pierrat S, Sönnichsen C, Rai M. Mycosynthesis of silver nanoparticles using the fungus *Fusarium acuminatum* and its activity against some human pathogenic bacteria. Curr Nanosci. 2008; 4: 141-144.
59. Ingle A, Rai M, Gade A, Bawaskar M. *Fusarium solani*: a novel biological agent for the extracellular synthesis of silver nanoparticles. J Nanopart Res. 2009; 11: 2079-2085.
60. Kathiresan K, Manivannan S, Nabeal MA, Dhivya B. Studies on silver nanoparticles synthesized by a marine fungus, *Pencillium fellutanum* isolated from coastal mangrove sediment. Coll Surf B Biointerface. 2009; 71: 133-137.
61. Durán N, Marcato PD, De Souza GIH, Alves OL, Esposito E. Antibacterial effect of silver nanoparticles produced by fungal process on textile fabrics and their effluent treatment. J Biomed Nanotechnol. 2007; 3: 203-208.
62. Syed A, Saraswati S, Kundu GC, Ahmad A. Biological synthesis of silver nanoparticles using the fungus *Humicola* sp. and evaluation of their cytoxicity using normal and cancer cell lines. Spectro Acta Part A Mol Biomol Spectros. 2013; 114: 144-147.
63. Sanghi R, Verma P. Biomimetic synthesis and characterisation of protein capped silver nanoparticles. Biores Technol. 2009; 100: 501-504.
64. 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. Int J Nanomed. 2013; 8: 4277-4290.
65. Gaidhani SV, Raskar AV, Poddar S, Gosavi S, Sahu PK, Pardesi KR, et al. Time dependent enhanced resistance against antibiotics and metal salts by planktonic and biofilm form of *Acinetobacter haemolyticus* MMC8 clinical isolate. Indian J Med Res. 2014; 140: 665-671.
66. Mouxing F, Qingbiao L, Daohua S, Yinghua L, Ning H, Xu D, et al. Rapid preparation process of silver nanoparticles by bioreduction and their characterizations. Chin J Chem Eng. 2006; 14: 114-117.
67. Wang H, Chen H, Wang Y, Huang J, Kong T, Lin W, et al. Stable silver nanoparticles with narrow size distribution non-enzymatically synthesized by *Aeromonas* sp. SH10 cells in the presence of hydroxyl ions. Curr Nanosci. 2012; 8: 838-846.
68. Thomas R, Jasim B, Mathew J, Radhakrishnan EK. Extracellular synthesis of silver nanoparticles by endophytic *Bordetella* sp. isolated from *Piper nigrum* and its antibacterial activity analysis. Nano Biomed Eng. 2012; 4: 183-187.

69. Karthik C, Radha KV. Biosynthesis and characterization of silver nanoparticles using *Enterobacter aerogenes*: a kinetic approach. Dig J Nanomater Biostruct. 2012; 7: 1007-1014.
70. Gurunathan S, Kalishwaralal K, Vaidyanathan R, Deepak V, Pandian SRK, Muniyandi J, et al. Biosynthesis, purification and characterization of silver nanoparticles using *Escherichia coli*. Coll Surf B Biointerface. 2009; 74: 328-335.
71. Law N, Ansari S, Livens FR, Renshaw JC, Lloyd JR. The formation of nanoscale elemental silver particles via enzymatic reduction by *Geobacter sulfurreducens*. Appl Environ Microbiol. 2008; 4: 7090-7093.
72. Krishnaraj RN, Berchmans S. In vitro antiplatelet activity of silver nanoparticles synthesized using the microorganism *Gluconobacter roseus*: an AFM-based study. RSC Adv. 2013; 3: 8953-8959.
73. Seshadri S, Prakash A, Kowshik M. Biosynthesis of silver nanoparticles by marine bacterium, *Idiomarina* sp. p R58-8. Bull Mater Sci. 2012; 35: 1201-1205.
74. Duraisamy K, Yang SL. Synthesis and characterization of bactericidal silver nanoparticles using cultural filtrate of simulated microgravity grown *Klebsiella pneumoniae*. Enzyme Microb Technol. 2013; 52: 151-156.
75. Parikh RY, Singh S, Prasad BLV, Patole MS, Sastry M, Shouche YS. Extracellular synthesis of crystalline silver nanoparticles and molecular evidence of silver resistance from *Morganella* sp.: towards understanding biochemical synthesis mechanism. Chem Bio Chem. 2008; 9: 1415-1422.
76. Samadi N, Golkaran D, Eslamifar A, Jamalifar H, Fazeli MR, Mohseni FA. Intra/extracellular biosynthesis of silver nanoparticles by an autochthonous strain of *Proteus mirabilis* isolated from photographic waste. J Biomed Nanotechnol. 2009; 5: 247-253.
77. Srivastava SK, Constanti M. Room temperature biogenic synthesis of multiple nanoparticles (Ag, Pd, Fe, Rh, Ni, Ru, Pt Co, and Li) by *Pseudomonas aeruginosa* SM1. J Nanopart Res. 2012; 14: 831-840.
78. Kumar CG, Mamidyala SK. Extracellular synthesis of silver nanoparticles using culture supernatant of *Pseudomonas aeruginosa*. Coll Surf B Biointerface. 2011; 84: 462-466.
79. Otaqsara SMT. Biosynthesis of quasi-spherical Ag nanoparticle by *Pseudomonas aeruginosa* as a bioreducing agent. Eur Phys J Appl Phys. 2011; 56: 30402.
80. Bai HJ, Yang BS, Chai CJ, Yang GE, Jia WL, Yi ZB. Green synthesis of silver nanoparticles using *Rhodobacter sphaeroides*. World J Microbiol Biotechnol. 2011; 27: 2723-2728.
81. Husen A. Gold nanoparticles from plant system: synthesis, characterization and their application. In: Ghorbanpourn M, Manika K, Varma A, eds. Nanoscience and plant-soil systems, vol. 48. Cham: Springer International Publication; 2017: 455-479.
82. Moldovan B, David L, Achim M, Clichici S, Filip GA. A green approach to phytomediated synthesis of silver nanoparticles using *Sambucus nigra* L. fruits extract and their antioxidant activity. J Mol Liq. 2016; 221: 271-278.
83. Syed A, Saraswati S, Kundu GC, Ahmad A. Biological synthesis of silver nanoparticles using the fungus *Humicola* sp. and evaluation of their cytoxicity using normal and cancer cell lines. Spectro Acta Part A Mol Biomol Spectros. 2013; 114: 144-147.
84. Chowdhury S, Basu A, Kundu S. Green synthesis of protein capped silver nanoparticles from phytopathogenic fungus *Macrophomina phaseolina* (Tassi) Goid with antimicrobial properties against multidrug-resistant bacteria. Nano Res Lett. 2014; 9: 365.

85. Shaligram NS, Bule A, Bhambure R, Singhal RS, Singh SK, Szakacs G, Pandey A. Biosynthesis of silver nanoparticles using aqueous extract from the compactin producing fungal strain. Process Biochem. 2009; 44: 939-943.
86. Maliszewska I, Juraszek A, Bielska K. Green synthesis and characterization of silver nanoparticles using ascomycota fungi *Penicillium nalgiovense* AJ12. J Clust Sci. 2014; 25: 989-1004.
87. Vigneshwaran N, Kathe AA, Varadarajan PV, Nachane RP, Balasubramanya RH. Biomimetics of silver nanoparticles by white rot fungus, *Phaenerochaete chrysosporium*. Coll Surf B Interface. 2006; 53: 55-59.
88. Birla SS, Tiwari VV, Gade AK, Ingle AP, Yadav AP, Rai MK. Fabrication of silver nanoparticles by *Phoma glomerata* and its combined effect against *Escherichia coli*, *Pseudomonas aeruginosa* and *Staphylococcus aureus*. Lett Appl Microbiol. 2009; 43: 173-179.
89. Al-Bahrani R, Raman J, Lakshmanan H, Hassan AA, Sabaratnam V. Green synthesis of silver nanoparticles using tree oyster mushroom *Pleurotus ostreatus* and its inhibitory activity against pathogenic bacteria. Mat Lett. 2017; 186: 21-25.
90. Vigneshwaran N, Kathe A. Silver-protein (core-shell) nanoparticle production using spent mushroom substrate. Langmuir. 2007; 23: 7113-7117.
91. Mukherjee P, Roy M, Mandal BP, Dey GK, Mukherjee PK, Ghatak J, et al. Green synthesis of highly stabilized nanocrystalline silver particles by a non-pathogenic and agriculturally important fungus *T. asperellum*. Nanotechnoloy. 2008; 19: 1-7.
92. Vahabi K, Mansoori GA, Karimi S. Biosynthesis of silver nanoparticles by fungus *Trichoderma reesei* (a route for large-scale production of AgNPs). Insci J. 2011; 1: 65-79.
93. Fayaz M, Tiwary CS, Kalaichelvan PT, Venkatesan R. Blue orange light emission from biogenic synthesized silver nanoparticles using *Trichoderma viride*. Coll Surf B Biointerfaces. 2010; 75: 175-178.
94. Kumari M, Pandey S, Giri VP, Bhattacharya A, Shukla R, Mishra A, Nautiyal CS. Tailoring shape and size of biogenic silver nanoparticles to enhance antimicrobial efficacy against MDR bacteria. Microb Pathog. 2017; 105: 346-355.
95. Brayner R. The toxicological impact of nanoparticles. Nanotoday. 2008; 3: 48-55.
96. Panda KK, Achary VMM, Krishnaveni R, Padhi BK, Sarangi SN, Sahu SN, Panda BB. In vitro biosynthesis and genotoxicity bioassay of silver nanoparticles using plants. Toxicol Vitro. 2011; 25: 1097-1105.
97. Jayasree L, Janakiram P, Madhavi R. Characterization of *Vibrio* spp. associated with diseased shrimp from culture ponds of Andhra Pradesh (India). J World Aquacult Soc. 2006; 37: 523-532.
98. Oberdorster E. Manufactured nanomaterials (fullerenes, C60) Induce oxidative stress in the brain of juvenile largemouth bass. Environ Health Perspect. 2004; 112: 1058-1062.
99. Kim S, Ryu DY. Silver nanoparticle-induced oxidative stress, genotoxicity and apoptosis in cultured cells and animal tissues. J Appl Toxicol. 2013; 33: 78-89.
100. Hackenberg S, Scherzed A, Kessler M, Hummel S, Technau A, Froelich K, et al. Silver nanoparticles: evaluation of DNA damage, toxicity and functional impairment in human mesenchymal stem cells. Toxicol Lett. 2011; 201: 27-33.
101. Samberg ME, Loboa EG, Oldenburg SJ, Monteiro-Riviere NA. Silver nanoparticles do not influence stem cell differentiation but cause minimal toxicity. Nanomedicine. 2012; 7: 1197-1209.
102. Kittler S, Greulich C, Diendorf J, Koller M, Epple M. Toxicity of silver nanoparticles increases during storage because of slow dissolution under release of silver ions. Chem Mater. 2010; 22: 4548-4554.

103. Beer C, Foldbjerg R, Hayashi Y, Sutherland DS, Autrup H. Toxicity of silver nanoparticles-nanoparticle or silver ion? Toxicol Lett. 2012; 208: 286-292.
104. Cronholm P, Karlsson HL, Hedberg J, Lowe TA, Winnberg L, Elihn K, et al. Intracellular uptake and toxicity of Ag and CuO nanoparticles: a comparison between nanoparticles and their corresponding metal ions. Small. 2013; 9: 970-982.
105. Rai M, Yadav A, Gade A. Silver nanoparticles as a new generation of antimicrobials. Biotechnol Adv. 2009; 27: 76-83.
106. Agnihotri S, Mukherji S, Mukherji S. Size-controlled silver nanoparticles synthesized over the range 5-100 nm using the same protocol and their antibacterial efficacy. RSC Adv. 2014; 4: 3974-3983.
107. Mendis E, Rajapakse N, Byun HG, Kim SK. Investigation of jumbo squid (*Dosidicus gigas*) skin gelatin peptides for their in vitro antioxidant effects. Life Sci. 2005; 77: 2166-2178.
108. Dibrov P, Dzioba J, Gosink KK, Hase CC. Chemiosmotic mechanism of antimicrobial activity of Ag(+) in *Vibrio cholerae*. Antimicrob Agents Chemother. 2002; 46: 2668-2670.
109. Hamouda T, Myc A, Donovan B, Shih A, Reuter JD, Baker JR Jr. A novel surfactant nanoemulsion with a unique non-irritant topical antimicrobial activity against bacteria, enveloped viruses and fungi. Microbiol Res. 2000; 156: 1-7.
110. Sondi I, Salopek-Sondi B. Silver nanoparticles as antimicrobial agent: a case study on *E. coli* as a model for Gram-negative bacteria. J Coll Interface Sci. 2004; 275: 177-182.