

***Calotropis procera* Mediated Synthesis of silver Nanoparticles and its Antibacterial Effect on Selected Pathogens**

ABSTRACT

The green synthesis of silver nanoparticles (AgNPs) using leaves extract from *Calotropis procera* have been investigated. The AgNPs was characterized using Ultraviolet-Visible (UV-VIS) Spectroscopy, Fourier Transform Infrared Spectroscopy (FTIR), Scanning and Transmission Electron Microscopy (SEM and TEM), Energy Dispersive X-ray (EDX) and X-ray Diffraction (XRD). The spectrum from UV-VIS had a peak centered at 445 nm, SEM-TEM micrographs showed them as aggregated, spherical in shape and about 15.30 – 17.66 nm in size, while EDX revealed Ag with highest proportion (75.56 %). The FTIR analysis revealed the presence of functional groups such as alcohols, ethers, esters, alkenes, carboxylic acid and amines. The XRD confirmed the crystalline nature of the synthesized CP-AgNPs. The synthesized AgNPs showed strong antibacterial activity against *Escherichia coli* (18.1±0.2 mm), *Enterobacter sichuanensis* (16.8±0.5 mm), *Pseudomonas aeruginosa* (14.4±0.3 mm), *Staphylococcus aureus* (22.2±0.5 mm) and *Streptococcus agalactiae* (21.5±0.1 mm). This study gives a clear efficacy and reality of the use of low cost and environmentally benign extract a main precursor in the synthesis of Ag nanoparticles.

Keywords: Antibacterial; *Calotropis procera*; Pathogens; Silver nanoparticles

1. INTRODUCTION

Calotropis procera is a soft-wooded, evergreen plant that is a member of the Apocynaceae family and the Asclepiadaceae subfamily. It is primarily found in dry and semi-arid environments. This plant has many uses; it can be used for medicine, fuel, fodder, wood and fibre production, phytoremediation, and nanoparticle synthesis (Kaur et al., 2021). It is acknowledged as an ornamental species as well. Numerous studies have reported finding metabolites in different portions of the plant, including flavonoids, tannins, terpenoids, saponins, alkaloids, steroids, and cardiac glycosides (Moustafa et al., 2010; Al-Rowaily et al., 2020). Research has demonstrated that *C. procera* extracts have potent antipyretic, analgesic, depressive, and neuromuscular blocking properties (Garabadu et al., 2019). According to Singhal et al. (2011), *C. procera* is also utilised by many tribes worldwide as a remedy for conditions like rheumatism, asthma, leprosy, toothaches, skin diseases, and elephantiasis. Bark and leaf extracts shown significant antibacterial activity against *Escherichia coli*, *Pseudomonas aeruginosa*, *Bacillus subtilis*, and *Klebsiella pneumoniae* (Mehmood et al., 2020). *C. procera* leaf extracts also significantly lower blood glucose, suggesting that they may have antihyperglycemic effects (Nadeem et al., 2019).

Green synthesized nanoparticles are more efficient and environmentally benign than those made chemically. Because they can create natural capping agents and don't contain any hazardous chemicals, plants provide an excellent platform for the synthesis of nanoparticles. When compared to other biological techniques, the rate of metal nanoparticle synthesis

using plant extract is stable, significantly faster, and incredibly mono-dispersive (Singhal et al., 2011; Sakhare, 2020). Additionally, the cost-effectiveness of nanoparticle synthesis is increased by the use of plant extracts, which lowers the cost of microorganism isolation and growth (Alkammash, 2017). Metallic nanoparticles based on the oxides of magnesium, copper, zinc, cadmium, titanium, silver, and gold have been studied because of their antibacterial activity and preservation capabilities (AbdelRahim et al., 2017). Among metallic nanoparticles, silver nanoparticles (AgNPs) have drawn particular interest because of their potential use in biological applications such as waste treatment, food production, agriculture, biomolecular detection and diagnostics, medicine administration, and therapies (Yaqoob et al., 2020). Similar to other therapeutic herbs, *C. procera* (L.) has qualities that are purgative, anti-inflammatory, antibacterial, anticoagulant, and parasitocidal. Therefore, the objective of this research is to synthesize and characterize *C. procera*AgNPs (CP-AgNPs) and assessment of its antibacterial effect on selected pathogens.

2. MATERIAL AND METHODS

2.1 Collection of leaf samples

Fresh *Calotropis procera* leaves were collected from the Botanical garden of Moshood Abiola Polytechnic, Abeokuta, Ogun State. A sample of the plant was authenticated by the Botanists of Environmental Biology Unit, Science Laboratory Department, School of Science & Technology, Moshood Abiola Polytechnic, Abeokuta, Ogun State.

2.2 Preparation of aqueous extract of *C. procera* leaves

This was carried out according to the modified method of Essien et al. (2019). The leaves were washed with tap water and rinsed with distilled water to remove dust and particle pollutants. They were then size reduced and sun-dried, ground into fine powder and stored in an airtight container for future use. The powder (4.0 g) was mixed with 100 mL of distilled water, sealed, and left for 48 h at room temperature. Afterwards, the mixture was filtered to get the *C. procera* aqueous leaf extract. The resultant extract was then kept at 4 °C till further use.

2.3 Synthesis of silver nanoparticles

The synthesis was performed by the method of Dada et al. (2017) and Essien et al. (2019). The *C. procera* aqueous leaf extract (1 mL) was added to 9 mL of 10 mM solution of AgNO₃. The reaction was incubated at 25°C at 60 rpm for 48 h in the dark condition. A colour change from colourless to brown was observed which is due to the **reduction of silver ions (Ag⁺) to silver nanoparticles (Ag⁰)**. The solution was centrifuged at 15,000 rpm for 15 min and particles formed washed in deionized water to remove any residual organic compounds present in the AgNPs. The wet particles were dried at 60 °C in an oven (NYC-101 oven, FCD-3000 serials, Medical and Scientific, UK) for 12 h, stirred in absolute ethanol to reduce aggregation and then dried at 60 °C for 30 min in an oven to expel the solvent.

2.4 Characterization of Biosynthesized Silver Nanoparticles

2.4.1 UV-visible absorption spectrophotometer

UV-Vis spectral details were recorded in a UV-visible absorption spectrophotometer (Camspec M 106) in the wavelength between 200 nm and 700 nm to monitor the formation of AgNPs in the reaction medium between *C. procera* extract and AgNO₃. The UV-visible spectrum of the CP-AgNPs was also obtained at a similar wavelength range.

2.4.2 Fourier Transformed infrared (FTIR) spectroscopy

The type of bonds present in the CP-AgNPs was assessed using FTIR spectroscopy (Nicolet iS10 FT-IR Spectrometer) in the wave number range of 350-4400 cm⁻¹.

2.4.3 Scanning electron microscope – Energy dispersive X-ray (SEM-EDX)

A morphological evaluation to determine the microstructure, particle distribution and elemental composition of the CP-AgNPs was performed in a scanning electron microscope (SEM) having an energy dispersive X-ray analysis (EDX) unit (JOEL JSM-7600F). The

sample was analyzed using an accelerating voltage of 15 kV (Essie et al., 2019). Samples for SEM analysis were prepared by coating them in gold using a Balzers' Sputtering device.

2.4.4 Transmission electron microscopy (TEM)

The particle size and structure of the CP-AgNPs was assessed by TEM (JOEL JEM-F200) operating at 200 kV accelerating voltage. The average particle size and distribution was determined from the TEM micrograph using software Image J.

2.4.5 X-ray Diffraction (XRD)

XRD was carried out using Rigaku D/Max-IIIC X-ray diffractometer developed by the Rigaku Int. Corp. Tokyo, Japan. Powdered samples were pelletized and sieved to 0.074 mm, these were taken in an aluminum alloy grid (35mm x 50mm) on a flat glass plate and covered with a paper. The samples were compacted by gently pressing them with the hand. Each sample was run through the diffractometer which is based on passing X-ray beam through a sample. This was set to produce diffractions at scanning rate of 2 °/min in the 2 to 50° at room temperature with a CuK α radiation set at 40 kV and 20 mA. The X-ray on passing through the samples gives peaks that is typical of each type of diffracted along a group of planes.

2.5 Antibacterial activity of CP-AgNPs

Antibacterial activity of the aqueous extract and synthesized CP- AgNPs were determined by the agar well diffusion method. This was assayed against spoilage bacteria (*Pseudomonas aeruginosa*, *Enterobacter sichuanensis*, *Escherichia coli*) isolated from previous study. The method of Mohamed et al. (2014) was used. Two days culture of the spoilage bacteria were spread on Mueller–Hinton agar. The agar plates (Mueller–Hinton agar) seeded with the test organisms was punched with a sterile cork- borer (6 mm diameter) to make open wells. The aqueous extract of *C. procera*, CP-AgNPs and Ciprofloxacin were added into the open wells and left for 10 minutes to allow diffusion on agar plates. All plates were inoculated at 37°C for 24 h and zone of inhibition (in mm) measured. The antimicrobial property of aqueous extract and AgNPs was determined by measuring the zone of inhibition around the discs after incubation. This was done in triplicates and recorded as mean \pm standard error of mean.

3. RESULTS AND DISCUSSION

The CP-AgNPs was successfully synthesized from silver nitrate (AgNO $_3$) and *C. procera* aqueous leaf extract as the synthesized AgNPs became dark brown in an aqueous solution, suggesting the reduction of Ag $^+$ into Ag 0 with the AgNO $_3$ serving as a precursor and extracts as a reducer or capping agent. The UV-Vis spectroscopic study confirmed the synthesis of CP-AgNPs as distinct surface plasmon resonance band with a peak centered at around 445 nm was obtained (Fig. 1). This is in agreement with a similar study by Dada et al. (2017) and Nagime et al. (2023) whose UV-Vis spectroscopy findings revealed the synthesis of CP-AgNPs with a peak centered on 420 nm and peak of ~400 nm respectively. The finding is in contrast to the study by Nawab et al. (2024) peak was observed at 271 nm. The FTIR spectra peaks were found to occur in the range between 579.00 and 4257.00 cm $^{-1}$ (Fig. 2). The FTIR spectrum shows several significant peaks indicative of various functional groups. A broad peak at 1020 cm $^{-1}$ indicates C-O stretching in alcohols, ethers, or esters, and the peak at 1159 cm $^{-1}$ is also related to C-O stretching in these functional groups. The 1251 cm $^{-1}$ peak is attributed to C-O stretching in ethers or esters, while the 1455 cm $^{-1}$ peak corresponds to C-H bending in alkanes or possible C=C stretching in alkenes. The peak at 1650 cm $^{-1}$ suggests C=C stretching in alkenes or aromatic compounds, while the strong peak at 1716 cm $^{-1}$ is characteristic of C=O stretching in carbonyl compounds such as ketones, aldehydes, or esters. The 2600 cm $^{-1}$ peak indicates broad O-H stretching, which is commonly found in carboxylic acids. Additionally, the peak at 2925 cm $^{-1}$ reflects C-H stretching in alkanes. The peaks at 3207 cm $^{-1}$ and 3492 cm $^{-1}$ suggest the presence of O-H stretching in alcohols or phenols and N-H stretching in amines. The FTIR analysis reveals the presence of functional groups such as alkyl halides, aromatic compounds, alcohols,

ethers, esters, alkenes, carbonyl compounds, carboxylic acids, and amines. These findings are in concordance with similar studies by Akshaya et al. (2022) and Mohamed et al. (2014). Awad et al. (2022) also recorded similar FTIR analysis results during the synthesis of AgNPs by *Aspergillus niger* strain. These various peaks indicated the presence of biomolecules which are responsible for the reduction and stabilization of AgNPs.

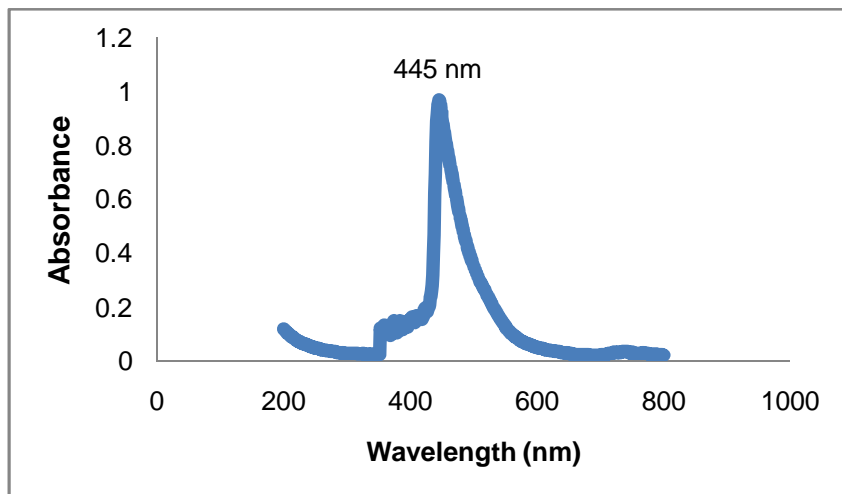


Fig. 1. The UV-Vis spectra of the synthesized CP-AgNPs

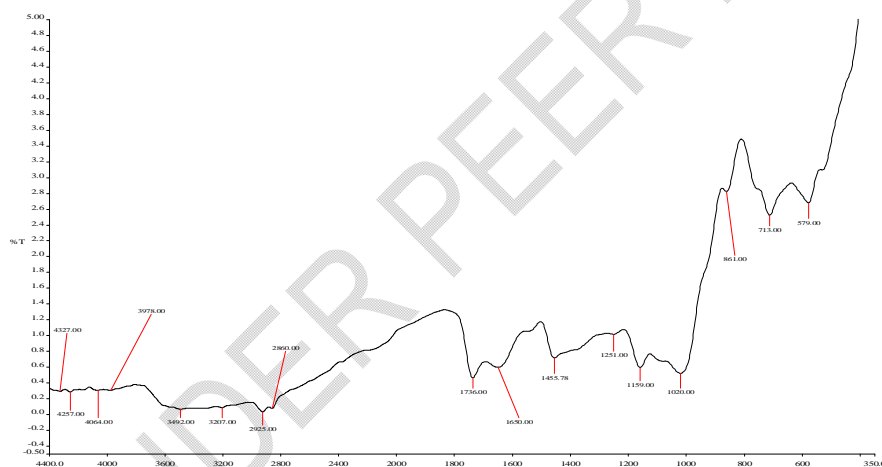


Fig. 2. FTIR Analysis of synthesized CP-AgNPs

The SEM and TEM image for aqueous extract of *C. procera* AgNPs is presented in Fig. 3 and 4. The SEM images had width 50 μm while the view field value is 13 mm. The SEM image TEM micrographs of the synthesized *C. procera* AgNPs showed them as aggregated, spherical in shape, well dispersed with a diameter of about 15.30 – 17.66 nm and an average particle size of 16.79 nm in size. This is similar to the work of Marimuthu et al. (2013) and Oraibi et al. (2022). This affirms that it may function as a reducing and capping agent in the synthesis of AgNPs. The EDX analysis gives qualitative as well as quantitative status of the constituents of a nanoparticle. The elements identified in the CP-AgNPs (EDX) with their weight and atomic size is shown in Fig. 5 with silver (Ag) having the highest proportion (75.56%). The strongest peak observed (3KeV) was from Ag. Generally, metallic silver nanocrystals showed typical optical absorption peak approximately at 3 keV due to their Surface Plasmon Resonance (Dada et al., 2017). One of the advantages of green

synthesis is the presence of other phytochemical elements from the EDX spectrum which may possibly arise from the *C. procera* extra serving as the capping agents. This is supported by the findings of other researchers (Prathnaet al., 2011; Singh et al., 2013; Ramesh et al., 2015; Oluwaniyet al., 2016). The XRD result confirmed the crystalline nature of the particles (Mohamed et al., 2014). It is a powerful technique used to study the crystal structure of materials. Peak intensity is relative to quantity of arranged semi-crystalline structures and/or variations in electron density between crystalline and amorphous lamellae (Hamley, 2013) while the sharp peaks correlated to crystalline region. A number of Bragg reflections at 2θ values of 38.10° , 44.3° , 77.5° , are shown corresponding to 111, 200 and 311 planes respectively (Fig 6). The peak positions are expected for AgNPs and serve as a means of identifying silver nanoparticles in XRD analysis. The strong and sharp peaks revealed the crystalline nature of AgNPs. The peaks assigned in the AgNP sample agree with a similar study by Nawabet al. (2024).

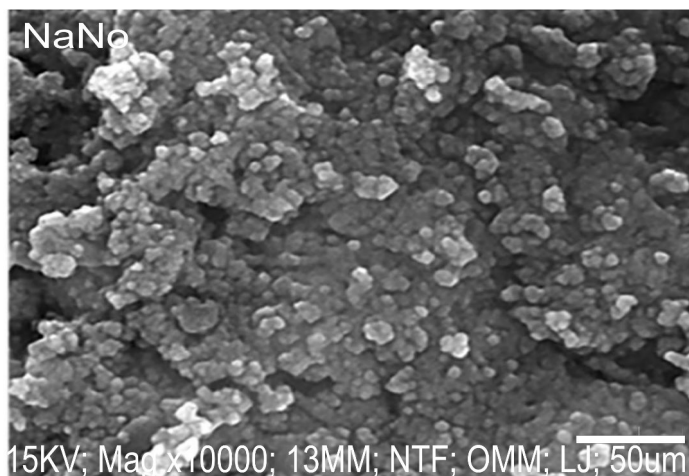


Fig. 3. SEM micrograph of synthesized CP-AgNPs at magnification of 10000X

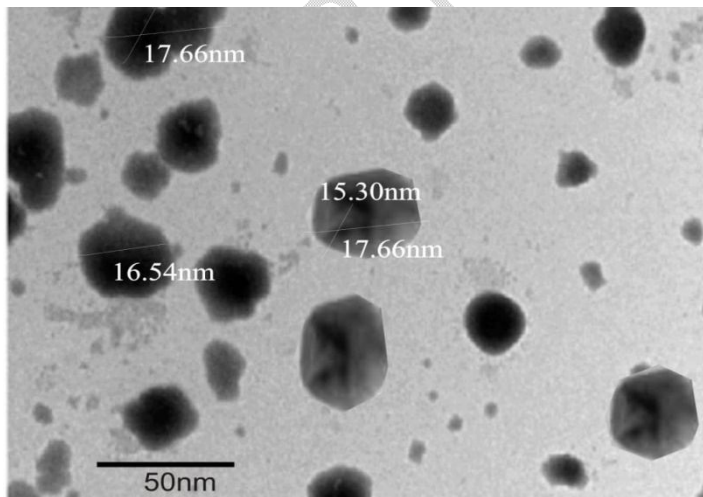


Fig. 4. TEM micrograph of synthesized CP-AgNPs

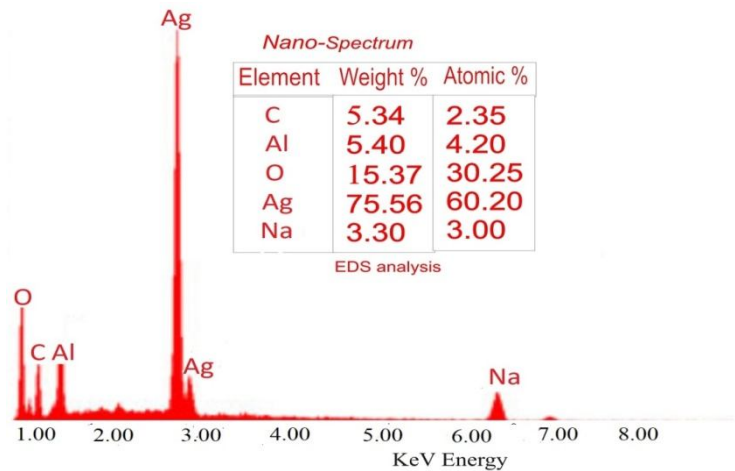


Fig. 5. EDX Spectrum of Synthesized CP-AgNPs

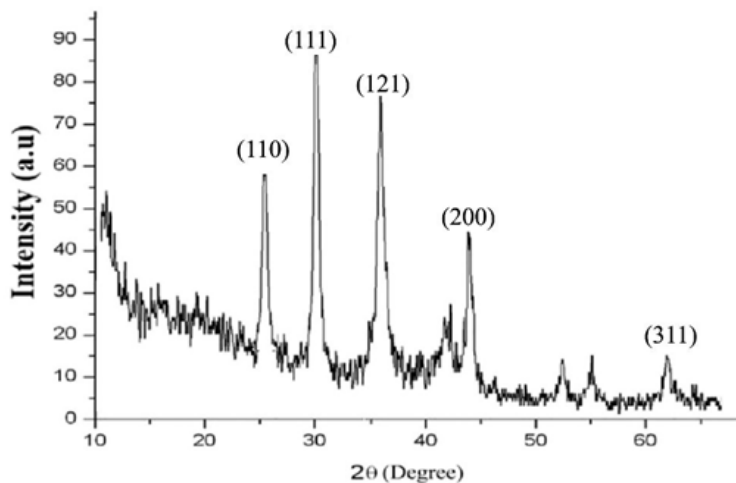


Fig. 6.XRD of Synthesized CP-AgNPs

The CP-AgNPs exhibited good antibacterial activity against Gram-negative bacteria and Gram-positive bacteria (Table 1). A zone of inhibition was observed in the area surrounding the test sample containing the well. The CP-AgNPs exhibited higher effect than the use of crude extract. The Gram-negative bacteria strain (*E. coli*, *E. sichuanensis* and *P. aeruginosa*) revealed a zone of 18.1±0.2 mm, 16.8±0.5 mm and 14.4±0.3 mm whereas Gram-positive bacteria (*Staphylococcus aureus* and *Streptococcus agalactiae*) showed a zone of 22.2±0.5 mm and 21.5± 0.1 mm. The strong antimicrobial activity depends on the large surface area of the nanoparticles which gave more surface area for interaction with the organisms and is also possible that the AgNPs not only interact with the surface of membrane, but also can penetrate inside the bacteria. Additionally, the high susceptibility of the synthesized AgNPs against these organisms indicated that it could be a valuable candidate for the treatment of infectious diseases (Labulo et al., 2022). Mohamed et al. (2014) also reported that latex of *C. procerca* has successfully synthesized Ag-NPs which

exhibited good antibacterial activity against Gram-negative bacteria such as *E. coli*, *Serratia* sp. and *P. aeruginosa*.

Table 1: Antibacterial activity of CP-AgNPs on tested bacteria

Test Organisms	Zone of Inhibition, Mean \pm SE (mm)			
	<i>C. procera</i> extract (300 μ L)	<i>C. procera</i> AGNPs (10 μ L)	<i>C. procera</i> AGNPs (20 μ L)	Ciprofloxacin (20 μ L)
<i>Pseudomonas aeruginosa</i>	10.5 \pm 0.1	11.7 \pm 0.2	14.4 \pm 0.3	18.1 \pm 0.4
<i>Enterobacter sichuanensis</i>	11.1 \pm 0.3	12.4 \pm 0.3	16.8 \pm 0.5	19.3 \pm 0.4
<i>Escherichia coli</i>	12.8 \pm 0.5	13.9 \pm 0.1	18.1 \pm 0.2	22.1 \pm 0.2
<i>Staphylococcus aureus</i>	9.3 \pm 0.3	15.2 \pm 0.2	22.2 \pm 0.5	25.3 \pm 0.4
<i>Streptococcus agalactiae</i>	10.5 \pm 0.5	14.8 \pm 0.3	21.5 \pm 0.1	23.1 \pm 0.3

Values are represented as means of triplicate readings \pm Standard error of mean

4. CONCLUSION

AgNPs were successfully synthesized from aqueous extract of *C. proceraleaves*, thus making it an effective stabilizing reducing agent for the synthesis of AgNPs. The SEM, TEM result showed the formed CP-AgNPs as highly stable spherical shaped particles, showing strong antibacterial activity against *E. coli*, *E. sichuanensis* and *P. aeruginosa*. The findings of this study proved that the green AgNPs could become a new technology for sustainable control of pathogens.

COMPETING INTERESTS

"The authors declare no conflicts of interest."

REFERENCES

- AbdelRahim, K., Mahmoud, S. Y., Ali, A. M., Almaary, K. S., Mustafa, A. E., & Husseiny, S. M. (2017). Extracellular biosynthesis of silver nanoparticles using *Rhizopus stolonifer*. *Saudi Journal of Biological Sciences*, 24(1), 208-216. <https://doi.org/10.1016/j.sjbs.2016.02.025>
- Akshaya, T., Aravind, M., Kumar, S. M., & Divya, B. (2022). Evaluation of in-vitro antibacterial activity against gram-negative bacteria using silver nanoparticles synthesized from *Dypsislutescens* leaf extract. *Journal of the Chilean Chemical Society*, 67(2), 5477-5483. <https://www.jcchems.com/index.php/JCCEMS/article/view/1890>
- Alkammash, N. M. (2017). Synthesis of silver nanoparticles from *Artemisia sieberi* and *Calotropis procera* medical plant extracts and their characterization using SEM analysis. *Biosciences Biotechnology Research Asia*, 14(2), 521-526. <http://dx.doi.org/10.13005/bbra/2474>

Al-Rowaily, S. L., Abd-ElGawad, A. M., Assaeed, A. M., Elgamal, A. M., El Gendy, A. E. G., & Mohamed, T. A. et al. (2020). Essential oil of *Calotropis procera*: Comparative chemical profiles, antimicrobial activity, and allelopathic potential on weeds *Molecules*, 25(21), 5203. <https://doi.org/10.3390/molecules25215203>

Awad, M. A., Eid, A. M., Elsheikh, T. M. Y., Al-Fifi, Z. E., Saad, N., Sultan, M. H., et al. (2022). Mycosynthesis, characterization, and mosquitocidal activity of silver nanoparticles fabricated by *Aspergillus niger* Strain. *Journal of Fungi*, 8(396), 1-16. <https://doi.org/10.3390/jof8040396>.

Dada, A. O., Ojediran, O. J., Dada, F. E., Olalekan, A. P., & Awakan, O. J. (2017). Green synthesis and characterization of silver nanoparticles using *Calotropis procera* extract. *Journal of Applied Chemical Science International*, 8(4), 137-143.

Essien, E. R., Atasie, V. N., Udobang, E. U., & Umanu, G. (2019). Preparation of monodispersed and cytotoxic silver nanoparticles using *Launaeataraxacifolia* leaf extract. *Journal of Nanostructure in Chemistry*, 9, 259-268. <https://doi.org/10.1007/s40097-019-00316-x>

Hamley, I. W. (2013). *Introduction to Soft Matter: Synthetic and Biological Self accessing Materials*. John Wiley and Sons, UK.

Kaur, A., Batish, D. R., Kaur, S., & Chauhan, B. S. (2021). An overview of the characteristics and potential of *Calotropis procera* from botanical, ecological, and economic perspectives. *Frontiers in Plant Science*, 12, 690806. <https://doi.org/10.3389/fpls.2021.690806>

Labulo, A. H., David, O. A., & Terna, A. D. (2022). Green synthesis and characterization of silver nanoparticles using *Morinda lucida* leaf extract and evaluation of its antioxidant and antimicrobial activity. *Chemical Papers* <https://doi.org/10.1007/s11696-022-02392>

Marimuthu, S., Rahuman, A. A., Jayaseelan, C., Kirthi, A. V., Santhoshkumar, T., Velayutham, K., et al. (2013). Acaricidal activity of synthesized titanium dioxide nanoparticles using *Calotropis gigantea* against *Rhipicephalus microplus* and *Haemaphysalis bispinosa*. *Asian Pacific journal of tropical medicine*, 6(9), 682-688. [https://doi.org/10.1016/S1995-7645\(13\)60118-2](https://doi.org/10.1016/S1995-7645(13)60118-2)

Mehmood, T., Arshad, H., Nawaz, S., Ullah, A., Hafeez, A., Anwar, F., et al. (2020). Pharmaceutical potential and phenolics profiling of leaves and bark of *Calotropis procera* in relation to extraction solvents. *Pharmaceutical Chemistry Journal*, 54, 631-641. <https://doi.org/10.1007/s11094-020-02250-7>

Mohamed, N. H., Ismail, M. A., Abdel-Mageed, W. M., & Shoreit, A. A. M. (2014). Antimicrobial activity of latex silver nanoparticles using *Calotropis procera*, *Asian Journal of Tropical Biomedicine*, 4(11), 876-883. <https://doi.org/10.12980/APJTB.4.201414B216>

Moustafa, A. M. Y., Ahmed, S. H., Nabil, Z. I., Hussein, A. A., & Omran, M. A. (2010). Extraction and phytochemical investigation of *Calotropis procera*: Effect of plant extracts on the activity of diverse muscles. *Pharmaceutical Biology*, 48(10), 1080-1190. <https://doi.org/10.3109/13880200903490513>

Nadeem, M., Mumtaz, M. W., Danish, M., Rashid, U., Mukhtar, H., Anwar, F., et al. (2019). *Calotropis procera*: UHPLC-QTOF-MS/MS based profiling of bioactive antioxidant and anti-diabetic potential of leaf extracts and an insight into molecular docking. *Journal of Food*

Measurement and Characterization, 13, 3206–3220. <https://doi.org/10.1007/s11694-019-00243-z>

Nagime, P. V., Singh, S., Shaikh, N. M., Gomare, K. S., Chitme, H., Abdel-Wahab, B. A., et al. (2023). Biogenic fabrication of silver nanoparticles using *Calotropis procera* flower extract with enhanced biomimetics attributes. *Materials (Basel)*, 16(11), 4058. <https://doi.org/10.3390/ma16114058>

Nawab, R., Ali, M., Haroon, U., Kamal, A., Akbar, M., Anwar, F., et al. (2022). *Calotropis procera* (L.) mediated synthesis of AgNPs and their application to control leaf spot of *Hibiscus rosa-sinensis* (L.). *Brazilian Journal of Biology*, 84, e261123. <https://doi.org/10.1590/1519-6984.261123>

Oluwaniyi, O. O., Adegoke, H. I., Adesuji, E. T., Aderemi, B. A., Sunday, O. B., Ayomide, H. L., et al. (2016). Biosynthesis of silver nanoparticles using aqueous leaf extract of *Thevetia peruviana* Juss and its antimicrobial activities. *Applied Nanoscience*, 6, 903-912.

Oraibi, A.G., Yahia, H. N., & Alobaidi, K. H. (2022). Green biosynthesis of silver nanoparticles using *Malva parviflora* extract for improving a new nutrition formula of a hydroponic system. *Scientifica*, 22, 1-10. <https://doi.org/10.1155/2022/4894642>

Prathna, T. C., Chandrasekaran, N., Raichur, A. M., & Mukherjee, A. (2011). Biomimetic synthesis of silver nanoparticles by Citrus limon (lemon) aqueous extract and theoretical prediction of particle size. *Colloids and Surfaces B: Biointerfaces*, 82(1), 152-159. <https://doi.org/10.1016/j.colsurfb.2010.08.036>

Ramesh, P. S., Kokila, T., & Geetha, D. (2015). Plant mediated green synthesis and antibacterial activity of silver nanoparticles using *Embllica officinalis* fruit extract. *Spectrochimica Acta Part A: Molecular and Biomolecular Spectroscopy*, 142, 339-343.

Sakhare, D. T. (2020). Green synthesis, characterization, antimicrobial activity and applications of Cu, and CuO, nanoparticles. *International Journal of Scientific & Engineering Research*, 11(6), 1471-1499.

Singh, S., Saikia, J. P., & Buragohain, A. K. (2013). A novel 'green' synthesis of colloidal silver nanoparticles (SNP) using *Dillenia indica* fruit extract. *Colloids and Surfaces B: Biointerfaces*, 102, 83-85.

Singhal, G., Bhavesh, R., Kasariya, K., Sharma, A. R., Singh, R. P. (2011). Biosynthesis of silver nanoparticles using *Ocimum sanctum* (Tulsi) leaf extract and screening its antimicrobial activity. *Journal of Nanoparticle Research*, 13(7), 2981-2988. <https://doi.org/10.1007/s11051-010-0193-y>

Yaqoob, A. A., Umar, K., & Ibrahim, M. N. M. (2020). Silver nanoparticles: Various methods of synthesis, size affecting factors and their potential applications—a review. *Applied Nanoscience*, 10(5), 1369-1378. <https://doi.org/10.1007/s13204-020-01318-w>