Research Article

Humaira Rizwana, Mona S. Alwhibi, Hadeel A. Aldarson, Manal Ahmed Awad, Dina A. Soliman, and Ramesa Shafi Bhat*

Green synthesis, characterization, and antimicrobial activity of silver nanoparticles prepared using *Trigonella foenum-graecum* L. leaves grown in Saudi Arabia

https://doi.org/10.1515/gps-2021-0043
received March 09, 2021; accepted June 17, 2021

**Abstract:** Silver nanoparticles (AgNPs) are widely used for medical applications particularly as antimicrobial agents against multidrug-resistant microbial strains. Some plants stimulate the reduction of Ag ions to AgNPs. In this study, we prepared AgNPs via the green synthesis approach using fenugreek leaves grown in Saudi Arabia. Furthermore, we characterized these AgNPs and evaluated their antimicrobial activities against pathogenic yeast, bacteria, and fungi.

The ultraviolet-visible peak at 380 nm confirmed the biosynthesis of NPs. Transmission electron microscopy analyses revealed particle size in the range of 9–57 nm with a spherical shape. Dynamic light scattering results confirm slight aggregation as the average particle size was shown as 68.71 nm and a polydispersity index of 0.083. The energy-dispersive X-ray spectroscopy results showed an intense peak at 3 keV, indicating the presence of elemental AgNPs. The synthesized AgNPs efficiently inhibit the growth of both Gram-positive and Gram-negative bacteria; however, varying degree of inhibition was shown toward fungi. The potent antimicrobial ability of the synthesized NPs can be attributed to their small size and round shape. Among all test organisms, the growth of *Candida albicans* and *Helminthosporium sativum* was remarkably affected by AgNPs treatment.

**Keywords:** green synthesis, *Trigonella foenum-graecum* L., silver nanoparticles, antimicrobial activity

1 Introduction

The emergence of multidrug-resistant strains of various pathogens like fungi, bacteria, and viruses has raised serious concern globally [1]. According to WHO, intensive and indiscriminate use of antimicrobials has led to the exponential increase in multidrug resistance [2], limiting the line of treatment [3]. Hence, alternative approaches to develop new antimicrobial or modify the existing ones are being researched with high priority.

Nanoparticles (NPs) have been widely explored and studied, thus opening new perspectives in the field of medicine, especially against multidrug resistance. Various metal NPs and nanocomposites like iron oxide [4], copper oxide [5], zinc oxide [6], graphene oxide [7], gold [8], and silver oxide have been used in different fields like medicine, agriculture, paint, and packaging industries [9–11]. Among them, silver nanoparticles (AgNPs) have been applied and exploited the most giving promising results against drug-resistant microbes. Recent studies have shown excellent antimicrobial activity of AgNPs against bacteria in synergism with antibiotics at concentrations that were not cytotoxic to human cells [12]. Many scientific communities started using AgNPs in therapeutic applications especially in many commercial items like soap, catheters, and bandages to curb infection against pathogenic agents [13–17]. Also, some surgical instruments, face masks, and bone cementing materials are incorporated with AgNPs for their excellent antibacterial properties [13,14]. Nowadays, silver sulfadiazine is being replaced by silver NPs for wound healing treatment [16].

Nanobiotechnology deals with the synthesis of metal NPs via nontoxic and ecofriendly methods using the solvent medium, reducing agent, and nontoxic NP stabilizer [18]. In the past few years, different methods have been employed to synthesize NPs, of which the biogenic method using plant extracts as reducing agents has drawn a lot of
attention. Although many chemical and physical methods are employed to synthesize AgNPs, these methods either require high energy or may produce toxic by-products [19,20], which are not encouraging for biomedical uses. This has prompted new investigations in the field of green synthesis [21]. Plants are a good source of active compounds, which can stimulate the reduction of Ag ions to AgNPs [22]. Although the exact mechanism for bioreduction still needs further elucidation, various studies have shown the safe, effective, and eco-friendly application of green synthesized AgNPs in the field of biomedicine [23–25].

Almost all the parts of plants like leaves, roots, and seeds can act as potential reducing agents during the synthesis of AgNPs without using any catalyst or a stabilizer [26]. Plants contain various active biomolecules such as amino acids, alkaloids, proteins, polysaccharides, phenolics, terpenoids, and flavones, which act as reducing and capping agents [27]. Among these biomolecules, phenols and flavonoids exhibit unique chemical properties and can reduce and wrap NPs. This is because these biomolecules contain hydroxyl and carboxyl groups, which can bind to the metal [28].

Fenugreek (*Trigonella Foenum-graecum L.*) also called as Helba in Arab countries is an herb that belongs to the Leguminosae family. This plant is used in Chinese and Ayurvedic medicines to treat many diseases in humans due to its antibacterial properties. Fenugreek (*T. foenum-graecum L.*) leaves have been used by humans since ancient times because of their medicinal properties. These leaves are rich in flavonoids, alkaloids, vitamins, and amino acids and are known to normalize blood glucose, blood lipids, and plasma cholesterol levels in patients. Different kinds of fungi are sensitive toward defensin proteins present in fenugreek leaves. In Saudi Arabia, fenugreek leaves are commonly used to ease childbirth and to increase breast milk production in lactating mothers.

It is well known that a plant grown under different climatic conditions shows different active components [29,30]. A study by Al-Jasass and Al-Jasser [31] demonstrated that fenugreek grown in Saudi Arabia is rich in nutrients and contains appreciable amounts of bioactive compounds. Hence, in this study, we used fenugreek grown in Saudi Arabia for the synthesis of AgNPs. We also evaluated the antimicrobial activity of the synthesized AgNPs.

## 2 Material and methods

### 2.1 Leaf extract

Fresh green leaves of fenugreek cultivated in the Qaseem region of Saudi Arabia were used in this study. Ten grams of healthy leaves were washed, chopped, and stirred at 70°C in 0.1 L of double-distilled water (1:10 volume/weight ratio) for half an hour. After cooling to room temperature, the broth was filtered and stored at 4°C. The plant was identified by Professor Najat Bukhari and Dr Mona Al Wahibi – Taxonomist, Department of Botany and Microbiology, King Saud University.

### 2.2 Biosynthesis of AgNPs

The freshly prepared leaf extract was added to the silver nitrate solution with a final concentration of 5 mM. The reduction of Ag ions to AgNPs in the plant extract was monitored through the color change from yellow to brown and was confirmed by the UV-visible spectroscopy (UV-Vis) analysis (Figure 1).

### 2.3 Characterization of the prepared NPs

The synthesis of AgNPs was further ascertained by using the UV-Vis spectrophotometer (Thermo Scientific 1500, USA) at different intervals for 3 h. The absorbance of the reaction mixture was measured over the range of 200–700 nm. The FTIR (functional group) analysis of the extract and the synthesized NPs was carried out by FTIR spectrometer at a scan range of 400–4,000 cm⁻¹ (Thermo Scientific-Nicolet-6700, USA). The average size of NPs was measured by Zeta sizer (Nano–ZS-90 Malvern) after diluting the samples with pure water. Transmission electron microscopy (TEM) was also used for determining the average size of the synthesized AgNPs. The samples were prepared by placing a drop of the synthesized AgNPs on a grid coated with copper and imaged under the transmission electron microscope (JEOL JEM-1400 Plus). The elemental composition of NPs was determined by the EDX analysis. A thin film of AgNPs was prepared on a glass slide by adding the sample dropwise and allowing the solvent to evaporate after which it was coated with platinum and observed under the FESEM (FESEM-JSM-7610F, JAPAN).

### 2.4 Antimicrobial activity

The bacterial strains and *Candida* used in this study were provided by King Khalid Hospital, Riyadh Saudi Arabia. *Staphylococcus aureus* (Gram positive), *Escherichia coli*,...
Pseudomonas aeruginosa (Gram negative), Candida albicans (yeast), Helminthosporium sativum, Fusarium solani, Fusarium oxysporum, and Alternaria alternata were provided by the Department of Botany and Microbiology, King Saud University. The antibacterial activity of the synthesized AgNPs against bacteria and C. albicans was evaluated using the well diffusion method. Conversely, the antifungal activity of the synthesized AgNPs against fungi was evaluated using the poison food method. The overnight prepared suspensions of bacteria and Candida (0.5 McFarland; 10^6 CFU mL^{-1}) were aseptically spread on Muller Hinton agar plates with the help of sterile cotton swabs. After drying, 6 mm wells were punched in the lawn agar with a sterile cork borer. Each well was loaded with 50 µL of the synthesized NPs. The treated culture plates were incubated at 37°C for 24 h, after which the diameter of the clear area around each well was measured (in millimeters). This area represented the zone of inhibition. The in vitro antifungal assay of the synthesized NPs was carried out using potato dextrose agar (PDA). The synthesized NPs (1 mL) were placed on a 9 cm Petri plate followed by the addition of 19 mL of molten PDA. After the solidification of the media, a fungal plug (6 mm) was placed at the center. The plate was then incubated at 28 ± 2°C until it showed full growth. The radial growth of the fungal mycelium was measured for all the fungi used in this study, and the percentage of growth inhibition was calculated as follows:

\[ PI = CR - RI/C, \]

where CR is the radial growth of fungal mycelia on the control plate and RI is the radial growth of fungal mycelia on the plate treated with AgNPs.

2.4.1 Statistical analysis

All experiments were carried out in triplicate, and the results are reported as means ± SD. Values of percentage mycelial growth inhibition were subjected to analysis of variance and Turkey HSD test, and the difference between the values was considered significant at \( P < 0.05 \).

3 Results and discussion

NPs interact with specific wavelengths of light depending on their size, shape, and cluster state. Hence, UV-Vis spectroscopy is a primary technique for confirming the synthesis of NPs. In this study, the reduction of Ag ions to AgNPs with the help of plant extract was indicated by the color change of the reaction mixture (from yellow to brown), as shown in Figure 1a. The mixture showed a surface plasmon resonance (SPR) peak at 380 nm, confirming the presence of AgNPs. AgNPs can show SPR peak between 380 and 470 nm subjected to their size and shape as small-sized AgNPs absorbed at smaller wavelength [32]. SPR is due to free electrons vibrating in metal NPs resonating with the light waves. The absorption of NPs is related to their particle size. A decrease in the size of NPs shifts their SPR peak toward shorter wavelengths [33].

Fenugreek leaves are rich in active compounds [34], which can facilitate the green synthesis of NPs. Plant sources that are rich in active secondary metabolites act as capping agents due to which aggregation of synthesized nanoparticles is reduced [35]. These active compounds can
be analyzed by IR spectroscopy. The green method of synthesizing metal NPs is a three-step process. It begins with the activation phase where metal ions in salt are reduced with the help of reducing agents present in the plant extract. In the growth phase, reduced metal ions combine to form NPs. NPs are finally capped by plant metabolites for stability [36]. The IR spectrum (Figure 2a) of the extract shows peaks at 3,396 cm⁻¹, which corresponds to the OH stretching due to phenols, and a strong peak at 1,603 and 1,410 cm⁻¹ is due to N–H and C–H bending corresponding to amide and aromatic groups. A peak at 1,075 cm⁻¹ is due to the C=C stretch. However, the IR spectrum of the synthesized NP (Figure 2b) shows a shift in the peaks and also the appearance of a new peak at 2,927 cm⁻¹. The peaks at 3,396 and 1,603 cm⁻¹ in leaf extract were replaced by peaks at 3,430 and 1,622 cm⁻¹.

Figure 2: IR spectra of (a) *Trigonella foenum-graecum* aqueous leaf extract and (b) AgNPs.
respectively in synthesized NP. The resulting peaks in NP were much narrower and less intense, thus indicating encapsulation. The reduction and capping of the synthesized AgNPs might be due to the presence of phenols, flavonoids, carboxylic, or amide groups, which were seen in the IR spectrum. Previous reports on fenugreek have shown polyphenols as a major phytoconstituents [37,38].

Similar to our findings, the IR spectrum of AgNPs synthesized from seeds of fenugreek had shown the presence of OH, COOH, and N=O groups [39].

In this study, we used dynamic light scattering (DLS) to determine the particle size distribution of the synthesized AgNPs (Figure 3a and b). The Z-average mean size of the synthesized AgNPs was 68.71 nm, and the polydispersity index (PDI) was 0.083. DLS is an efficient technique to determine the PDI of NPs. The size of the NPs prepared in this study was satisfactory because PDI values of more than 0.7 indicate a broad size distribution [31]. The particle size of AgNPs ranged from 9 to 57 nm (Figure 4), which is in agreement with the zeta size readings to some extent. Our results showed the low PDI value, which indicates low aggregation, but DLS shows the hydrodynamic diameter that includes core plus any molecule attached or adsorbed on the surface unlike TEM, which gives the size of NPs in a dried form [40].

The energy-dispersive spectrum (EDX) of the synthesized NPs exhibited strong signals in the silver region, and an absorption peak was observed at 3 keV (Figure 5). The peak in this region is due to SPR, indicating the formation of AgNPs [41]. The weight percent of silver was 10.

The presence of other elements including carbon, oxygen, chlorine, potassium, and calcium was also observed in the
Figure 5: EDX elemental analysis of the AgNPs.

Figure 6: (a) Antimicrobial activity of the *Trigonella foenum-graecum* aqueous leaf extract and synthesized AgNPs and (b) antifungal activity of the *T. foenum-graecum* aqueous leaf extract and synthesized AgNPs. Ampicillin was used as a standard antibiotic for bacteria; fluconazole was used as a standard antifungal against *Candida albicans*; and carbendazim as a standard antifungal against fungi. The value shown represents the mean of the three replicates (±SD). Significant difference in means (*P* < 0.05) was determined by analysis of variance.
spectrum with the weight percent of 53, 31, 3, 2, and 1 wt%, respectively.

AgNPs are used as antimicrobial agents in detergents and disinfectants because many pathogenic microbes including bacteria, fungi, and yeast are resistant to chemical fungicides and disinfectants [42]. In this study, we evaluated the antimicrobial efficiency of AgNPs against pathogenic bacteria, fungi, and yeast. AgNPs significantly inhibited the growth of both the Gram-positive and Gram-negative bacteria (Figure 6). However, varying degree of inhibition was shown toward fungi. This antibacterial efficacy of the synthesized NPs can be attributed to their small size and round shape. Our results are consistent with the previous reports that suggest the potent antimicrobial activity of synthesized NP, which was attributed to their small size and round shape [43–46]. Hence, the significant antibacterial efficacy of the AgNPs observed in the present study indicates that NPs could penetrate the thick and rigid cell walls of Gram-positive bacteria and also the tough lipopolysaccharide membrane of Gram-negative bacteria, unlike many other plant-synthesized NPs that are potent only against Gram-negative bacteria [47, 48]. The antibacterial properties of the plant-derived AgNPs can be also be attributed to their ability to permeate the cell and interact with the genetic material (DNA) and other important constituents, thereby disturbing its integrity, which ultimately leads to cell death. In addition, the adherence of NPs to negatively charged cell surfaces alters the chemical and physical properties of the cell wall and the membrane. These changes affect the stability of the cell by disturbing its osmoregulation, permeability, respiration, and electron transport [49–51]. A recent study shows that the AgNPs synthesized from fenugreek caused bacterial cell death due to maximum leakage of proteins in the 4 h of treatment due to an increase in the cell membrane permeability.

AgNPs synthesized in this study significantly inhibited the growth of C. albicans. Similar findings have been reported earlier with Candida sp. [52]. Panacek et al. [53] reported that even low concentrations of AgNPs can significantly inhibit the growth of fungi. They also reported that AgNPs do not show toxicity toward human antifungal drugs used for controlling several pathogenic fungi. The plant-derived AgNPs have also been reported to be effective for controlling plant pathogenic fungi such as Magnaporthe grisea and Bipolaris sorokiniana [54]. Botrytis cinerea and Alternaria alternata treated with AgNPs show severe damaging effects on conidial and hyphal structures [55]. Similarly, wood-degrading fungi such as Chaetomium globosum, Gloeophyllum abietinum, and Phanerochaete sordida are significantly inhibited by biogenic AgNPs [56]. However, the mechanism underlying the inhibition of the fungal growth by AgNPs is unclear. Some studies have reported that AgNPs reduce the ergosterol level of fungal cells. Since ergosterol plays a vital role in cell functioning, any disturbance in its concentration leads to the instability of the cell structure, which may result in cell damage or cell death [57].

4 Conclusion

Fenugreek leaves extract act as a reducing and stabilizing agent in the process of synthesizing AgNPs. Prepared NPs were of small size and round shape and validating were a potential excellent antifungal and antibacterial agent.

Acknowledgment: The author extends their appreciation to the researchers supporting project number (RSP-2021/173) of King Saud University Riyadh Saudi Arabia.

Funding information: The author extends their appreciation to the researchers supporting project number (RSP-2021/173) of King Saud University Riyadh Saudi Arabia.

Author contributions: Humaira Rizwana: project administration; Mona S. Alwibi: project administration and resources; Hadeel A. Aldarsone: methodology; Manal Ahmed Awad: methodology; Dina A. Soliman: methodology; Ramesha Shafi Bhat: writing – original draft.

Conflict of interest: The authors state no conflict of interest.

References

[1] Tenover FC. Mechanisms of antimicrobial resistance in bacteria. Am J Med. 2006;119(6 Suppl 1):53–10. Discussion S62–70. doi: 10.1016/j.amjmed.2006.03.011. PMID: 16735149.
[2] World Health Organization. 10 Facts on antimicrobial resistance; 2018. Available online: http://www.who.int/features/factfiles/antimicrobial_resistance/en/ [accessed on 10 June 2018].
[3] Roca I, Akova M, Baquero F, Carlet J, Cavalieri M, Coenen S, et al. The global threat of antimicrobial resistance: science for intervention. N Microbes N Infect. 2015 16;6:22–9. doi: 10.1016/j.mmni.2015.02.007.
[4] Dinali R, Ebrahiminejad A, Manley-Harris M, Ghasemi Y, Berenjian A. Iron oxide nanoparticles in modern microbiology and biotechnology. Crit Rev Microbiol. 2017 Aug;43(4):493–507. doi: 10.1080/1040841X.2016.12677085.
Ingle AP, Duran N, Rai M. Bioactivity, mechanism of action, and cytotoxicity of copper-based nanoparticles: a review. Appl Microbiol Biotechnol. 2014;98:1001–9.

Gao Y, Arokiya Vijaya Anand M, Ramachandran V, Karthikkumar V, Shalini V, Vijayalakshmi S, et al. Biofabrication of zinc oxide nanoparticles from aspergillus niger, their antioxidant, antimicrobial and anticancer activity. J Clust Sci. 2019;30:937–46.

Mariadoss AVA, Saravanakumar K, Sathiyaseelan A, Wang MH. Preparation, characterization and anti-cancer activity of graphene oxide-silver nanocomposite. J Photochem Photobiol B. 2020;210:111984.

Peng J, Liang X. Progress in research on gold nanoparticles in cancer management. Med (Baltim). 2019;98(18):e15311. doi: 10.1097/MD.0000000000015311.

Ertem E, Gutt B, Zuber F, Allegri S, Le Ouay B, Mefti S, et al. Green synthesis of metal and metal oxide nanoparticles using whole cells of geotrichum candidum. Nanopart. 2013;7:1–6. doi: 10.1155/2013/150414.

Gao Y, Arokia Vijaya Anand M, Ramachandran V, Karthikkumar V, Shalini V, Vijayalakshmi S, et al. Biofabrication of zinc oxide nanoparticles from aspergillus niger, their antioxidant, antimicrobial and anticancer activity. J Clust Sci. 2019;30:937–46.

Mariadoss AVA, Saravanakumar K, Sathiyaseelan A, Wang MH. Preparation, characterization and anti-cancer activity of graphene oxide-silver nanocomposite. J Photochem Photobiol B. 2020;210:111984.

Peng J, Liang X. Progress in research on gold nanoparticles in cancer management. Med (Baltim). 2019;98(18):e15311. doi: 10.1097/MD.0000000000015311.

Ertem E, Gutt B, Zuber F, Allegri S, Le Ouay B, Mefti S, et al. Core-shell silver nanoparticles in endodontic disinfec-
solutions enable long-term antimicrobial effect on oral biofilms. ACS Appl Mater Interfaces. 2017 11;9(40):34762–72. 10.1021/acsami.7b13929.

Nakazato G, Kobayashi , R, Seabra AB, Duran N. Use of nanoparticles as a potential antimicrobial for food packaging. In: Grumezescu A, editor. Food preservation. 1st ed. Cambridge, MA, USA: Academic Press; 2016.

Holtz RD, Lima BA, Filho AGS, Brocchi M, Alves OL. Nanostructured silver vanadate as a promising antibacterial additive to water-based paints. Nanomod Nanomed NBM. 2012;8:935–40.

Abo-Shama UH, El-Gendy H, Moussa WS, Hamouda RA, Yousuf WE, Hetta HF, et al. Synergistic and antagonistic effects of metal nanoparticles in combination with antibiotics against some reference strains of pathogenic microorganisms. Infect Drug Resist. 2020 7;13:351–62. doi: 10.2147/IDR.S524425.

Lee SH, Jun BH. Silver nanoparticles: synthesis and application for nanomedicine. Int J Mol Sci. 2019 17;20(4):865. doi: 10.3390/ijms20040865.

Pascuci B, Negrea A, Ciopoec M, Davidescu CM, Negrea P, Gherman V, et al. New generation of antibacterial products based on colloidal silver. Mater Today. 2020;29:1578.

Nakamura S, Sato M, Sato Y, Ando N, Takayama T, Fujita M, et al. Synthesis and application of silver nanoparticles (Ag NPs) for the prevention of infection in healthcare workers. Int J Mol Sci. 2019 24;20(15):3620. doi: 10.3390/ijms20153620.

Paladini F, Pollini, M. Antimicrobial silver nanoparticles for wound healing application: progress and future trends. Mater (Basel). 2019;12(16):2540. doi: 10.3390/ma12162540.

Butrón Téllez Girón C, Hernández Sierra JF, DeAlba-Montero I, Urbano Peña MLA, Ruiz F. Therapeutic use of silver nanoparticles in the prevention and arrest of dental caries. Bioinorg Chem Appl. 2020;12:8882930.

Mariadoss AVA, Ramachandran V, Shalini V, Agilan B, Franklin JH, Sanjay K, et al. Green synthesis, characterization and antibacterial activity of silver nanoparticles by Malus domestica and its cytotoxic effect on (MCF-7) cell line. Microb Pathog. 2019;135:103609.

El Shafey AM. Green synthesis of metal and metal oxide nanoparticles from plant leaf extracts and their applications: a review. Green Process Synth. 2020;9:304–39. doi: 10.1515/gps-2020-0031.
Eaton P, Quaresma P, Soares C, de Almeida MP, Moramics G, Siram K, Maqbool Q, Selvakesavan RK, Kruschka D, Wani SA, Kumar P. Fenugreek: a review on its nutraceutical properties and utilization in various food products. J Saudi Soc Nanopart. 2014;2014:302429. doi: 10.1155/2014/302429.

Varghese R, Almalki MA, Ilavenil S, Rebecca J, Choi KC. Silver nanoparticles: a review on its nutraceutical properties and utilization in various food products. J Saudi Soc Agric Sci. 2018;17(2):97–106. doi: 10.1016/j.jsas.2016.01.007.

Devasena T, Nathiya S, Durga M. Therapeutic role of Trigonella foenum-graecum [fenugreek] – a review. Int J Pharm Sci Res. 2014;5:74–80.

Varghese R, Almalki MA, Ilavenil S, Rebecca J, Choi KC. Silver nanoparticles synthesized using the seed extract of Trigonella foenum-graecum L. and their antimicrobial mechanism and anticancer properties. Saudi J Biol Sci. 2019;26:148–54.

Clayton KN, Salameh JW, Wereley ST, Kizner-Ursem TL. Physical characterization of nanoparticle size and surface modification using particle scattering diffusimetry. Biomicrofluidics. 2016 Sep 21;10(5):054107. doi: 10.1063/1.4962992.

Eaton P, Quaresma P, Soares C, Neves C, de Almeida MP, Pereira E, et al. A direct comparison of experimental methods to measure dimensions of synthetic nanoparticles. Ultramicroscopy. 2017 Nov;182:179–90. doi: 10.1016/j.ultramic.2017.07.001.

Das J, Das MP, Velusamy P. Sesbania grandiflora leaf extract mediated green synthesis of antibacterial silver nanoparticles against selected human pathogens. Spectrochimica Acta Part A: Mol Biomolecular Spectros. 2013;104:265–70.

Hedberg J, Skoglund S, Karlsson ME, Wold S, Odnevall I, Hedberg Y. Sequential studies of silver released from silver nanoparticles in aqueous media simulating sweat, laundry detergent solutions and surface water. Env Sci Technol. 2014;48:7314–22.

Rai MK, Deshmukh SD, Ingle AP, Gade AK. Silver nanoparticles: the powerful nanoweapon against multidrug-resistant bacteria. J Appl Microbiol. 2012 May;112(5):841–52. doi: 10.1111/j.1365-2672.2012.05253.x.

Durán N, Marcato PD, Conti RD, Alves OL, Costa FTM, Brocchi M. Potential use of silver nanoparticles on pathogenic bacteria, their toxicity and possible mechanisms of action. J Braz Chem Soc. 2010;21:949–59. doi: 10.1590/S0103-5053201000600002.

Pal S, Tak YK, Song JM. Does the antibacterial activity of silver nanoparticles depend on the shape of the nanoparticle? A study of the Gram-negative bacterium Escherichia coli. Appl Env Microbiol. 2007;73(6):1712–20. doi: 10.1128/AEM.02218-06.

Morones JR, Elechiguerra JL, Camacho A, Holt K, Kouri JB, Ramirez JT, et al. The bactericidal effect of silver nanoparticles. Nanotechnology. 2005;16(10):2346–53. doi: 10.1088/0957-4484/16/10/059.

Haythem M, Ibrahim M. Green synthesis and characterization of silver nanoparticles using banana peel extract and their antimicrobial activity against representative microorganisms. J Radiat Res Appl Sci. 2015;8:265–75. doi: 10.1016/j.jrras.2015.01.007.

Shrivastava S, Bera T, Roy A, Singh G, Ramachandrarao P, Dash D. Characterization of enhanced antibacterial effects of novel silver nanoparticles. Nanotechnology. 2007;18:103–12.

Marambo-Jones C, Hoek EMV. A review of the antibacterial effects of silver nanomaterials and potential implications for human health and the environment. J Nanopart Res. 2010;12:1531–51. doi: 10.1007/s11051-010-9900-y.

AshaRani PV, Low Kah Mun G, Hande MP, Vallyaveettil S. Cytotoxicity and genotoxicity of silver nanoparticles in human cells. ACS Nano. 2009 Feb 24;3(2):279–90. doi: 10.1021/nn800596w. PMID: 19236062.

Senthil B, Devasena T, Prakash B, Rajasekar A. Non-cytotoxic effect of green synthesized silver nanoparticles and its antibacterial activity. J Photochem Photobiol B. 2017 Dec;177:1–7. doi: 10.1016/j.jphotobiol.2017.10.010. Published 2017 Oct 7. PMID: 29028495.

Panacek A, Kolar M, Vecerova R, Prucek R, Soukupova J, Rystof V, et al. Antifungal activity of silver nanoparticles against Candida spp. J Biomater. 2009;30:6333–40.

Jo Y-K, Kim BH, Jung G. Antifungal activity of silver ions and nanoparticles on phytopathogenic fungi. Plant Dis. 2009;93:1037–43. doi: 10.1094/PDIS-93-10-1037.

Ouda SM. Antifungal activity of silver and copper nanoparticles on two plant pathogens, Alternaria alternata and Botrytis cinerea. Res J Microbiol. 2014;9:34–42.

Narayanan KB, Park HH. Antifungal activity of silver nanoparticles synthesized using turnip leaf extract (Brassica rapa L.) against wood rotting pathogens. Eur J Plant Pathol. 2014;140(2):185–92. doi: 10.1007/s10658-014-0399-4.

Radhakrishnan VS, Reddy Mudiam MK, Kumar M, Dwivedi SP, Singh SP, Prasad T. Silver nanoparticles induced alterations in multiple cellular targets, which are critical for drug susceptibilities and pathogenicity in fungal pathogen (Candida albicans). Int J Nanomed. 2018 May 3;13:2647–63. doi: 10.2147/IJN.S150648.