Original Article

Biogenic Synthesis of Silver Nanoparticles (AgNPs) using *Solanum indicum* Linn.

Sadeq Khalid Alhag[1,2], Hamed Ali Ghramah[3,4], Lamya Ahmed Al-keridis[5], Fahd Abdu Al-Mekhlafi[6,7,*], Essam Hassan Ibrahim[3,8,9], Khalid Ali Khan[3,10]

[1]Biology Department, College of Science and Arts, King Khalid University, Muhayl Asser, SAUDI ARABIA.
[2]Biology Department, College of Science, Ibb University, YEMEN.
[3]Biology Department, Faculty of Science, King Khalid University, P.O. Box 9004, Abha 61413, SAUDI ARABIA.
[4]Research Center for Advanced Materials Science (RCAMS), King Khalid University, P.O. Box 9004, Abha 61413, SAUDI ARABIA.
[5]Department of Biology, Faculty of Science, Princess Nourah bint Abdulrahman University, Riyadh, SAUDI ARABIA.
[6] Bioproducts Research Chair, Department of Zoology, Faculty of Science, King Saud University, SAUDI ARABIA.
[7]Department of Agricultural Production, College of Agriculture and Veterinary Medicine, Thamar University, YEMEN.
[8]Research Center for Advanced Materials Science (RCAMS), King Khalid University, P.O. Box 9004, Abha 61413, SAUDI ARABIA.
[9]Blood Products Quality Control and Research Department, National Organization for Research and Control of Biologicals, Cairo, EGYPT.
[10]Unit of Bee Research and Honey Production, Faculty of Science, King Khalid University, P.O. Box 9004, Abha 61413, SAUDI ARABIA.

ABSTRACT

Background: Synthesis of silver nanoparticles (AgNPs) using green plants is important for biocompatibility, reduced hazards, green policy and eco-friendliness. **Materials and Methods:** In this study, a leaf extract of *Solanum indicum* and associated AgNPs were used to examine larvicidal properties and other biological activities. AgNP forms were characterized with scanning electron- microscopy (SEM), Fourier Transform Infrared Radiation spectroscopy (FTIR) and UV-vis spectra. Larvicidal activity was assessed with *Culex pipiens* larvae using the World Health Organization method. Antibacterial potential of *S. indicum* leaf extract and AgNPs were evaluated with a well diffusion assay. *In vitro* impacts of *S. indicum* extract and AgNPs were studied using spleen cell propagation. **Results:** *S. indicum* ethanol extract and associated AgNPs show larvicidal activity against 4^{th} instar of *Cx. pipiens*. Synthesized AgNPs were more toxic, with lower lethal concentration values, (LC_{50} = 47.181 ppm; LC_{90} = 243.776ppm) compared to plant extract (LC_{50} = 131.448 ppm; LC_{90} = 4397.528 ppm) after a twenty-four hour of exposure. Synthesized AgNPs also show significant impact *Staphylococcus aureus, Proteus mirabilis, Escherichia coli* and *Shigella flexneri*. Cytotoxic effects were demonstrated for *S. indicum* extract and AgNPs on normal spleen cells. The extract and associated AgNPs were also safe for red blood cells (RBCs) and failed to cause substantial elevation in serum liver enzymes. **Conclusion:** Leaf extracts of *S. indicum* and associated AgNPs may be efficient and eco-friendly for control of *Cx. pipiens.* Their antibacterial activity may be useful if care is taken to prevent cytotoxic effects.

Key words: Cytotoxic effect, *Culex pipiens*, Silver Nanoparticles, Antibacterial, Larvicidal, *Solanum indicum.*

Submission Date: 03-06-2020;
Revision Date: 08-10-2020;
Accepted Date: 18-12-2020

DOI: 10.5530/ijper.55.1s.51
Correspondence:
Dr. Fahd A Almekhlafi
Associate Professor of Entomology, Bioproducts Research Chair, Department of Zoology, College of Science, King Saud University,
Riyadh-11451, SAUDI ARABIA.
Phone: +966 011 4699662
Email id: falmekhlafi@ksu.edu.sa

www.ijper.org

INTRODUCTION

Design and synthesis of nanoparticles is a promising area of research for physics, electronics, biotechnology, medicine, chemistry, catalysis and material sciences. Nanoparticles display many attractive physical-chemical features.[1,2] Silver nanoparticles (AgNPs) specifically are identified for multiple uses in medicine and biotechnology.[3] Recently, substantial progress for synthesis of AgNPs using green extracts or essential oils. Plant extracts can be important for mosquito control factor since they may be ecologically suitable for use as larvicides. Green extract are generally recognized as eco-friendly agents for insect control.[4] Mosquito control necessitates new and improved control approaches that are low-cost, eco-friendly and harmless to non-target animals.[5] Biogenic forms of NPs from green extracts meet these criteria as an appropriate alternative for control of mosquito larvae.[3] Nanoparticles display larvicidal properties that, in many cases, are better than properties of plant extracts used for synthesis. The combination of extracts and AgNPs may be more effective than other chemical larvicides. Biogenic AgNPs may also be useful for targeting bacteria because of their small size.[6] Several research papers are available that focus on the synthesis of AgNPs using plant extracts. For instance, *Tamarindus india* and *T. graveolens* in the family Fabaceae,[7,10] *Aloe vera* in the Asphodelaceae,[8] and *Emblica officinalis* in the Phyllanthaceae.[9]

Moreover, antimicrobial properties of AgNPs are recognized against both viruses[11] and bacteria.[12] AgNPs have a highly particular region than their volume which prompts a great antimicrobial activity as compared with bulk Ag metal.[13] *S. indicum* is a widely distributed plant existing throughout India, Nepal, China and the Arab region. It is used for treatment of many diseases. Pharmacology and phytochemistry *S. indicum* was recently reviewed.[14] The review highlights the potential of this plant as a source of alternative medicine. Bioactive compounds in *S. indicum* are responsible for its substantial therapeutic efficacy.[15]

The current study examined larvicidal efficiency, antibacterial action and cytotoxicity of AgNPs synthesized biogenically using a leaf extract of *Solanum indicum*. The structure of the NPs was evaluated with UV–VIS spectroscopy and volume and form were imaged using Scanning Electron Microscopy (SEM).

MATERIALS AND METHODS

Plant extract

Fresh leaves of *S. indicum* were collected from Rejalalma Village, Abha, Asir Region, Saudi Arabia and washed three times with tap water, dried at 25°C and triturated into fine powder. Fifty grams of dried leaf powder was mixed with 500mL of 70% ethanol. The suspension was left for three hours, filtered through Whatman no. 1 filter paper and the filtrate stored in brown air-tight bottle at 10°C.[16] One gram of dried leaf powder dissolved separately with 100 mL of either 70% ethanol or acetone to prepare two 1% stock solutions.[17]

Rearing of *Cx pipiens*

A field strain of *Cx. pipiens* was used. The parental strain was raised from wild larvae, collected from Wadi Bn Hashbal sites in Abha governorate, Saudi Arabia and maintained under laboratory conditions of 27 ± 2°C and 70% ± 10% relative humidity with 14:10 light/dark cycle. Larvae were fed on a diet of fish food or dried bread powder and dried milk.[18]

Synthesis and characterization of (AgNPs)

With few exceptions, AgNPs were synthesized using the method of Ibrahim *et al.*[19] One mL of 1mM (AgNO3) was added to 99 mL of *S. indicum* extracts. The pH value of the solution was adjusted to 7.0 using 0.1 M sodium hydroxide. The formation of AgNPs was revealed by a color change. The suspension of biogenic AgNPs was examined with UV–vis spectra, wavelength 475–600 nm in a UV-3600 Shimadzu spectrophotometer at 1 nm resolution. The form of the shaped nanoparticles was examined using a SEM (JEM-1011Tokyo, Japan).[20] Functional groups of the botanical extract and synthesized AgNPs were evaluated using a Perkin-Elmer Spectrum 2000 FTIR within a range of 600–4000 cm^{-1}, a rate of 16 and a resolution of 4 cm^{-1}.

Larvicidal bioassay

Larvicidal activity was estimated using the method of WHO[21] with revisions described by Rahuman *et al.*[22] Different concentrations in five replicates were prepared from *S. indicum* extract and extract containing AgNPs in plastic cups filled with tap water (100 mL). One cup per replicate was used as a negative control. Twenty-four 4th instar larvae of *Cx. pipiens* in each cup were incubated for 24 hr at 27°C with a 16:8h light/dark cycle. Larval deaths were documented 24 hr post-treatment for the *S. indicum* extract and extract with AgNPs. Larvae were considered dead when failed to move after probing their siphon with a needle.

Well diffusion method for antibacterial efficacy

Escherichia coli, *Shigella flexneri, Proteus mirabilis* and *Staphylococcus aureus* were used in this study. Nutrient agar and broth (HiMedia Laboratories Pvt. Ltd. India) were prepared by following manufacturer instructions to culture bacterial strains. Antimicrobial potential of *S. indicum* extract and its extract with AgNPs was evaluated by agar well diffusion following Ghramh *et al.*[23]

In vitro impacts of *S. indicum* extract and AgNPs on spleen cell propagation

Spleens of healthy adult male Sprague Dawley rat weighing about 244 g, kindly provided by the animal house at King Khalid University, were used to obtain spleen cells as described previously by Ibrahim *et al.*[19] Analysis of the results involved calculating percent increase and decrease in growth, as described previously by Oves *et al.*[24] inexpensive, and ecofriendly, therefore, are used preferably in industries, medical and material science research. Considering the importance of biofabricated materials, we isolated, characterized and identified a novel bacterial strain OS4 of Stenotrophomonas maltophilia (GenBank: JN247637.1

Lytic impacts of *S. indium* extract and associated silver nanoparticles on (RBCs)

The lytic impact of *S. indicum* leaf extract and associated silver nanoparticles were evaluated as described previously by Ibrahim *et al.*[19] The extract and AgNPs at concentrations of 1 mg/mL in sterile phosphate-buffered saline (PBS, pH 7.4) were prepared. A 150μL aliquot was added from the extract with AgNPs and the plant extract only to 850 μL of prepared RBCs in 1.5 mL Eppendorf tubes and incubated for 60min at 37°C. 1%Triton (X-100) and phosphate buffer saline (PBS) was used as positive control and negative controls, respectively.

Statistical analysis

Statistical analysis of larvicidal bioassay

LSD compared means of larval mortality at $P \leq 0.05$ using SAS program while LC_{50} and LC_{90} regression equations were estimated using computerized log-probity analysis and LDP Line software.

Statistical analysis of antimicrobial activity

Antimicrobial activity was measured in terms of average+/- standard deviation (SD) of three replicates ZOI measurements. One-way analysis of variance (ANOVA) used Statistix 8.1 software. All pairwise comparison of means was performed with Tukey's Honest Significant Difference test. Means differences of $p < 0.05$ were considered statistically significant.

RESULTS

Identification of AgNPs

Colors in plant extract/$AfNO_3$ preparations changed from dark yellow to black then to dark brown (Figure 1). The blackening of the brownish color occurs over time. Color changes were easily seen by visually.

S. indicum biogenic AgNPs were examined by UV-vis spectra after mixing with an aqueous solution of $AgNO_3$. The electronic absorption spectrum of the extract before adding silver nitrate shows a broad absorption at 488 nm. Electronic absorption spectra of AgNPs displays absorbency constructivism at 490 nm (Figure 2).

FTIR spectroscopy analyses were performed to identify bioactive components responsible for stabilizing of synthesized AgNPs using *S. indicum*. FTIR spectra of

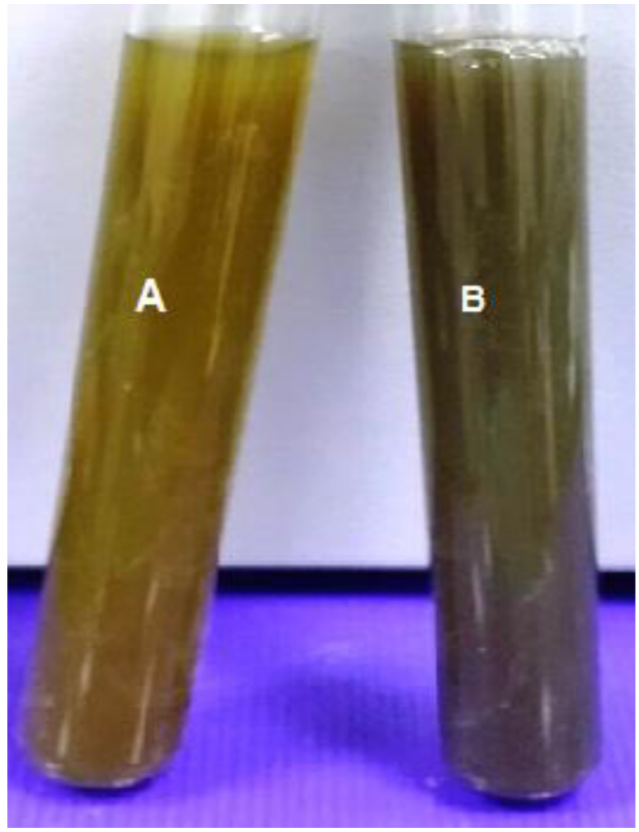


Figure 1: Change in color: (A) before adding $AgNO_3$ in *S. indicum* leaf ethanol extract and (B) after adding $AgNO_3$ to *S. indicum* leaf ethanol extract.

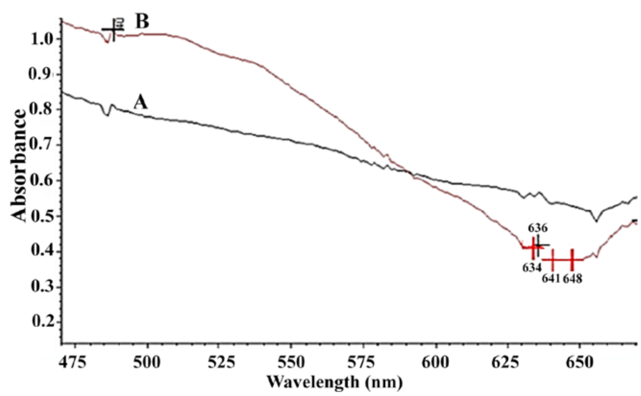


Figure 2: UV–Vis spectra of silver nanoparticles synthesized by *S. indicum* leaf extract. Where (A) plant extract without $AgNO_3$ and (B) plant extract with $AgNO_3$.

silver nanoparticles showed a sharp vibrational band at 3350.87 cm^{-1} (Figure 3). A weak band was visualized at 2100.52–1949.21 cm^{-1} and a strong stretching band at 1650.23 cm^{-1}. Weak bands were also observed at 1450.33 and 1327.40 cm^{-1}.

SEM images of AgNPs show irregular and aggregated shapes with an average size of 70 nm with the distance between particles. These particles were magnified 30000 times (Figure 4.)

Larvicidal activity of *S. indicum* extract and the extract contains $AgNO_3$ against *Cx. pipiens* larvae

At concentrations between 500 to 2500 and 50 to 250 ppm, respectively, extracts and extracts plus nanoparticles caused 72.727% to 89.899% and 53.535% to 94.949% larva mortality, respectively (Table 1). With decreasing concentrations of nanoparticles, the mortality rate in 4th instar larvae decreased. The extract of *S. indicum* with silver nanoparticles produced an LC_{50} (47.181 ppm) lower than the extract of *S. indicum* alone (131.448 ppm). The extract with nanoparticles was thus 2.786 times more potent (Figure 5).

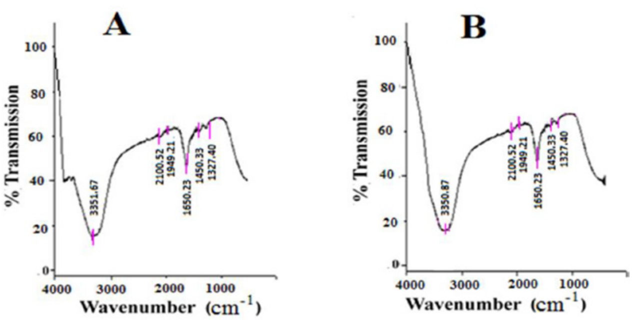


Figure 3: (A) Ftir spectra of *S. indicum* extract (B) *S. indicum* with AgNPs.

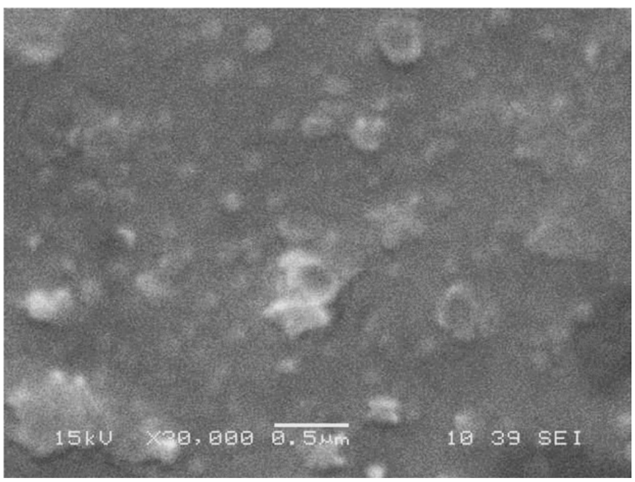


Figure 4: SEM image of silver nanoparticles in aggregated and irregular shapes.

Antibacterial activity

In vitro antibacterial potential of *S. indicum* leaf extract and associated AgNPs both inhibited growth of bacterial pathogens (Table 2). Average diameters of ZOI formed by *S. indicum* plant extract + AgNPs were statistically comparable ($p > 0.05$) with the positive control for *E. coli* and *S. aureus* but significantly different from positive controls and extract alone against *Shigella flexneri* and *P. mirabilis* ($p < 0.05$). Average diameters of ZOI formed by plant extract alone were statistically similar ($p > 0.05$) with positive controls against *P. mirabilis* and *Shigella flexneri* but were significantly different ($p < 0.05$) from positive controls against *E. coli* and *S. aureus*.

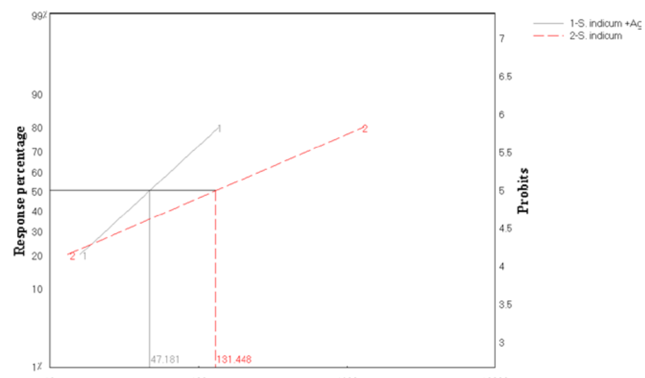


Figure 5: Dose-relationship between concentrations of plant extracts and mortality of 4th instar larvae of *Cx. pipiens*. Line 1: *S. indicum* +$AgNo_3$, Line 2: *S. indicum*.

Table 1: Susceptibility of *Culex pipiens* larvae to *S. indicum* and associated silver nanoparticles (AgNPs)

Bioinsecticide	Conc. (ppm)	Mortality[a] (%)	LC_{50} (ppm) (LCL-UCL)	LC_{90} (ppm) (LCL-UCL)	χ2 d.f (*n.s*) = 4[b]	slope
S. indicum	500 1000 1500 2000 2500 0	72.727 72.727 76.768 84.848 89.899 1.33	142.686 6.9161–328.409	4611.37 2628.8–31647.9	4.7113	0.849
***S. indicum* + $AgNo_3$ (AgNPs)**	50 100 150 200 250 0	53.535 72.727 76.768 84.848 94.949 1.33	49.433 34.199–62.300	248.70 199.81–350.65	4.727	1.826

a: Five replicates, 20 larvae each

b. Tabulated **(Chi)** = 7.8, larger than the calculated value for an 0.05 level of significance, indicates the line is fit well and data are homogenous.

Table 2: Antibacterial potential of *S. indicum* leaf extract and extract with silver nanoparticles (AgNPs), with 1mM concentration.

Treatments	Zone of inhibition (mm)			
	Bacterial strains			
	Escherichia coli	*Proteus mirabilis*	*Staphylococcus aureus*	*Shigella flexneri*
Extract	19.33 ± 1.15^{b}	20.67 ± 2.31^{b}	15.67 ± 2.51^{b}	19.33 ± 2.31^{b}
Extract + AgNPs	21.33 ± 2.31^{ab}	24.67 ± 1.15^{a}	19.00 ± 3.61^{ab}	28.00 ± 2.00^{a}
Control (Positive)	22.67 ± 1.15^{a}	20.00 ± 1.00^{b}	21.00 ± 1.00^{a}	19.67 ± 0.58^{b}

NB: Zones of inhibitions are expressed as the average of three replicates ± SD. Means with same superscript letters are not significantly different.

Table 3: Effects of *S. indicum* leaf extract and extract with AgNPs on normal rat spleen cells.

(µg/mL)	% of spleen cells growth inhibition	
	***Solanum indicum* leaf extract**	***Solanum indicum* leaf extract with AgNPs**
200	63.50 ± 2.50	108.30 ± 1.5
100	55.78 ± 1.80	85.. ± 1.20
50	49.87 ± 1.86	66.57 ± 0.97

Table 4: Effects of *S. indicum* L. leaf acetone extract alone and with biosynthesized silver nanoparticles (AgNPs) on red blood cell (RBCs) lysis.

No.	Treatment	Absorbance at wavelength of 576 nm	RBC hemolysis (%)
1	Plant leaf acetone extract	> 3.00	100
2	Plant extract with (AgNPs)	> 3.00	100
3	Control (Negative)	0.067	0
4	Control (Positive)	> 3.00	100

Cytotoxic/proliferative effects

S. indicum leaf extract and associated AgNPs were cytotoxic to normal spleen cells. The cytotoxic impact decreased with decreasing leaf extract and leaf plus AgNPS concentrations (Table 3). The extract without AgNPs showed less cytotoxicity.

Lytic impacts of *S. indicum* extract and associated AgNPS on (RBCs)

The cytotoxicity was studied by testing the hemolytic impacts on cow RBCs using a positive control (1% Triton-X-100) and negative control (PBS). Hemolysis was measured by comparing the absorbance of the sample to negative and positive controls (Table 4 and Figure 6). 100% lysis was observed in the positive control, while no lysis of RBCs was observed in the

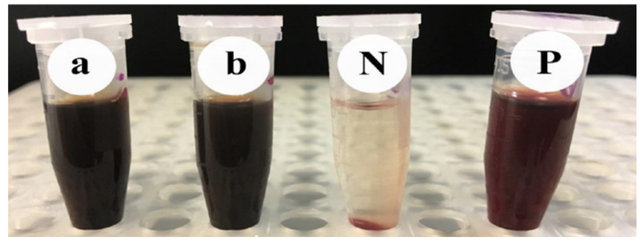


Figure 6: The effect of (a) *S. indicum* L. leaf acetone extract alone and (b) associated biosynthesized silver nanoparticles (AgNPs) on cow RBCs. Where, N is the negative control and P is the positive control.

negative control (PBS). The lysis may be attributed to the effect of the NPs on RBCs' membranes. Other authors refer to the hemolytic effect as due to induced oxidative stress following exposure.

DISCUSSION

The distinctive brown color refers to the stimulation of exterior Plasmon Response with AgNPs as discussed in Ranganathan *et al.*[25] This color transference is often evidence of changes in oxidation state where Ag^{+} is reduced to Ag^{0} in a reaction with *S. indicum* extract enzymes and nitrate. When the enzymes go out to the solution that can reduce the $AgNO_3$ to AgNPs through covering agents like proteins.[26] UV-vis spectra is extensively used for structural characterization of NPs.[27] This method may respond to interactions of silver ions with biomolecules found in the leaf extracts.[26,27] Ftir spectroscopy analyses of silver nanoparticles (Figure 3) show a sharp vibrational band at 3350.87 cm^{-1} that corresponds to the stretching OH band of alcohols. The weak bending band at 2100.52–1949.21 cm^{-1} may be attributed C-H in aromatic compounds. The strong stretching band at 1275 cm^{-1} may correspond to C-O in alkyl aryl ethers. The strong stretching band observed at 1650.23 cm^{-1} is assigned to C=O attributed to δ-lactam. Weak bands observed at 1450.33 and 1327.40 cm^{-1} may indicate the presence of C–H and O–H of alkanes and alcohols.[28] SEM analysis shows a size and shape of AgNPs in *S. indicum* plant extract that may increase their toxicity to mosquito larvae.[29] The extract of *S. indicum* with nanoparticles shows substantial activity against larvae of *Cx. pipiens* consistent with reports from other authors.[30-32] *S. indicum* extract and associated AgNPs showed a promising larvicidal potential against *Aedes aegypti* and *Anopheles stephensi* larvae.[33] Generally, the blending of *S. indicum* extract with silver nitrate produces an agent more effective against larvae of *Cx. pipiens*. Reduction of silver ion to elemental silver may be key to this activity. Compounds in the extract are likely linked to surfaces of the particles thus increasing their activity.[34]

The small size of particles likely also increases parricidal activity, consistent with the report by Rajasekharreddy and Rani declared.[35]

S. indicum leaf extract also displays antimicrobial activity against pathogenic bacteria (Table 1). The plant extract alone is an effective antibacterial and silver nanoparticles substantially increased activity against all tested bacteria. These results are consistent with other studies.[36] examined the antimicrobial effects mentioned in ancient historical references of Ghanaian medicinal plant extracts, including *Solanum* sp., against bacteria. They found that extracts from the leaves of *Solanum verbascifolium* show antibacterial activity against several Gram-positive microbes. Antibacterial factors in *Solanum* sp. might include a phosphorylated purine.[37] Similar results were reported by Sengottaiyan *et al.*[38] who studied the antibacterial potential of *S. indicum* synthesized AgNPs against *Staphylococcus* sp. and *Klebsiella* sp. Antibacterial properties of AgNPs that are green synthesized by *S. indicum* may reflect their small size, leading to large surface areas. Thus, particle size may result in increased binding to bacterial cell walls, damage to cell walls and membrane-bound cellular enzymes, penetration through the cell membrane.[39] Further, antibacterial effects may involve the interaction of AgNPs with thiol groups of L-cysteine residues in proteins, leading to enzymatic dysfunction.[40] Also, AgNPs may encourage formation reactive oxygen species with resulting oxidative damage to cellular components, triggering cell death.[41] Further, cytotoxicity to normal spleen cells caused by the extract alone is augmented when AgNPs are present. Similar results were obtained by Aravinthan *et al.*[42] and Sengottaiyan *et al.*[38] where nanoparticles produced by the extract significantly reduced rat spleen cell viability in a dose-dependent manner. Several species of the genus *Solanum* have been assessed for their cytotoxicity in healthy and cancer cells. Raw extracts or compounds from *Solanum* spp. Inhibit proliferation of human and animal cells.[43]

This study confirm that extracts of *S. indicum* and associated nanoparticles display antimicrobial, cytotoxic, hemolytic and larvicidal activities.

CONCLUSION

This present study indicates that leaf extracts of *S. indicum* and associated biogenic AgNPs may be effective and eco-friendly for control of *Cx. pipiens* larvae. They also display significant antibacterial activity. Caution is advised to prevent human contact since substantial cytotoxicity to normal spleen cells is observed.

ACKNOWLEDGEMENT

This research was funded by the Deanship of Scientific Research at Princess Nourah bint Abdulrahman University through the fast-track Research Funding Program.

CONFLICT OF INTEREST

The authors declare that there is no conflict of interest.

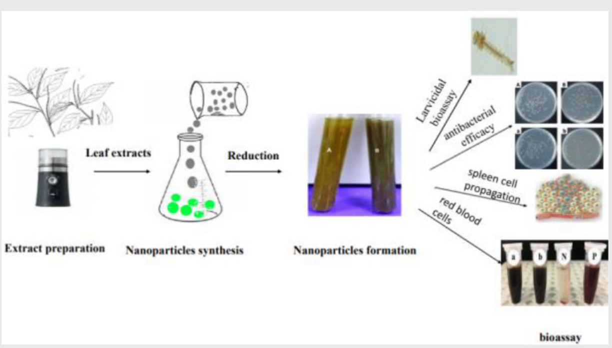
REFERENCES

1. Venkatpurwar V, Pokharkar V. Green synthesis of silver nanoparticles using marine polysaccharide: Study of *in-vitro* antibacterial activity. Mater Lett. 2011;65(6):999-1002.
2. Babu SA, Prabu HG. Synthesis of AgNPs using the extract of Calotropis procera flower at room temperature. Mater Lett. 2011;65(11):1675-7.
3. Albrecht M. Green chemistry and the health implications of nano-particles. Green Chem. 2006;8(5):417-32.
4. Rahuman AA, Bagavan A, Kamaraj C, Saravanan E, Zahir AA, Elango G. Efficacy of larvicidal botanical extracts against *Culex quinquefasciatus* Say (Diptera: Culicidae). Parasitol Res. 2009;104(6):1365.
5. Kamaraj C, Bagavan A, Rahuman AA, Zahir AA, Elango G, Pandiyan G. Larvicidal potential of medicinal plant extracts against *Anopheles subpictus* Grassi and C*ulex tritaeniorhynchus* Giles (Diptera: Culicidae). Parasitol Res. 2009;104(5):1163.
6. Zayed MF, Eisa WH, Shabaka AA. *Malva parviflora* extract assisted green synthesis of silver nanoparticles. Spectrochim Acta Part A Mol Biomol Spectrosc. 2012;98:423-8.
7. Shankar SS, Rai A, Ahmad A, Sastry M. Rapid synthesis of Au, Ag and bimetallic Au core--Ag shell nanoparticles using Neem (*Azadirachta indica*) leaf broth. J Colloid Interface Sci. 2004;275(2):496-502.
8. Chandran SP, Chaudhary M, Pasricha R, Ahmad A, Sastry M. Synthesis of gold nanotriangles and silver nanoparticles using Aloevera plant extract. Biotechnol Prog. 2006;22(2):577-83.
9. Ankamwar B, Damle C, Ahmad A. Sastry M. Biosynthesis of gold and silver nanoparticles using *Emblica officinalis* fruit extract, their phase transfer and transmetallation in an organic solution. J Nanosci Nanotechnol. 2005;5(10):1665-71.
10. Shankar SS, Ahmad A, Sastry M. Geranium leaf assisted biosynthesis of silver nanoparticles. Biotechnol Prog. 2003;19(6):1627-31.
11. Lara HH, Ayala-Nuñez NV, Ixtepan-Turrent L, Rodriguez-Padilla C. Mode of antiviral action of silver nanoparticles against HIV-1. J Nanobiotechnology. 2010;8(1):1.
12. Sondi I, Salopek-Sondi B. Silver nanoparticles as antimicrobial agent: A case study on *E. coli* as a model for Gram-negative bacteria. Journal of Ccolloid and Interface Science. 2004;275(1):177-82.
13. Mahendra R. Silver nanoparticles as a new generation of antimicrobials. Biotechnol Adv. 2009;27(1):76-83.
14. Sharma V, Hem K, Seth A, Maurya SK. *Solanum indicum* Linn.: An ethnopharmacological, phytochemical and pharmacological review. Curr Res J Pharm Allied Sci. 2017;1(2):1-9.
15. Syu WJ, Don MJ, Lee GH, Sun CM. Cytotoxic and novel compounds from *Solanum indicum.* J Nat Prod. 200164(9):1232-3.
16. Hamed GA, Jazem MA, Sadeq AK. Synthesis of Silver Nanoparticles from Schinus Molle extract and its larvicidal activity against *Aedes aegypti* (L.), the vector of dengue fever in kingdom of Saudi Arabia. Res J Biotechnol. 2018;13(5):63-70.
17. Ibrahim SK, Traboulsi AF, El-Haj S. Effect of essential oils and plant extracts on hatching, migration and mortality of *Meloidogyne incognita.* Phytopathologia Mediterranea. 2006;45(3):238-46.
18. Mahyoub JA, Alsobhi AS, Al-Ghamdi K. Effectiveness of seven mosquito larvicides against the West Nile vector *Culex pipiens* (L.) in Saudi Arabia. Asian Pacific J Trop Dis. 2016;6(5):361-5.
19. Ibrahim EH, Kilany M, Ghramh HA, Khan KA, Ul Islam S. Cellular proliferation/cytotoxicity and antimicrobial potentials of green synthesized silver

nanoparticles (AgNPs) using *Juniperus procera*. Saudi Journal of Biological Sciences. 2018;26(7):1689-94.

20. Jyoti K, Baunthiyal M, Singh A. Characterization of silver nanoparticles synthesized using *Urtica dioica* Linn. leaves and their synergistic effects with antibiotics. J Radiat Res Appl Sci. 2016;9(3):217-27.
21. WHO. Report of the WHO Informal Consultation on the Evaluation and Testing of Insecticides W H O Geneva. 1996.
22. Rahuman AA, Gopalakrishnan G, Ghouse BS, Arumugam S, Himalayan B. Effect of *Feronia limonia* on mosquito larvae. Fitoterapia. 2000;71(5):553-5.
23. Ghramh HA, Khan KA, Alshehri AM. Antibacterial potential of some Saudi honeys from Asir region against selected pathogenic bacteria. Saudi Journal of Biological Sciences. 2018;26(6):1278-84
24. Oves M, Khan MS, Zaidi A. Antibacterial and cytotoxic efficacy of extracellular silver nanoparticles biofabricated from chromium reducing novel OS4 strain of *Stenotrophomonas maltophilia*. PLoS One. 2013;8(3):e59140.
25. Ranganathan R, Madanmohan S, Kesavan A, Baskar G, Krishnamoorthy YR, Santosham R, *et al*. Towards development of patient-friendly drug-delivery systems for oncological applications. Int J Nanomedicine. 2012;7:1043-6.
26. Manivasagan P, Venkatesan J, Senthilkumar K, Sivakumar K, Kim SK. Biosynthesis, antimicrobial and cytotoxic effect of silver nanoparticles using a novel Nocardiopsis sp. MBRC-1. Biomed Res Int. 2013.
27. Sun YP, Atorngitjawat P, Meziani MJ. Preparation of silver nanoparticles via rapid expansion of water in carbon dioxide microemulsion into reductant solution. Langmuir. 2001;17(19):5707-10.
28. Umoren SA, Obot IB, Gasem ZM. Green synthesis and characterization of silver nanoparticles using red apple (*Malus domestica*) fruit extract at room temperature. J Mater Env Sci. 2014;5(3):907-14.
29. Ramesh S, Grijalva M, Debut A, Beatriz G, Albericio F, Cumbal LH. Peptides conjugated to silver nanoparticles in biomedicine--a value-added phenomenon. Biomater Sci. 2016;4(12):1713-25.
30. Ghosh A, Chowdhury N, Chandra G. Plant extracts as potential mosquito larvicides. Indian J Med Res. 2012;135(5):581.
31. Grzybowski A, Tiboni M, Silva MAN, Chitolina RF, Passos M, Fontana JD. Synergistic larvicidal effect and morphological alterations induced by ethanolic extracts of *Annona muricata* and *Piper nigrum* against the dengue fever vector *Aedes aegypti*. Pest Manag Sci. 2013;69(5):589-01.
32. Mahesh P, Kumar K, Murugan K, Kovendan J, Subramaniam DA. Mosquito larvicidal and pupicidal efficacy of *Solanum xanthocarpum* (Family: Solanaceae) leaf extract and bacterial insecticide, *Bacillus thuringiensis*, against *Culex quinquefasciatus* Say (Diptera: Culicidae). Parasitol Res. 2012;110(6):2541-50.
33. Patil CD, Borase HP, Patil SV, Salunkhe RB, Salunke BK. Larvicidal activity of silver nanoparticles synthesized using *Pergularia daemia* plant latex against *Aedes aegypti* and *Anopheles stephensi* and nontarget fish *Poecillia reticulata*. Parasitol Res. 2012;111(2):555-62.
34. Borase HP, Patil CD, Salunkhe RB, Narkhede CP, Salunke BK, Patil SV. Phyto-synthesized silver nanoparticles: A potent mosquito biolarvicidal agent. J Nanomedicine Biother Discov. 2013;3(1):1-7.
35. Rajasekharreddy P, Rani PU. Biofabrication of Ag nanoparticles using *Sterculia foetida* L. seed extract and their toxic potential against mosquito vectors and HeLa cancer cells. Mater Sci Eng C. 2014;39:203-12.
36. Pesewu GA, Cutler RR, Humber DP. Antibacterial activity of plants used in traditional medicines of Ghana with particular reference to MRSA. J Ethnopharmacol. 2008;116(1):102-11.
37. Beaman-Mbaya V, Muhammed SI. Antibiotic action of *Solanum incanum* Linnaeus. Antimicrob Agents Chemother. 1976;9(6):920-4.
38. Sengottaiyan A, Mythili R, Selvankumar T, *et al*. Green synthesis of silver nanoparticles using *Solanum indicum* L. and their antibacterial, splenocyte cytotoxic potentials. Res Chem Intermed. 2016;42(4):3095-103.
39. Su HL, Chou CC, Hung D. The disruption of bacterial membrane integrity through ROS generation induced by nanohybrids of silver and clay. Biomaterials. 2009;30(30):5979-87.
40. Gordon O, Slenters TV, Brunetto PS, Villaruz AE, Sturdevant DE, Otto M, *et al*. Silver coordination polymers for prevention of implant infection: Thiol interaction, impact on respiratory chain enzymes and hydroxyl radical induction. Antimicrob Agents Chemother. 2010;54(10):4208-18.
41. Abdal DA, Hossain MK, Lee SB. The role of reactive oxygen species (ROS) in the biological activities of metallic nanoparticles. Int J Mol Sci. 2017;18(1):120.
42. Aravinthan A, Govarthanan M, Selvam K. Sunroot mediated synthesis and characterization of silver nanoparticles and evaluation of its antibacterial and rat splenocyte cytotoxic effects. Int J Nanomedicine. 2015;10:1977.
43. Nyeem MAB, Rashid AMU, Nowrose M, Hossain MA. *Solanum nigrum* (Maku): A review of pharmacological activities and clinical effects. IJAR. 2017;3(1):12-7.

PICTORIAL ABSTRACT

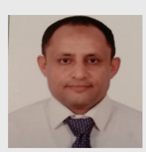


SUMMARY

- *Culex pipiens* is a common mosquito that is a vector of several arboviruses
- Synthesis of silver nanoparticles using *Solanum indicum* leaf extracts
- Leaf extracts of *S. indicum* and associated AgNPs may be efficient and eco-friendly for control of *Cx. pipiens*. Their antibacterial activity may be useful if care is taken to prevent cytotoxic effects

About Authors

Sadeq Alhag: Obtained his Ph.D. in 2009 from Dept of Zoology, Faculty of Science, Huazhong Normal University, China. He worked in Biology Department, College of Science and Arts, King Khalid University, Muhayel Aseer, Saudi Arabia.



Fahd Almekhlafi: Obtained his Ph.D. in 2010 from Dept. of Zoology, Faculty of Science, King Saud University, Saudi Arabia. He worked in the area of natural products, biological control and forensic entomology.

Cite this article: Alhag SK, Ghramah HA, AL-keridis LA, *et al*. Biogenic Synthesis of Silver Nanoparticles (AgNPs) using *Solanum indicum* Linn. Indian J of Pharmaceutical Education and Research. 2021;55(1s):s202-s208.