

Review

Nanosilver: Potent antimicrobial agent and its biosynthesis

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Silver ions and its salts are well known for their potent antimicrobial agent. These days, the nanosilver are widely used in a growing number of applications ranging from home disinfectants and medical devices to water purifier due to properties of silver at the nano level. Nanosilver has a large ratio of surface which dramatically increases the potential for silver ions to be accessed anywhere in body where larger silver particles cannot. The synthesis of silver nanoparticles has been reported using chemical and physical methods. This review describes a cost effective and ecofriendly approach for the synthesis of silver nanoparticles. Thus, in this review we focus on the role of microorganisms and plants in the synthesis of nanosilver and their potent application as antimicrobial agent.

Key words: Nanosilver, antimicrobial, disinfectant, nanoparticles.

INTRODUCTION

Nanoscale science is the discipline that examine the unique behaviors and properties of materials that emerge at the size range of 1 to 100 nanometers (a billionth of a meter). Nanobiotechnology is a sub-discipline of nanoscience that has arisen more recently. It manipulates unique behaviors and properties at the nanoscale to manipulate materials for various applications in biology. Nanobiotechnology already impact in medicine as therapeutic agent.

Nanobiotechnology promises to be critical in advances in other related fields. Silver has been valued for many of its properties that are useful for mankind. It is used in precious goods such as currencies, ornaments, jewelry, electrical contacts and photography, among others. The one of the most potent uses of silver as antimicrobial agent that is toxic to bacteria, fungi, and viruses. Due to their size, nanosilver have a very large surface area which typically results in greater biological activity, chemical reactivity and catalytic behavior compared to larger particles of the same chemical composition (Garnett and Kallinteri, 2006; Limbach et al., 2007). Nanotechnology is being utilized in offering many new developments in the

fields of biosensors, biomedicine, bio nanotechnology diagnosis, therapeutic drug delivery and the development of treatments for many diseases and disorders. Nanosilver have novel or enhanced properties based on specific characteristics such as size, distribution and morphology. Nanosilver show potential of applications in various fields such as catalysts in chemical reactions, electrical batteries and in selective coatings for absorption of solar energy, as optical elements, pharmaceutical components and in chemical sensing and biosensing (Kamat, 2002), plasmonics (Maier et al., 2001), optoelectronics (Gracias et al., 2002), biological sensor (Mirkin et al., 1996; Han et al., 2001) and pharmaceutical applications like their potential in drug delivery formulations and routes.

The synthesis of nanosilver has been remarkable developments in the field of nanotechnology from the decade. A large numbers of methods have been reported for the synthesis of nanosilver of particular shape and size depending on specific requirements (Figure 1). Nanosilver was produced by physical and chemical methods. Some of the commonly used physical and chemical

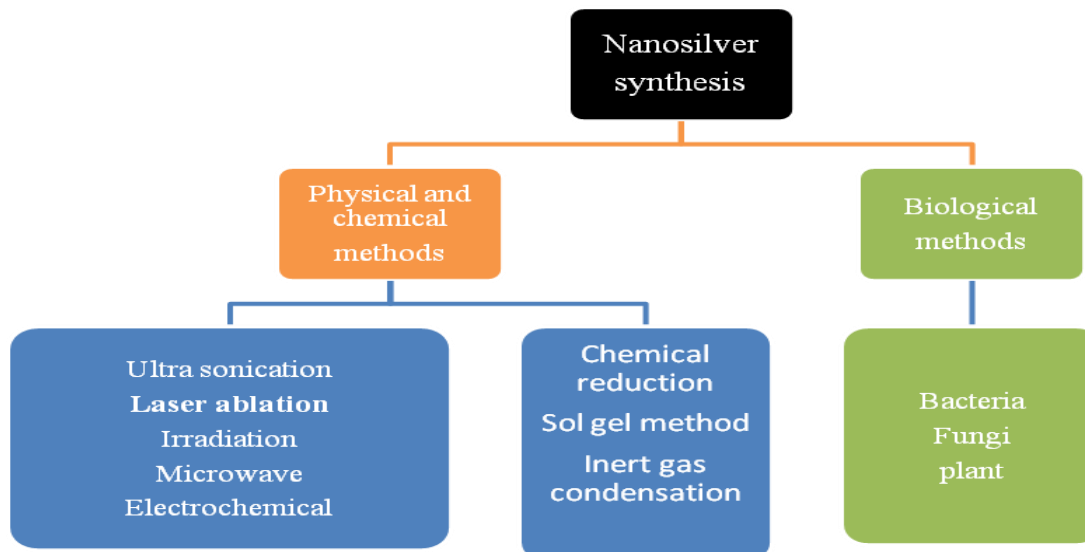


Figure 1. Different methods for nanosilver synthesis.

methods are ion sputtering, thermal synthesis, Inert gas condensation, reduction and sol gel technique.

Unfortunately, nanosilver synthesis involves the use of hazardous chemicals, low material conversions, high energy requirements, difficult and wasteful purifications. Further, the synthesis of nanosilver including physical and chemical processes is costly. Therefore, there is a growing need to develop environmentally friendly processes for nanoparticle synthesis without using toxic chemicals. Biosynthetic methods employing either microorganisms or plant extracts have emerged as a simple and viable alternative to chemical synthetic procedures and physical methods.

The development of cheaper reliable, eco-friendly processes for the synthesis of nanosilver is an important aspect of nanotechnology today. Many biological synthesis protocols have been reported using bacteria (Kalimuthu et al., 2008; Fu et al., 1999) fungi (Bhainsa and D'Souza, 2006; Vigneshwaran et al., 2006; Basavaraja et al., 2008; Kathiresan et al., 2009) and plants (Selwal et al., 2013; Singh et al., 2010; Dubey et al., 2009). In this review, we focus on the biological synthesis of silver nanoparticles, potential and the possible mechanism of antimicrobial actions.

NANOSILVER SYNTHESIS- AN OVERVIEW

Nano silver are one of the promising products in the nanotechnology industry. The development of consistent processes for the synthesis of silver nanoparticles is an important aspect of current nanotechnology research. One of such promising process is green synthesis. Silver nanoparticles can be synthesized by several physical, chemical and biological methods.

However for the past few years, various rapid chemical methods have been replaced by greens synthesis because of avoiding toxicity of the process and increased quality.

Approaches for nanosilver synthesis

Basically there are two approaches for nanoparticle synthesis namely the Bottom up approach and the Top down approach (Figure 2).

Top down approach

In the Top down approach involve production of nanosilver involve mechanical grinding of a bulk piece of the material.

Bottom up approach

The Bottom up approach involves chemical and biological methods to make nanostructures and nanoparticles. These processes involve controlled condensation of solute molecules that are formed during a chemical reaction. The restriction of the condensation or growth leads to the formation of particles of desired size and shape.

Biosynthesis of nanoparticles is a kind of scale down or bottom up approach where the main reaction occurring is reduction/oxidation. The microbial enzymes or the phytochemicals with anti oxidant or reducing properties are usually responsible for reduction of metal compounds into their respective nanoparticles.



Figure 2. The top-down approach versus the bottom-up approach.

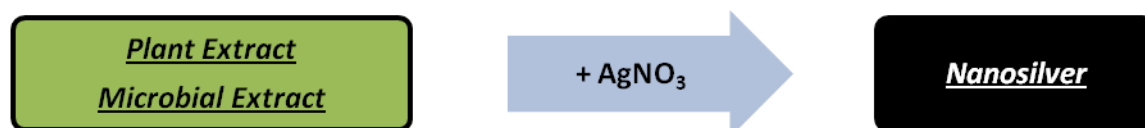


Figure 3. Plant and microbial mediated synthesis of nanosilver.

Physical and chemical methods of nanosilver synthesis

Some of the very successful physical methods for the synthesis of nanoparticles include radiolysis, ultrasonication, laser ablation, microwave and electrochemical methods. However, physical methods have had limited success and therefore chemical methods for the synthesis of inorganic nanoparticles are widely accepted and commonly practiced. Nanosilver can be synthesized chemically by reduction or oxidation of metal ions, inert gas condensation, or by the sol gel methods.

Disadvantages of using physical and chemical methods

The synthesis of nanoparticles including physical and chemical processes is costly. The use of these synthesis methods requires both strong and weak chemical reducing agents and protective agents like sodium borohydride, sodium citrate and alcohols. These agents are mostly toxic, flammable, cannot be easily disposed off due to environmental issues and also show a low production rate.

There is need to search of cheaper path-ways for nanoparticle synthesis, so used microorganisms and plant extracts for synthesis. The biosynthesis of nano-scale nanosilver may contribute to the development of relatively new and largely unexplored area of research.

Biological synthesis of nanosilver

Green plant and microorganisms have a remarkable ability to form exquisite nanosilver. Biological synthesis using plant and microorganisms is eco-friendly and cheaper. Nowadays a large number of microorganisms and plant extracts are used for nanosilver synthesis (Figure 3).

Bacterial mediated synthesis of nanosilver

The probability of the bacterial mediated synthesis of silver nanoparticles has been successfully reported (Table 1). Bacterial cells are used to produce silver nanoparticles. These particles possess interesting physical and chemical properties (Figure 4).

Fungus mediated synthesis of nanosilver

The probability of the fungal system for the synthesis of silver nanoparticles has been successfully demonstrated (Table 2). The fungal system shows the capability of both intracellular and extracellular synthesis of silver nanoparticles. In the recent past, research work using the fungal system has been carried out using both aspects of intracellular and extracellular methods for synthesis of nanosilver.

Plant mediated synthesis of nanosilver

The probability of the plants extract for the synthesis of silver nanoparticles has been successfully reported (Table 3). Plants extracts can be used in the synthesis of silver nanoparticles. However, the mechanism for the synthesis of silver nanoparticle from plants is not yet fully understood. Phytochemicals are assumed to be responsible for the formation of silver nanoparticles.

APPLICATIONS OF NANOSILVER

Nanosilver as powerful antimicrobial

The potent application of nanosilver is use as antimicrobial agent. Nanosilver shows strong antimicrobial activity is a major reason for the development of nano-

Table 1. List of bacteria synthesizing silver nanoparticles.

Bacteria	Size of the particle (nm)	Reference
<i>Bacillus licheniformis</i>	50	Kalimuthu et al., 2008
<i>Bacillus megaterium</i>	46.9	Fu et al., 2009
<i>Pseudomonas stutzeri</i>	200	Tanja et al., 1999
<i>Corynebacterium sp.</i>	10-15	Zhang et al., 2005
<i>Bacillus licheniformis</i>	50	Kalishwaralal et al., 2008
<i>Geobacter sulfurreducens</i>	200	Law et al., 2008
<i>Morganella sp.</i>	20-25	Parikh et al., 2008
<i>Bacillus subtilis</i>	5-60	Saifuddin et al., 2009
<i>Escherichia coli</i>	1-100	Gurunathan et al., 2009b
<i>Klebsiella pneumonia</i>	50	Ahmad et al., 2007
<i>Proteus mirabilis</i>	10-20	Samadi et al., 2009
<i>Bacillus sp.</i>	5-15	Pugazhenthiran et al., 2009
<i>Staphylococcus aureus</i>	1-100	Nanda and Saravanan, 2009
<i>Lactic acid bacteria</i>	11.2	Sintubin et al., 2009
<i>Brevibacterium casei</i>	50	Kalishwaralal et al., 2010
<i>Cryphonectria sp.</i>	30-70 nm	Dar et al., 2013

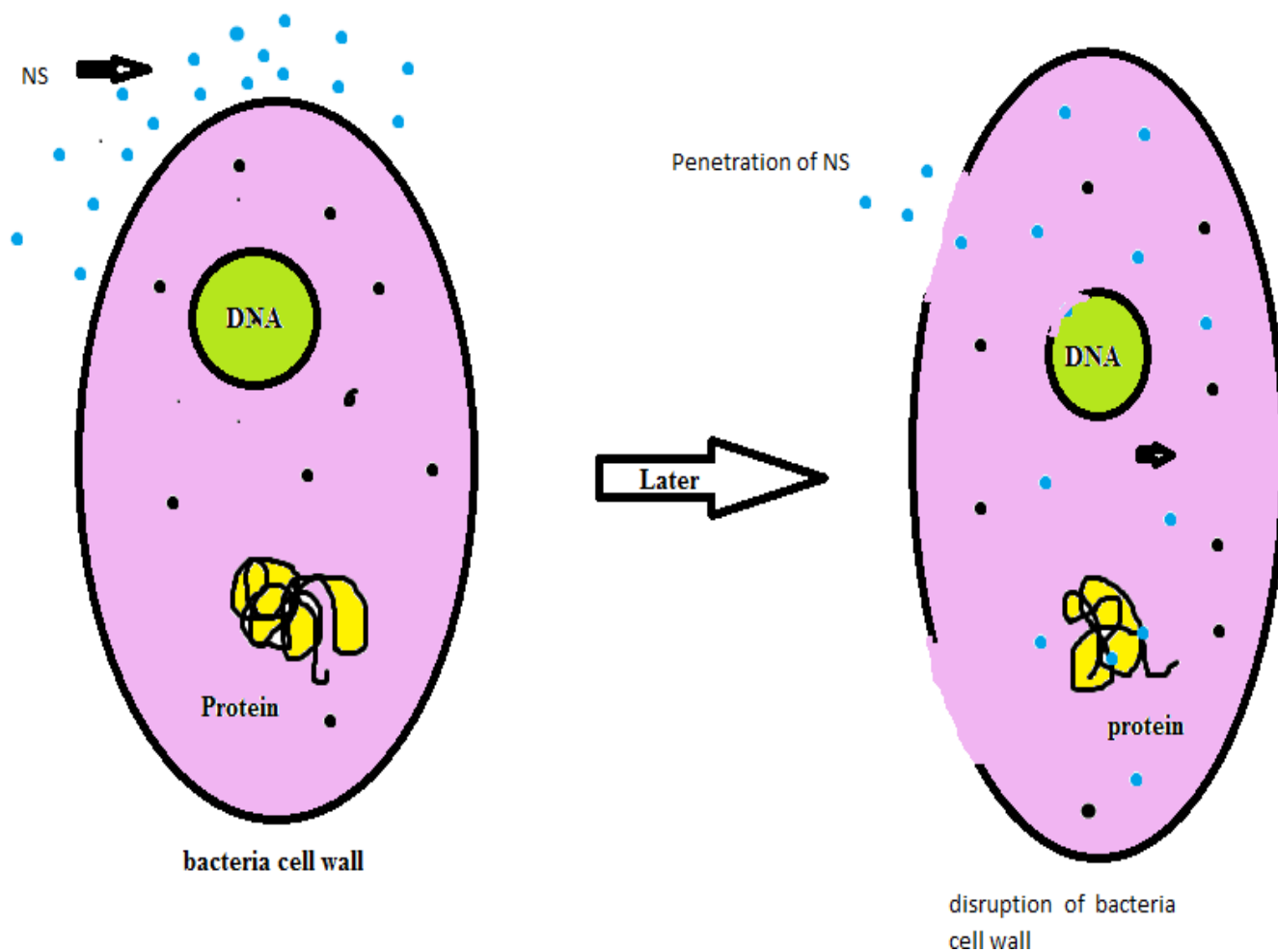
**Figure 4.** Attachment and penetration of nanosilver with bacterial cell membrane.

Table 2. List of Fungi synthesizing silver nanoparticles.

Fungi	Size of the particle (nm)	Reference
<i>Aspergillus fumigates</i>	5-25	Bhainsa et al., 2006
<i>Phaenerochaete chrysosporium</i>	100	Vigenshwaran et al., 2006
<i>Fusarium semitectum</i>	10-60	Basavaraja et al. 2008
<i>Penicillium fellutanum</i>	1-100	Kathiresan et al, 2009
<i>Fusarium oxysporum</i>	5-50	Ahmad et al., 2003
<i>Trichoderma viride</i>	5-40	Fayaz et al., 2010
<i>Fusarium oxysporum</i>	5-40	Kumar et al., 2007
<i>Fusarium semitectum</i>	13-18	Basavaraja et al., 2007
<i>Aspergillus niger</i>	20	Gade et al., 2008
<i>Fusarium acuminatum</i>	5-40	Ingle et al., 2008a
<i>Trichoderma asperellum</i>	13-18	Mukherjee et al., 2008
<i>Penicillium</i>	10-100	Sadowski et al., 2008
<i>Phoma glomerata</i>	60-80	Birla et al., 2009
<i>Fusarium solani</i>	5-35	Ingle et al., 2008b
<i>Coriolus versicolor</i>	67.6-74.52	Sanghi and Verma, 2009
<i>Cladosporium cladosporioides</i>	10-100	Balaji et al., 2009

Table 3. List of plant synthesizing silver nanoparticles.

Plant	Size of the particle (nm)	Reference
<i>Mangifera indica</i>	-	Selwal et al., 2013
<i>Argemone mexicana</i>	10-50	Singh et al., 2009
<i>Eucalyptus hybrid</i> (Safeda)	50-150	Dubey et al., 2009
<i>Brassica juncea</i>	15-25	Lamb et al., 2001
<i>Azadirachta indica</i>	5-100	Shankar et al., 2004
<i>Emblica officinalis</i>	10-20	Ankamwar et al., 2005
<i>Aloe vera</i>	15±4.2	Chandran et al., 2006
<i>Capsicum annum</i>	-	Li et al., 2007
<i>Helianthus annuus</i>	-	Leela and Vivekanandan, 2008
<i>Gliricidia sepium</i>	10-50	Raut et al., 2009
<i>Jatropha curcas</i>	10-20	Bar et al., 2009
<i>Carica papaya</i>	60-80	Mude et al., 2009
<i>Coriandrum sativum</i>	26	Sathyavathi et al., 2010
<i>Artemisia nilagirica</i>	70-90	Vijayakumar et al., 2013
<i>Rhinacanthus nasutus</i>	11.5- 22	Pasupuleti et al., 2013

silver containing products. Nano-silver have used for thousands of years without ill effects. Nanosilver is an effective killing for bacteria, fungus, and viruses.

Nanosilver as antibacterial

Nanosilver is an effective killing agent against a broad spectrum of Gram negative and Gram- positive bacteria (Burrell et al., 1999; Wijnhoven et al., 2009; Yin et al., 1999) including antibiotic-resistant strains (Percival et al.,

2007; Wright et al., 1998). Silver nanoparticles show potential antimicrobial effects against infectious organisms including *Escherichia coli*, *Bacillus subtilis*, *Vibrio cholera*, *Pseudomonas aeruginosa*, *S.typhus*, and *Staphylococcus aureus*. It is important that silver is a natural element that is commonly used throughout the world at low concentrations with no evidence to support a concern for widespread bacterial resistance. Nanosilver has a large surface which increases the potential for silver ions to interact with the bacteria and reduction in size of silver at nanoscale make enable it to be released

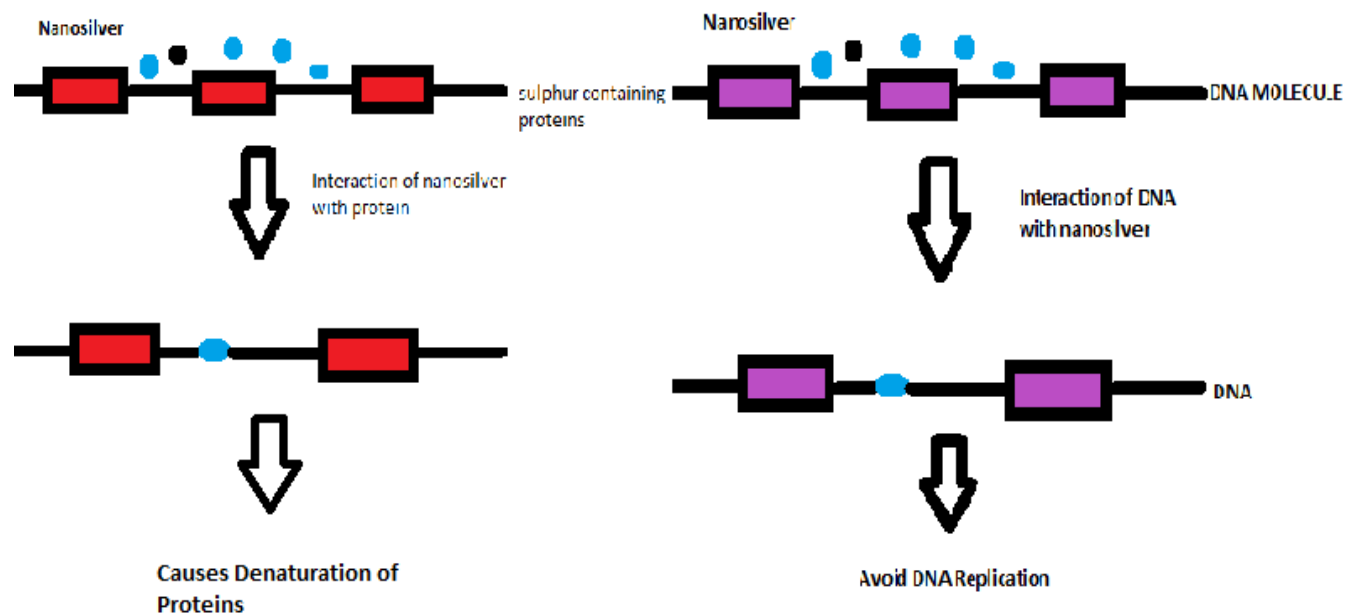


Figure 5. Interaction of nanosilver with proteins and DNA.

anywhere in body where larger silver particles cannot. The exact mechanism of silver nanoparticles is not scientifically justified and is a debated topic. There are however various theories are put forwarded on the possible mechanism for the antimicrobial action of nano silver. The possible mechanisms of action are:

1. Nanosilver as nanometer scale silver provides an extremely large surface area for better contact with bacteria. These silver nanoparticles get attached to the cell membrane and easily penetrate inside the bacteria (Rai et al., 2009).
2. Nanosilver attack the respiratory chain in microbial mitochondria which lead in to the death (Sondi and Salopek-Sondi, 2009).
3. Nanosilver interacts with sulphur containing proteins on microbial cell membrane causing disruption (Liau et al., 1997) (Figures 4 and 5).
4. The surface of microbes having phosphorus containing compound like DNA, nanosilver inhibit their functions (Matsumura et al., 2003).
5. Nanosilver release Ag^+ ion inside the microbial cell which may create free radicals and induce oxidative stress, thus further enhancing their bactericidal activity (Kim et al., 2007).

Nanosilver as antifungal

Nanosilver is an effective, fast-acting fungicide against a broad spectrum of fungi including genera such as *Aspergillus*, *Candida*, and *Saccharomyces*. The mecha-

nisms similar to that of the antibacterial actions have been proposed for fungi (Wright et al., 1999).

Nanosilver as antiviral

Nanosilver (average diameter ~10 nm) inhibit HIV-1 virus replication (Sun et al., 2005). Size- dependent antiviral activity of silver nanoparticles has been shown with HIV-1 virus (Elechiguerra et al., 2005). It is evident that nanosilver due to its biological and physiochemical properties is potent as antimicrobials and therapeutic agents. They can be used for many challenges in the field of nanomedicine.

Nanosilver in medicine

Nanosilver shows potent antibacterial activities against various pathogens and immensely useful in the medical field (Guzman et al., 2012). Earlier studies have suggested that nanosilver can inhibit the gamma interferon and alpha tumor necrosis factor which are involved in inflammation (Shin et al., 2007). These anti-inflammatory responses induced by nanosilver make it an anti-inflammatory agents. Polymethyl methacrylate along with nanosilver is being considered as bone cement as the nanosilver can encourage antimicrobial activity (Bechert et al., 2004). The antimicrobial property of nanosilver shows enormous potential to be used in disinfectants (Brady et al., 2003).

The plasmonic properties of nanosilver can effectively

biosense that makes it ideal biosensors for a large number of proteins that normal biosensors find more difficulty in detections. This unique advantage that nanosilver has, can be utilized for detecting various abnormalities and diseases in the human body including cancer (Moore and Goettmann, 2006; Zhang et al., 2009; Ghodselahi et al., 2011). Due to potent application as antimicrobial agent nanosilver used for development of novel chitin/nanosilver composite scaffolds for wound dressing (Madhumathi et al., 2010), nanosilver are currently being used in many household products such as cloths, washers, water purification systems, tooth paste, shampoo, fabrics, deodorants, filters, paints, kitchen utensils, and toys to impart antimicrobial properties (Baker et al., 2005).

CONCLUSION AND FUTURE PROSPECTS

Silver nanoparticles are conveniently prepared through leaves extract. The biological synthesis of silver nanoparticles is fast, ecofriendly and cheaper. The biological method for synthesis of silver nanoparticles with high antimicrobial activity has been developed. Nanosilver is an excellent antimicrobial and has been used for many years. Chemical and physical methods of nanosilver synthesis have been used for decades, but they are found to be expensive and the use of various toxic chemicals for their synthesis therefore, the biological synthesis is the most preferred option. Plant, bacterial, and fungal extract can be used for nanosilver synthesis, the easy availability, the nontoxic nature, the various options available, and the advantage of quicker synthesis make plant extracts the best and an excellent choice for nanosilver synthesis.

Rapid synthesis and excellent reproducibility of silver nanoparticles from the plant extract is a time saving and advantage over microbial synthesis because laborious and lengthy procedures are involve in mantainace of microbial cultures. Nanosilver contributes into potential application as antimicrobial agent. This has been utilized in various processes in the medical field and has hence been exploited well.

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REFERENCES

- Ahmad A, Mukherjee P, Senapati S, Mandal D, Khan MI, Kumar R (2003). Extracellular biosynthesis of silver nanoparticles using the fungus *Fusarium oxysporum*. Coll. Surf. B. 28:313-318
- Ahmad RS, Sara M, Hamid RS, Hossein J, Ashraf-Asadat N (2007). Rapid synthesis of silver nanoparticles using culture supernatants of Enterobacteria: a novel biological approach. Process Biochem. 42:919-923
- Ankamwar B, Damle C, Ahmad A, Sastry M (2005). Biosynthesis of gold and silver nanoparticles using *Emblica officinalis* fruit extract, their phase transfer and transmetalation in an organic solution. J. Nanosci. Nanotechnol. 5:1665-1671.
- Baker C, Pradhan A, Pakstis L, Pochan DJ, Shah SI (2005). Synthesis and antibacterial properties of silver nanoparticles. J. Nanosci. Nanotechnol. 5:244-249
- Balaji DS, Basavaraja S, Bedre Mahesh D, Prabhakar BK, Venkataraman A (2009). Extracellular biosynthesis of functionalized silver nanoparticles by strains of *Cladosporium cladosporioides*. Coll. Surf. B. 68:88-92.
- Bar H, Bhui DK, Gobinda PS, Priyanka S, Santanu P, Ajay M (2009). Green synthesis of silver nanoparticles using seed extract of *Jatropha curcas*. Colloids Surf A Physico Chem. Eng. Asp. 348:212-216.
- Basavaraja S, Balaji SD, Lagashetty A, Rajasab AH, Venkataraman A (2008). Extracellular biosynthesis of silver nanoparticles using the fungus *Fusarium semitectum*, J. Mater. Res. Bull. 43:1164- 1170.
- Basavaraja S, Balaji SD, Lagashetty A, Rajasab AH, Venkataraman A (2008). Extracellular biosynthesis of silver nanoparticles using the fungus *Fusarium semitectum*. Mater. Res. Bull. 43(5):1164-1170.
- Bechert T, Steinrücke P, Wagener M, Seidel P, Dingeldein E, Scheddin D, Domann E, Schnettler R (2004). Nanoparticulate silver. A new antimicrobial substance for bone cement. Orthopade. 33:885-892.
- Bhainsa KC, D'Souza SF (2006). Extracellular synthesis using the fungus *Aspergillus fumigates*, Coll. Surf. B. 47:152-157.
- Birla SS, Tiwari VV, Gade AK, Ingle AP, Yadav AP, Rai MK (2009). Fabrication of silver nanoparticles by *Phoma glomerata* and its combined effect against *Escherichia coli*, *Pseudomonas aeruginosa* and *Staphylococcus aureus*. Lett. Appl. Microbiol. 48:173-179.
- Brady MJ, Lissay CM, Yurkovetskiy AV, Sarwan SP (2003). Persistent silver disinfectant for environmental control of pathogenic bacteria. Am. J. Infect. Control. 31:208-214
- Burrell RE, Heggors JP, Davis GJ, Wright JB (1999). Efficacy of silver-coated dressings as bacterial barriers in a rodent burn sepsis model. Wounds. 11:64- 71.
- Chandran SP, Chaudhary M, Pasricha R, Ahmad A, Sastry M (2006). Nanotriangles and silver nanoparticles using *Aloe vera* plant extract. Biotechnol. Progr. 22:577-583
- Dar MA, Ingle A, Rai M (2013). Enhanced antimicrobial activity of silver nanoparticles synthesized by *Cryphonectria sp.* evaluated singly and in combination with antibiotics. Nanomed. Nanotechnol. Biol. Med. 9:105-110.
- Dubey M, Bhadauria S, Kushwah BS (2009). Green synthesis of nanosilver particles from extract of *Eucalyptus hybrid* (Safeda) leaf Dig. J. Nanomater. Biostruct. 4:537-543.
- Elechiguerra JL, Burt JL, Morones JR, Camacho-Bragado A, Gao X, Lara HH, Yacaman MJ (2005). Interaction of silver nanoparticles with HIV-1. J. Nanobiotechnol., June 29:3-6.
- Fayaz M, Tiwary CS, Kalaichelvan PT, Venkatesan R (2010). Blue orange light emission from biogenic synthesized silver nanoparticles using *Trichoderma viride*. Coll. Surf. B. 75(1):175-178.
- Fu JK, Zhang WD, Liu YY, Lin ZY, Yao BX, Weng SZ, (1999). Characterization of adsorption and reduction of noble metal ions by bacteria. Chem. J. Chin. Univ. 20:1452-4.
- Gade AK, Bonde P, Ingle AP, Marcato PD, Dura'n N, Rai MK (2008). Exploitation of *Aspergillus niger* for synthesis of silver nanoparticles. J. Biobased Mater Bioenergy. 3:123-129.
- Garnett MC, Kallinteri P (2006). Nanomedicines and nanotoxicology: some physiological principles. Occ. Med. 56:307-311.
- Ghodselahi T, Nejad TN, Vesaghil MA Salimi KZ, Mobasheri H (2011). Synthesis of Silver Nanoparticles Array and Application of Their Localized Surface Plasmon Resonance in Biosensor Design IPCBEE vol.2
- Gracias DH, Tien J, Breen T, Hsu C, Whitesides GM (2002). Forming electrical networks in three dimensions by self assembly, Sci. 289:1170-1172.
- Gurunathan S, Kalishwaralal K, Vaidyanathan R, Venkataraman D, Pandian SRK, Muniyandi J, Hariharan N, Eom SH (2009b). Biosynthesis, purification and characterization of silver nanoparticles

- using *Escherichia coli*. Colloids Surf B. 74(1):328-335
- Guzman M, Dille J, Godet S (2012). Synthesis and antibacterial activity of silver nanoparticles against gram-positive and gram-negative bacteria. Nanomed. Nanotechnol. Biol. Med. 8:35-45.
- Han M, Gao X, Su JZ, Nie S (2001). Quantum-dotted microbeads for multiplexed optical coding of biomolecules, Nature Biotechnol. 19:631-635.
- Ingle A, Rai M, Gade A, Bawaskar M (2008b). *Fusarium solani*: a novel biological agent for the extracellular synthesis of silver nanoparticles. Journal of Nanoparticle Research. 10: in press.
- Ingle AP, Gade AK, Pierrat S, Sønnichsen C, Rai MK (2008a). Mycosynthesis of silver nanoparticles using the fungus *Fusarium acuminatum* and its activity against some human pathogenic bacteria. Curr Nanosci. 4:141-144.
- Kalimuthu K, Babu RS, Venkataraman D, Bilal M, Gurunathan S (2008). Biosynthesis of silver nanocrystals by *Bacillus licheniformis*, Coll. Surf. B. 65:150-153.
- Kalishwaralal K, Deepak V, Pandian SRK, Kottaisamy M, BarathManiKanth S, Kartikeyan B, Gurunathan S (2010). Biosynthesis of silver and gold nanoparticles using *Brevibacterium casei*. Coll. Surf. B. 77(2):257-262
- Kalishwaralal K, Deepak V, RamkumarPandian S, Nellaiah H, Sangiliyandi G (2008). Extracellular biosynthesis of silver nanoparticles by the culture supernatant of *Bacillus licheniformis*. Mater Lett. 62:4411-3
- Kamat PV (2002). Photophysical, photochemical and photocatalytic aspects of metal nanoparticles, J. Phy. Chem. B. 106:7729-7744.
- Kathiresan K, Manivannan S, Nabeal MA, Dhivya B (2009). Studies on silver nanoparticles synthesized by a marine fungus, *Penicillium fellutanum* isolated from coastal mangrove sediment, Coll. Surf. B. 71:133-137.
- Kim JS, Kuk E, Yu KN, Kim JH (2007). Antimicrobial effects of silver nanoparticles, Nanomed.:Nanotechnol., Biol. Med. 3:95-101
- Kumar SA, Ayoobul AA, Absar A, Khan MI, (2007). Extracellular biosynthesis of CdSe quantum dots by the fungus, *Fusarium Oxysporum*. Journal of Biomedical Nanotechnology. 3:190-194.
- Lamb AE, Anderson WN, Haverkamp RG (2001). The induced accumulation of gold in the plants *Brassica juncea*, *Berkheya coddii* and *chicory*. Chem. New Zealand. 9:34-36.
- Law N, Ansari S, Livens FR, Renshaw JC, Lloyd JR (2008). The formation of nano-scale elemental silver particles via enzymatic reduction by *Geobacter sulfurreducens*. Appl. Environ. Microbiol. 74:7090-7093
- Leela A, Vivekanandan M (2008). Tapping the unexploited plant resources for the synthesis of silver nanoparticles. Afr. J. Biotechnol. 7:3162-3165.
- Li S, Qui L, Shen Y, Xie A, Yu X, Zhang L, Zhang Q (2007). Green synthesis of silver nanoparticles using *Capsicum annum* L. extract. Green Chem. 9:852-858.
- Liau SY, Read DC, Pugh WJ, Furr JR, Russell AD (1997). Interaction of silver nitrate with readily identifiable groups: relationship to the antibacterial action of silver ions. Lett. Appl. Microbiol. 25:279-283
- Limbach LK, Wich P, Manser P, Grass RN, Bruinink A, Stark WJ (2007). Exposure of engineered nanoparticles to human lung epithelial cells: influence of chemical composition and catalytic activity on oxidative stress. Environ. Sci. Technol. 41:4158-4163.
- Madhumathi K, Kumar PT, Abhilash S, Sreeja V, Tamura H, Manzoor K, Nair SV, Jayakumar R (2010). Development of novel chitin/nanosilver composite scaffolds for wound dressing applications. J. Mater. Sci. Mater Med. 21:807-813.
- Maier SA, Brongersma ML, Kik PG, Meltzer S, Requicha AAG, Atwater HA (2001). Plasmonics- A Route to Nanoscale Optical Devices, Adv. Mater. 19:1501-1505.
- Matsumura Y, Yoshikata K, Kunisaki SI, Tsuchido T (2003). Appl. Mode of Bactericidal Action of Silver Zeolite and Its Comparison with That of Silver Nitrate. Environ. Microbiol. 69:4278-4281
- Mirkin CA, Letsinger RL, Mucic RC, Strohof JJ (1996). A DNA-based method for rationally assembling nanoparticles into macroscopic materials. Nature 382:607-609.
- Moores A, Goettmann F (2006). The plasmon band in noble metal nanoparticles: an introduction to theory and applications. New J. Chem. 30:1121-1132
- Mude N, Ingle A, Gade A, Rai M (2009). Synthesis of silver nanoparticles using callus extract of *Carica papaya* - a first report. J. Plant Biochem. Biotechnol. 18(1):83-86
- Mukherjee P, Ahmad A, Mandal D, Senapati S, Sainkar SR, Khan MI, Parishcha R, Ajaykumar PV, Alam M, Kumar R, SastryM (2001). Fungus-mediated synthesis of silver nanoparticles and their immobilization in the mycelial matrix: a novel biological approach to nanoparticles synthesis. Nano Lett. 1:515-519
- Nanda A, Saravanan M (2009). Biosynthesis of silver nanoparticles from *Staphylococcus aureus* and its antimicrobial activity against MRSA and MRSE. Nanomedicine 5(4):452-456.
- Parikh RY, Singh S, Prasad BL, Patole MS, Sastry M, Shouche YS (2008). Extracellular synthesis of crystalline silver nanoparticles and molecular evidence of silver resistance from *Morganella*. sp.: towards understanding biochemical synthesis mechanism. Chem. Biochem. 9:1415-1422
- Pasupuleti VR, Prasad TNKV, Shiekh RA, Balam SK, Narasimhulu G, Reddy CS, Rahman IA, Gan SH (2013). Biogenic silver nanoparticles using *Rhinacanthus nasutus* leaf extract: synthesis, spectral analysis, and antimicrobial studies. Int. J. Nanomed. 8:3355-3364.
- Percival SL, Bowler PG, Dolman J (2007). Antimicrobial activity of silver-containing dressings on wound microorganisms using an in vitro biofilm model. Int. Wound. J. 4:186-191
- Pugazhenthiran N, Anandan S, Kathiravan G, Prakash NKU, Crawford S, Ashokkumar M (2009). Microbial synthesis of silver nanoparticles by *Bacillus* sp. J. Nanopart. Res. 11(7):1811-1815
- Rai M, Yadav A, Gade A (2009). Silver nanoparticles as a new generation of antimicrobials. Biotechnol. Adv. 27:76-83
- Raut R, Jaya SL, Niranjan DK, Vijay BM, Kashid S (2009). Photosynthesis of silver nanoparticles using *Gliricidia sepium* (Jacq.). Curr. Nanosci. 5(1):117-122
- Sadowski IH, Maliszewska B, Grochowalska I, Polowczyk T, Koźlecki M (2008). Synthesis of silver nanoparticles using microorganisms, Mater. Sci. Poland 26:2.
- Saifuddin N, Wong CW, AA Nur yasumira (2009) Rapid biosynthesis of silver nanoparticles using culture supernatant of bacteria with microwave irradiation. Eur. J. Chem. 6:61-70
- Samadi N, Golkaran D, Eslamifar A, Jamalifar H, Fazeli MR, Mohseni FA (2009). Intra/extracellular biosynthesis of silver nanoparticles by an autochthonous strain of *Proteus mirabilis* isolated from photographic waste. J. Biomed. Nanotechnol. 5(3):247-253
- Sanghi R, Verma P (2009). Biomimetic synthesis and characterisation of protein capped silver nanoparticles. Bioresour. Technol. 100:501-504.
- Sathyavathi R, Krishna MB, Rao SV, Saritha R, Rao DN (2010). Biosynthesis of silver nanoparticles using *Coriandrum sativum* leaf extract and their application in nonlinear optics. Adv. Sci. Lett. 3(2):138-143
- Selwal KK, Sarsar V, Selwal MK (2013). Green synthesis of silver nanoparticles using leaf extract of *Mangifera indica* and evaluation of their antimicrobial activity J. Microbiol. Biotech. Res. 3 (5):27-32
- Shankar SS, Rai A, Ahmad A, SastryM (2004). Rapid synthesis of Au, Ag and bimetallic Au core-Ag shell nanoparticles using Neem (*Azadirachta indica*) leaf broth. J. Coll. Int. Sci. 275:496-502
- Shin SH, Ye MK, Kim HS, Kang HS (2007). The effects of nano-silver on the proliferation and cytokine expression by peripheral blood mononuclear cells. Int. Immunopharmacol. 7:1813-1818
- Singh A, Jain D, Upadhyay M, Khandelwal N (2010). Green synthesis of silver nanoparticles using *Argemone mexicana* leaf extract and evaluation of their antimicrobial activities. J. Nanomater. 5:483-489.
- Sintubin L, De Windt W, Dick J, Mast J, Ha DV, Verstraete W, Boon N (2009). Lactic acid bacteria as reducing and capping agent for the fast and efficient production of silver nanoparticles. Appl. Microbiol. Biotechnol. 84(4):741-749
- Sondi I, Salopek-Sondi B (2009). Silver nanoparticles as antimicrobial agent: a case study on *E. coli* as a model for Gram-negative bacteria. J. Colloid Interface Sci. 275:177-82.
- Sun RW, Chen R, Chung NP, Ho CM, Lin CL, Che CM (2005). Silver nanoparticles fabricated in HEPES buffer exhibit cytoprotective activities toward HIV-1 infected cells. Chem. Commun. (Camb.):5059-5061.
- Tanja K, Ralph J, Eva O, Claes-Gé (1999). Silver-based crystalline

- nanoparticles, microbially fabricated. Proc Natl. Acad. Sci. 96:13611-13614
- Vigenshwaran N, Kathe A, Nacahe PV, Balasubramanya RH (2006). Biomimetics of silver nanoparticles by white rot fungus, *Phanerochaete chrysosporium*, Coll. Surf. B. 53:55-59.
- Vijayakumar M, Priya K, Nancy FT, Noorlidah A, Ahmed ABA (2013). Biosynthesis, characterization and anti-bacterial effect of plant-mediated silver nanoparticles using *Artemisia nilagirica*. Ind. Crop. Prod. 41:235-240.
- Wijnhoven SWP, Peijnenburg WJGM, Herberts CA, Hagens WI, Oomen AG, Heugens EHW, Roszek B, Bisschops J, Gosens I, Van de Meent D, Dekkers S, De Jong WH, Zijverden M, Sips AJAM, Geertsma RE (2009). Nanosilver - a review of available data and knowledge gaps in human and environmental risk assessment. Nanotoxicology. 3(2):109-138.
- Wright JB, Lam K, Burrell RE (1998). Wound management in an era of increasing bacterial antibiotic resistance: A role for topical silver treatment. Am. J. Infect. Control. 26:572-577.
- Wright JB, Lam K, Hansen D, Burrell RE (1999). Efficacy of topical silver against fungal burn wound pathogens. Am. J. Infect. Control 27:344-350.
- Yin HQ, Langford R, Burrell RE (1999). Comparative evaluation of the antimicrobial activity of Acticoat antimicrobial barrier dressing. J. Burn Care Rehabil. 20:195-200.
- Zhang H, Li Q, Lu Y, Sun D, Lin X, Deng X (2005). Biosorption and bioreduction of diamine silver complex by *Corynebacterium*. J. Chem. Technol. Biotechnol. 80:285-290.
- Zhang Y, Zhang K, Haiyan Ma (2009). Electrochemical DNA biosensor based on silver nanoparticles/poly(3-(3-pyridyl) acrylic acid)/carbon nanotubes modified electrode. Anal. Biochem. 387:13-19