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Eco-friendly Green Synthesis of Silver Nanoparticles from *Aloe vera* Leaf Extract: Characterisation and Antibacterial Evaluations

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Abstract

This study aims to synthesise silver nanoparticles (AgNPs) using natural plant extract as an alternative method to tackle the global health threat of Antimicrobial Resistance (AMR). The extract of *Aloe vera* leaves was mixed with silver nitrate solutions ($AgNO_3$) at an appropriate concentration and incubated at room temperature for 24 hrs. The characterisation of nanoparticles for the determination of shape, size, and crystalline parameters was done using TEM, UV-Vis spectroscopy, and X-ray diffraction. A change in colour from pale yellow to brown indicated nanoparticle synthesis, for which the surface plasmon resonance peak ranged from ~410 to ~430 nm, observed in UV-Vis spectroscopy. The concentration-dependent increase in AgNPs size ranged from 20 nm with 0.1 mM $AgNO_3$ to 500 nm with 10.0 mM $AgNO_3$. The AgNPs were crystalline structures with a crystallite size range of 21.71 to 26.05 nm and showed antibacterial activity against *Staphylococcus aureus* when prepared using 1.0 mM $AgNO_3$. A reduction in the antibacterial activity of AgNPs was observed as the Nanoparticle size increased. Therefore, this study could represent a significant alternative to antibiotics for the treatment of *S. aureus* infections.

Major Findings: *Aloe vera* extract facilitated the green synthesis of crystalline silver nanoparticles, confirmed by UV–Vis, TEM, and XRD. The size of AgNPs increased with higher $AgNO_3$ concentration (approximately 20–500 nm), showing a concentration-dependent formation. Small AgNPs (~50 nm) exhibited strong antibacterial activity against *S. aureus*, suggesting potential as an alternative antimicrobial agent.

Keywords: *Aloe vera*, Antibacterial, Eco-friendly Synthesis of Nanoparticles, Silver Nanoparticles, *S. aureus*

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1. Introduction

Antimicrobial Resistance (AMR) has become a global health challenge in multiple sectors, including medicine, agriculture, and the environment. WHO has identified AMR infections among the top three public health threats, which are found to be associated with 4.95 million deaths, among them 1.27 million deaths were directly caused by

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AMR bacterial infections. The alarming increase in the deaths of up to 10 million annually is expected by 2050[1]. Given the increasing incidence of AMR, it has been recommended that a sustainable, innovative therapeutic approach be developed to prevent its emergence and spread. Nanotechnology has been identified as a safe, effective, and eco-friendly technology to combat AMR by inhibiting bacterial growth[2]. Metal nanoparticles (NPs) have shown a significant ability to prevent the growth of both Gram-positive and Gram-negative bacteria by interfering with their metabolic activity in different ways, such as disrupting cell membranes, fragmenting nucleic acids, reducing ribosomal stability, and suppressing cytochrome enzyme production[3]. Due to unique physical, chemical, and biological properties, AgNPs, among other metal NPs, have substantial potential antibacterial and anticancer applications[4]. Previous studies have identified the synergistic activity of antibiotic-conjugated silver nanoparticles in inhibiting the growth of *Escherichia coli, Klebsiella pneumoniae, Pseudomonas aeruginosa*, *Micrococcus luteus, Actinobacillus pleuropneumonia, Bacillus subtilis, Salmonella enterica, Salmonella typhi*, and *Staphylococcus aureus*[5].

The Eco-friendly green synthesis of nanoparticles coated with plant extracts has gained significant attention from researchers compared with chemical or physical synthesis methods. Plant extracts act as natural reducing agents, containing bioactive compounds such as alkaloids, terpenoids, flavonoids, and phenols, as well as natural stabilisers, such as proteins and polysaccharides. All these properties of plant extracts make the nanoparticle synthesis process more sustainable, non-toxic, and biogenic[6]. Previously, many plant extracts, including *Aloe vera*, sesame, *Pandanus tectorius*, and *Lallemantia royleana*, have been used to synthesise silver nanoparticles and have demonstrated broad-spectrum therapeutic and catalytic properties[7-11]. The nanoparticle synthesised using *Aloe vera* leaf extract offers an additional advantage by preventing nanoparticle aggregation through steric repulsion and by lowering the total surface energy[12]. Beyond that, *Aloe vera* extract has also been identified as an enhancer of skin penetration in co-formulated treatments[13]. The biosynthetic nanoparticles are characterised using UV-Visible spectroscopy, FTIR, Transmission Electron Microscopy, and XRD[14].

Therefore, this study has been planned to synthesise eco-friendly silver nanoparticles using *Aloe vera* gel extract and to characterise them thoroughly. Moreover, the antibacterial activity of biosynthesised AgNPs was evaluated to assess their potential for combating *S. aureus* infections.

2. Materials and Methods

2.1 Materials

Silver nitrate was purchased from SD Fine Chemicals, Mumbai, and culture media were obtained from HiMedia Laboratories Private Limited, Mumbai. Fresh *Aloe vera* leaves were collected from the greenhouse of the university garden. The *S. aureus* MTCC 1144 culture was purchased from the Microbial Type Culture Collection (MTCC), Chandigarh and maintained in the laboratory.

2.2 Preparation of *Aloe vera* Leaf Extract

Fresh and green *Aloe vera* leaves were plucked from the greenhouse and brought to the laboratory for further processing. The leaf extract was prepared following the procedure described earlier[15], with some modifications. The leaves were washed multiple times with sterile, double-distilled water to remove dust particles and other contaminants, then carefully dried on filter paper. Afterwards, the leaves were chopped into small pieces, and about 20 g of the chopped leaves was mixed with 100 ml of sterile, double-distilled water. The mixture was then subjected to ultrasonication for 20 minutes at 60°C. After cooling to room temperature, the mixture was filtered twice through Whatman No. 1 filter paper to produce a clear leaf extract.

2.3 Biosynthesis of Silver Nanoparticles (AgNPs)

The silver nitrate solution was prepared at concentrations of 0.1 mM, 1.0 mM, and 10.0 mM $AgNO_3$ in 100 mL sterile double-distilled water in separate sterile, capped bottles. Ten millilitres of *Aloe vera* gel was mixed with 100.00 ml aqueous $AgNO_3$ solution at different concentrations. The mixture was microwaved for 5 min and incubated at room temperature for 24 hours on a magnetic stirrer in the absence of light to prevent photo-oxidation of the silver nitrate solution. The colour change indicates the successful formation of silver nanoparticles (AgNPs). The mixture was observed for a colour change from pale yellow to brown and scanned on UV-Vis spectrophotometer for analysis. Subsequently, the prepared solution was centrifuged at 20,000 rpm for 20 min. The supernatant and the pellets were stored at 4-8 °C in different containers. The pellet was washed three times with deionised water to remove the impurities before storage (Figure 1).

2.4 Characterisation of Silver Nanoparticles

Heterogeneous techniques were used to analyse synthesised nanoparticles. The AgNP preparations were diluted appropriately for the study of their absorbance using UV-Vis spectrophotometry in the wavelength range of 300–600 nm using a Xenon flash lamp bearing a UV-Vis spectrometer model GENESYS 180 (ThermoScientific).

The morphological study of AgNPs was performed by placing a drop of dilute AgNP solution on a carbon-coated 200-mesh copper grid. The sample was air-dried before being placed in the Transmission Electron Microscopy facility at AIIMS Delhi, operating at an accelerating voltage of 200 kV (Thermo Scientific, CRYO-TEM, TALOS S).

The samples were studied using a 2θ scanning range of 30°–80° and a step size of 0.05 with Cu Kα radiation on an X-ray Diffraction (Panalytical XPERT-PRO) in the Department of Physics and Electronics.

2.5 Antibacterial Activity

2.5.1 Disc Diffusion Assay

The antimicrobial activity of the supernatant and pelleted AgNPs was evaluated against *S. aureus* (MTCC 1144) using a disc diffusion assay in accordance with Clinical and Laboratory Standards Institute protocols[16]. Briefly, 8 mm sterile discs of Whatmann No. 1 filter paper were allowed to absorb 5 µl AgNPs, $AgNO_3$ solution, plant extract, and supernatant of AgNPs separately. The soaked discs were allowed to dry at room temperature. The overnight-grown bacterial culture containing 5×10^8 cfu mL^{-1} in Luria-Bertani was swabbed onto a Mueller-Hinton Agar (MHA) plate to create a bacterial lawn. The impregnated discs were placed on the media surface inoculated with bacterial culture, and the zone of inhibition around each disc was measured using a zone scale (HiMedia®) after 24 to 48 hours of incubation at 37 °C.

2.5.2 Determination of Minimum Inhibitory Concentration (MIC) and Maximum Tolerance Concentration (MTC)

The lowest concentration of the test compound (AgNP) that completely inhibited visible bacterial growth was identified as the minimum inhibitory concentration (MIC). The MIC of biosynthesised AgNPs against the *S. aureus* MTCC 1144 was determined in Luria-Bertani (LB) medium following the protocol described previously[17]. Briefly, suspension of

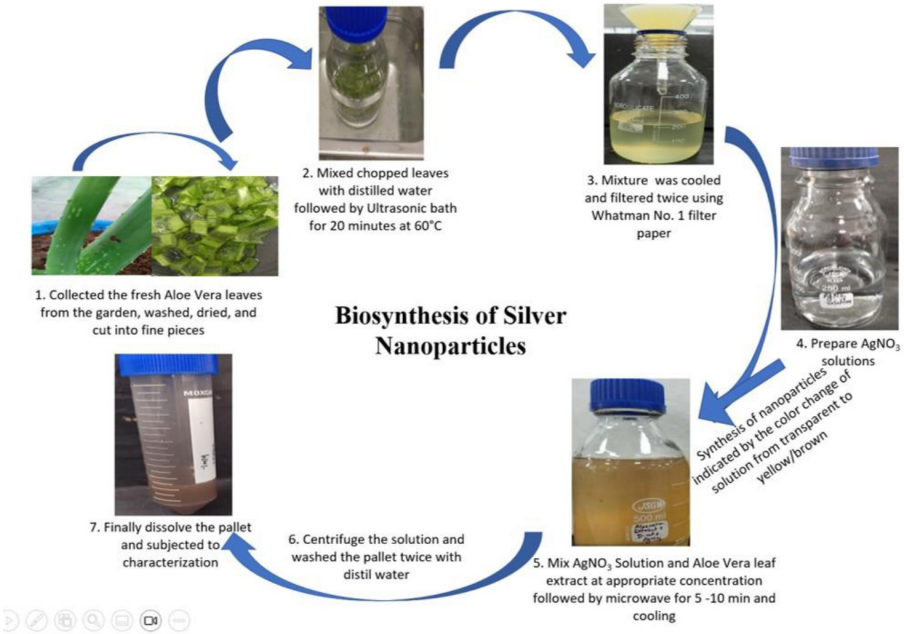


Figure 1. The image shows the seven-step process for synthesising silver nanoparticles (AgNPs) using *Aloe vera* leaf extract as a bio-reductant. The process includes: **(1)** collecting and preparing *Aloe vera* leaves, **(2)** ultrasonication-assisted extraction of *Aloe vera* gel, **(3)** filtration to remove impurities, **(4)** preparing $AgNO_3$ solutions at 0.1 mM, 1.0 mM, and 10.0 mM concentrations, **(5)** mixing *Aloe vera* gel with $AgNO_3$ (1:10 ratio) followed by microwave heating, **(6)** centrifugation to separate nanoparticles and their supernatant, and (7) characterizing the synthesized AgNPs.

bacterial culture at a final concentration of 5×10^8 CFU/ml (0.5 McFarland) was added to LB medium supplemented with different concentrations of synthesised AgNPs (0.0170 µg/ml, 0.0204 µg/ml, 0.0238 µg/ml, 0.0272 µg/ml, 0.0306 µg/ml, 0.0340 µg/ml, and 0.0372 µg/ml) in separate tubes. The control tube contained only LB broth and bacterial suspension, but no AgNPs. All tubes were incubated at 37 °C for 24 hrs and observed for visible growth. Following incubation, samples from all tubes showing positive or negative growth in the MIC assay were plated onto Nutrient agar and incubated at 37 °C for 24 hours to determine the Maximum Tolerance Concentration (MTC) at which the bacteria survive.

2.5.3 *Statistical Analysis*

The triplicate results of the antibiotic sensitivity assay were used to calculate the mean zone of inhibition and standard deviation.

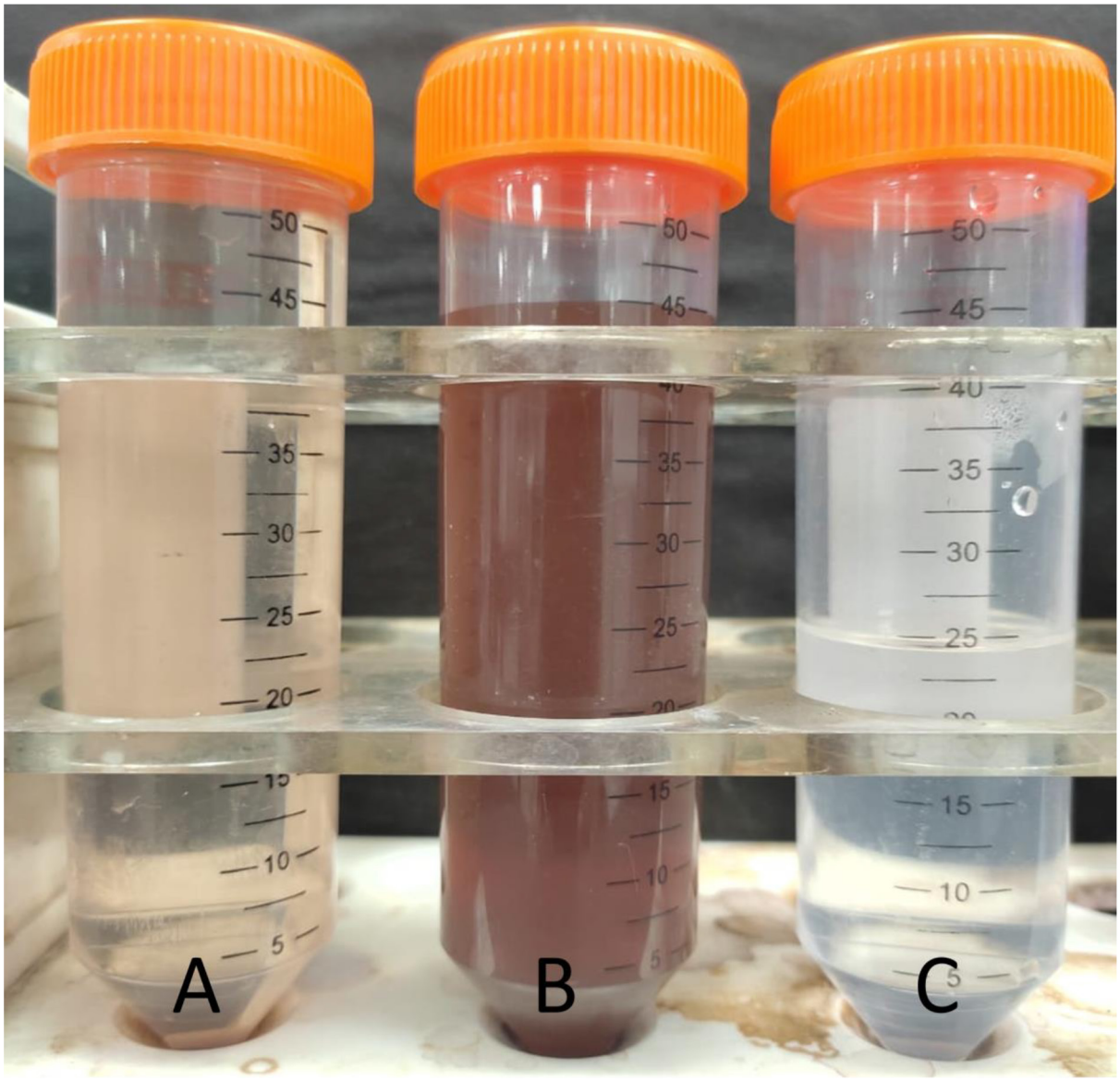


Figure 2. Representative picture showing the colour change. **A:** Pale yellow colour solution of *Aloe vera* leaf extract and $AgNO_3$ solution at a 1:10 ratio before incubation; **B:** Brown colour solution of *Aloe vera* leaf extract and $AgNO_3$ solution at a 1:10 ratio after incubation for 24 hours; **C:** Pure solution of $AgNO_3$.

3. Results and Discussion

3.1 Nanoparticle Synthesis

The reduction of Ag^{+} to Ag^{0} nanoparticles was confirmed by a colour change from pale yellow to brown (Figure 2). This colour change was further analysed using a UV-Vis spectrophotometer. Sharp absorbance peaks for 0.1 mM, 1.0 mM, and 10.0 mM AgNPs were observed at ~430 nm, ~430 nm, and ~410 nm, respectively, after 24 hours of incubation. The UV-Vis spectra recorded from the AgNPs synthesised using the *Aloe vera* extract are presented in Figure 3. The peaks arise due to the Surface Plasmon Resonance (SPR) band of AgNPs[18]. At the start of the reaction, a peak was observed at ~400 nm, and the intensity increased to a maximum after 24 hours.

3.2 Morphology of AgNPs

The TEM micrograph showed nearly spherical shapes, with sizes 20 nm in 0.1 mM AgNP, 50 nm in 1.0 mM AgNP, and 500 nm in 10.0 mM AgNP. The TEM image of AgNPs confirms that nanoparticle size increases with increasing $AgNO_3$ concentration. The high-resolution electron microscopy (TEM) images of AgNPs synthesised in this study are shown in Figure 4.

3.3 X-ray Diffraction (XRD)

The XRD analysis is recommended to obtain information on the nanoparticles' crystalline structure, crystalline grain size, and lattice parameters. Figure 5 shows the XRD pattern of the green-synthesised AgNPs. The XRD pattern of AgNPs showed a single sharp peak at 38° and multiple small peaks, indicating a face-centred cubic crystalline structure. This result is in good agreement with the JCPDS file number (04-0783). The intensity of the sharp peak increases with $AgNO_3$ concentration, suggesting higher crystallinity at higher precursor concentrations. The particle size increased with increasing $AgNO_3$ concentration, consistent with the TEM analysis. The

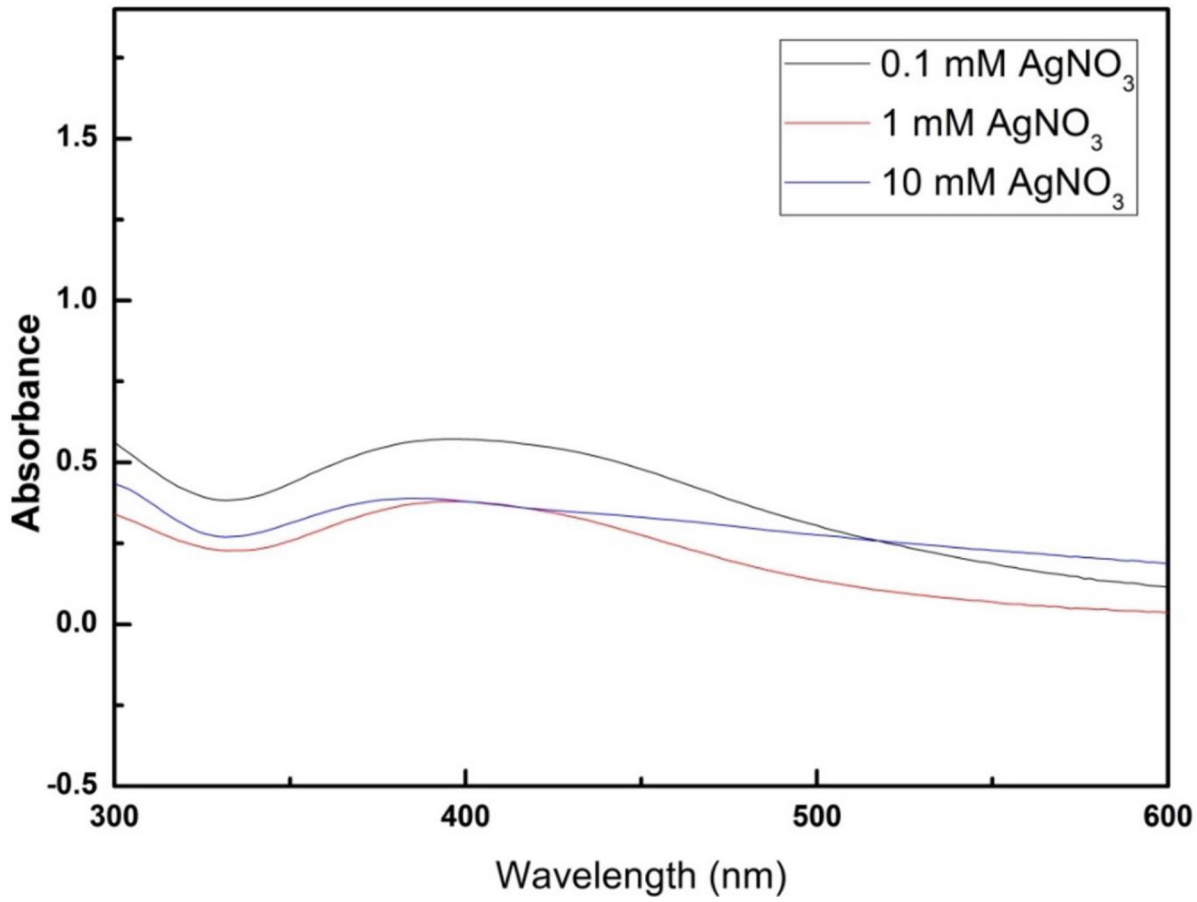


Figure 3. The graph depicts the UV-Visible absorption spectra of silver nanoparticles synthesised using *Aloe Vera* extract at different concentrations of $AgNO_3$.

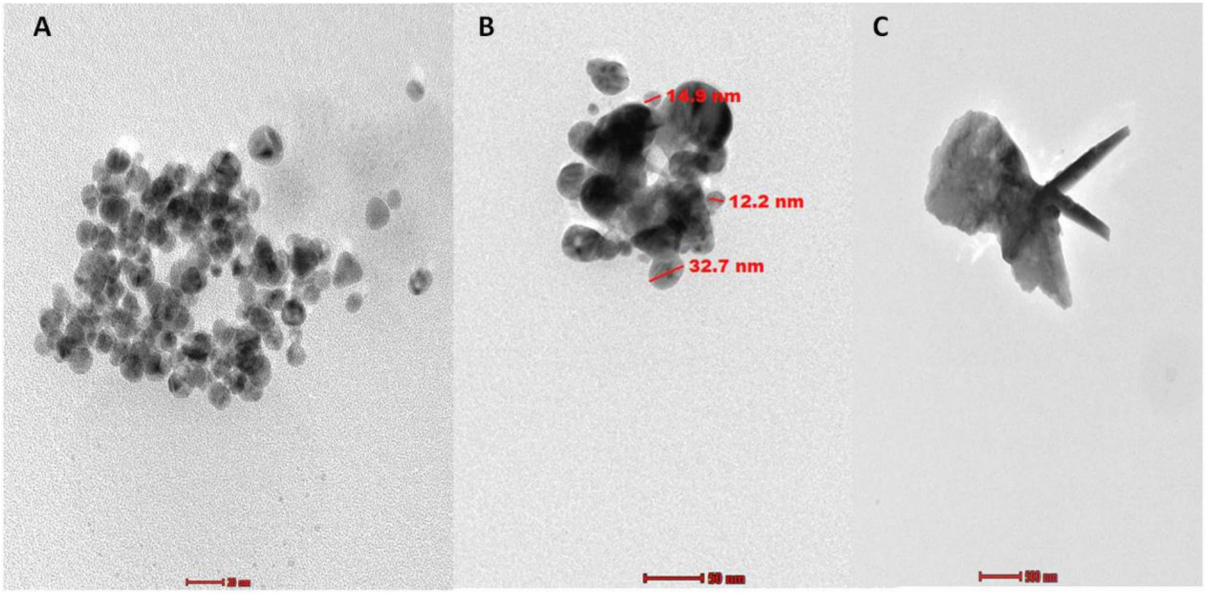


Figure 4. The TEM micrograph of silver nanoparticles (AgNPs). (A) AgNPs synthesised at 0.1 mM $AgNO_3$, (B) AgNPs at 1.0 mM $AgNO_3$, and (C) AgNPs at 10.0 mM $AgNO_3$.

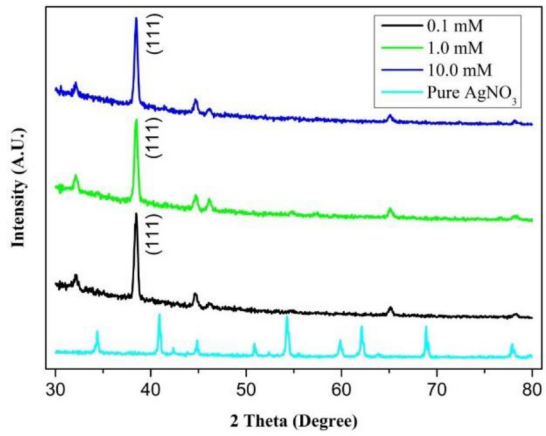


Figure 5. The XRD graph of AgNPs synthesised using an *Aloe vera* plant extract at various concentrations of silver nitrate, *viz*., 0.1 mM, 1.0 mM, and 10.0 mM Where the $AgNO_3$ solution served as control..

slight broadening of the peak at higher concentrations suggests variation in crystallite size, which was calculated to be 21.717 nm (0.1 mM), 21.714 nm (1.0mM), and 26.056 nm (10 mM) using the Scherrer equation[19].

3.4 Antimicrobial Assay

The disc diffusion assay results showed a 9.33±0.94 mm inhibition zone around a disc loaded with nanoparticles synthesised from 0.1 mM $AgNO_3$, whereas no zone formed around the disc loaded with supernatant of nanoparticle suspension. The zones of inhibition measuring 14.0±0.82 mm and 10.0±0.82 mm, respectively, were recorded around the disc loaded with AgNPs and the supernatant obtained from biosynthesis using 1.0 mM $AgNO_3$. While no zone was observed around the disc loaded with AgNPs or the supernatant of nanoparticles synthesised using

Table 1. Determination of MIC and MTC of AgNPs against *S. aureus*

Concentration of AgNPs	0.0170 µg/ml	0.0204 µg/ml	0.0238 µg/ml	0.0272 µg/ml	0.0306 µg/ml	0.0340 µg/ml	0.0374 µg/ml
Set 1	+	+	+	+	+	-	-
Set 2	+	+	+	+	+	-	-
Set 3	+	+	+	+	+	-	-

Positive (+): Turbidity indicating growth; Negative (–): No turbidity indicating no growth.

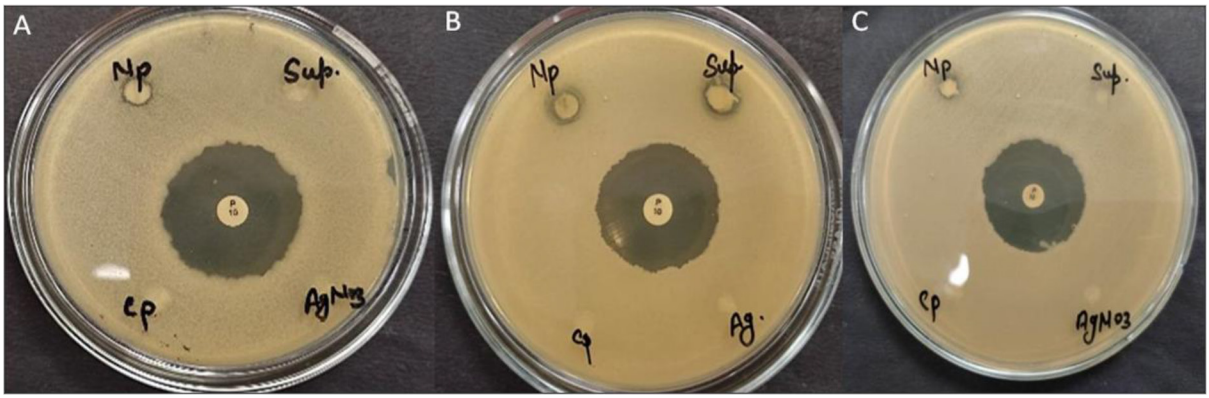


Figure 6. Disc diffusion assay (DDA) showing the inhibition zones indicating the antimicrobial potential of the synthesised nanoparticle using different concentrations of $AgNO_3$; **A:** disc coated with AgNPs of 0.1 mM; **B:** disc loaded with AgNPs of 1.0 mM; **C:** disc loaded with AgNPs of 10.0 mM (**Np:** disc loaded with pellets of AgNPs; **Sup:** disc loaded with supernatant of AgNPs; **Cp:** disc loaded with plant extract; **$AgNO_3$:** disc loaded with silver nitrate solution).

10.0 mM $AgNO_3$. The positive control penicillin (P10) formed a 23.33±0.94 mm zone of inhibition, whereas no clear zone was observed around the $AgNO_3$ solution or the disc loaded with plant extract alone. The results are shown in Figure 6.

The antibacterial assay was performed to determine the MIC and MTC of AgNPs synthesised at 1.0 mM against *S. aureus*. The AgNP concentrations of 0.0306 µg mL^{-1} and 0.0340 µg mL^{-1} were recorded as the MTC and MIC, respectively. The results are shown in Table 1.

4. Discussion

Green nanotechnology has emerged as a sustainable, eco-friendly approach to synthesising nanoparticles using natural plant extracts and agro-industrial bio-waste. This technology has several advantages over chemical and physical methods of nanoparticle synthesis, including reduced use of toxic and radioactive chemicals. Hence, green nanotechnology has emerged as an evolutionary, sustainable technology for addressing global challenges[20]. Therefore, this study aimed to synthesise silver nanoparticles using *Aloe vera* leaf extract. The formation of nanoparticles was detected by observing a colour change resulting from the excitation of surface plasmon resonance, as discussed previously[21]. This was subsequently observed for the maximum absorbance peak at different wavelengths. The UV spectra of biosynthetic nanoparticles in our study showed absorption maxima between ~410 and~430 nm. This was in accordance with previous studies showing a maximum absorbance peak at around 450 nm for plasmon resonance during the synthesis of silver nanoparticles using plant extracts[22,23]. The broad range of absorption peaks indicates the incorporation of biological substances into the nanoparticles during synthesis[24]. The size of nanoparticles significantly affects their physicochemical properties, including reactivity, stability, and therapeutic potential[6,25]. In this study, an increase in particle size with increasing $AgNO_3$ concentration was observed, attributed to the greater availability of $AgNO_3$ at higher concentrations. Similar observations of concentration-dependent increases in particle size have also been made previously[25-27]. The synthesised nanoparticles in this study also exhibited a crystalline structure, with particle size increasing as the $AgNO_3$ concentration increased. These findings are in accordance with the above observation of a concentration-dependent increase in particle size. The finding is also consistent with previous studies that observed an increase in crystalline size with increasing silver particle concentration[28].

Previous studies have reported the antibacterial and anticancer activity of green AgNPs[29]. The exact mechanism by which AgNPs inhibit bacteria is not fully understood. However, a few possible mechanisms include the production of reactive oxygen species (ROS), the binding of Ag^+ ions to proteins, disrupting their functions, and damage to the bacterial cell wall due to the attachment of AgNPs, leading to bacterial cell death[30-32]. In this study, the biosynthesised nanoparticle exhibited the highest antibacterial activity against the *S. aureus* strain when synthesised using 1.0 mM of $AgNO_3$. In

contrast, AgNPs synthesised at lower and higher $AgNO_3$ concentrations showed reduced inhibition or no zone of inhibition. The size of the nanoparticles increased with increasing $AgNO_3$ concentration. The AgNPs synthesised using 1.0 mM $AgNO_3$ had an appropriate size (~50 nm) for antibacterial activity. While the very small (<20 nm) or large sizes (~500 nm) of AgNPs synthesised, respectively at 0.1 mM and 10.0 mM $AgNO_3$, were not appropriate for the intended activity. Our findings contradict the previous report by Ginjupalli *et al*. 2018, which reported better antibacterial activity for nanoparticles with a size >10 nm[33]. This suggests that variations in nanoparticle size significantly affected the antibacterial activity of the synthesised nanoparticles. Our findings align with previous studies predicting an inverse relationship between nanoparticle size and antibacterial activity[34].

5. Conclusion

In this study, silver nanoparticles were successfully synthesised using a simple, eco-friendly green synthesis protocol from fresh *Aloe Vera* leaf extract, yielding AgNPs with a size distribution of 20-500 nm. They had a well-crystallised structure, were nearly spherical, stable, and showed antibacterial activity. This study shows that the synthesised AgNPs at 1.0 mM $AgNO_3$ exhibit effective antibacterial activity, with a Zone of Inhibition of about 14.0±0.82 mm against *S. aureus*. These AgNPs exhibit antibacterial activity at very low concentrations. These findings suggest that plant-mediated AgNPs may serve as a potential complementary approach to conventional antimicrobial agents and antibiotics. However, further investigations are required to better understand their mechanisms of action, safety, and effectiveness against antibiotic-resistant bacterial pathogens.

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8. References

1. Murray CJ, Ikuta KS, Sharara F, Swetschinski L, Robles Aguilar G, Gray A, *et al*. Global burden of bacterial antimicrobial resistance in 2019: a systematic analysis. Lancet. 2022; 399(10325):629–655. https://doi.org/10.1016/S0140-6736(21)02724-0 PMid: 35065702 PMCid: PMC8841637.
2. Elbehiry A, Marzouk E, Abalkhail A, El-Garawany Y, Anagreyyah S, Alnafea Y, Almuzaini AM, Alwarhi W, Rawway M, Draz A. The development of technology to prevent, diagnose, and manage antimicrobial resistance in healthcare-associated infections. Vaccines. 2022; 10(12):2100. https://doi.org/10.3390/vaccines10122100 PMid: 36560510 PMCid: PMC9780923.
3. Lee NY, Ko WC, Hsueh PR. Nanoparticles in the treatment of infections caused by multidrug-resistant organisms. Front Pharmacol. 2019; 10:1153. https://doi.org/10.3389/fphar.2019.01153 PMid: 31636564 PMCid: PMC6787836.
4. Lee SH, Jun BH. Silver nanoparticles: synthesis and application for nanomedicine. Int J Mol Sci. 2019; 20(4):865. https://doi.org/10.3390/ijms20040865 PMid: 30781560 PMCid: PMC6412188.
5. Muzammil S, Hayat S, Fakhar-e-Alam M, Aslam B, Siddique MH, Nisar MA, *et al*. Nanoantibiotics: future nanotechnologies to combat antibiotic resistance. Front Biosci - Elit. 2018; 10(2):352–374. https://doi.org/10.2741/e827 PMid: 29293463.
6. Kazemi S, Hosseingholian A, Gohari SD, Feirahi F, Moammeri F, Mesbahian G, *et al*. Recent advances in green synthesized nanoparticles: from production to application. Mater Today Sustain. 2023; 24:100500. https://doi.org/10.1016/j.mtsust.2023.100500
7. Ahmadi O, Jafarizadeh-Malmiri H, Jodeiri N. Eco-friendly microwave-enhanced green synthesis of silver nanoparticles using *Aloe vera* leaf extract and their physico-chemical and antibacterial studies. Green Process Synth. 2018; 7(3):231–240. https://doi.org/10.1515/gps-2017-0039
8. Alfuraydi AA, Devanesan S, Al-Ansari M, AlSalhi MS, Ranjitsingh AJ. Eco-friendly green synthesis of silver nanoparticles from the sesame oil cake and its potential anticancer and antimicrobial activities. J Photochem Photobiol B Biol. 2019; 192:83–89. https://doi.org/10.1016/j.jphotobiol.2019.01.011 PMid: 30710829.
9. Balamurugan V, Ragavendran C, Arulbalachandran D, Fahad Alrefaei A, Rajendran R. Green synthesis of silver nanoparticles using *Pandanus tectorius* aerial root extract: characterization, antibacterial, cytotoxic, and photocatalytic properties, and ecotoxicological assessment. Inorg Chem

Commun. 2024; 168:112882. https://doi.org/10.1016/j.inoche.2024.112882
10. Fahim M, Shahzaib A, Nishat N, Jahan A, Bhat TA, Inam A. Green synthesis of silver nanoparticles: a comprehensive review of methods, influencing factors, and applications. JCIS Open. 2024; 16:100125. https://doi.org/10.1016/j.jciso.2024.100125
11. Sharifi-Rad M, Elshafie HS, Pohl P. Green synthesis of silver nanoparticles (AgNPs) by *Lallemantia royleana* leaf extract: their bio-pharmaceutical and catalytic properties. J Photochem Photobiol A Chem. 2024; 448:115318. https://doi.org/10.1016/j.jphotochem.2023.115318
12. Logaranjan K, Raiza AJ, Gopinath SCB, Chen Y, Pandian K. Shape- and size-controlled synthesis of silver nanoparticles using *Aloe vera* plant extract and their antimicrobial activity. Nanoscale Res Lett. 2016; 11(1):520. https://doi.org/10.1186/s11671-016-1725-x PMid: 27885623 PMCid: PMC5122529.
13. Burange PJ, Tawar MG, Bairagi RA, Malviya VR, Sahu VK, Shewatkar SN, *et al*. Synthesis of silver nanoparticles by using *Aloe vera* and *Thuja orientalis* leaves extract and their biological activity: a comprehensive review. Bull Natl Res Cent. 2021; 45(1):181. https://doi.org/10.1186/s42269-021-00639-2
14. Joudeh N, Linke D. Nanoparticle classification, physicochemical properties, characterization, and applications: a comprehensive review for biologists. J Nanobiotechnology. 2022; 20(1):262. https://doi.org/10.1186/s12951-022-01477-8 PMid: 35672712 PMCid: PMC9171489.
15. Medda S, Hajra A, Dey U, Bose P, Mondal NK. Biosynthesis of silver nanoparticles from *Aloe vera* leaf extract and antifungal activity against *Rhizopus* sp. and *Aspergillus* sp. Appl Nanosci. 2015; 5(7):875–880. https://doi.org/10.1007/s13204-014-0387-1
16. Schuetz AN, Ferrell A, Hindler JA, Humphries R, Bobenchik AM. Overview of changes in the Clinical and Laboratory Standards Institute Performance Standards for Antimicrobial Susceptibility Testing: M100 32nd and 33rd editions. J Clin Microbiol. 2025; 63(9). https://pmc.ncbi.nlm.nih.gov/articles/PMC12421849/ PMid: 40772786 PMCid: PMC12421849.
17. Shirisha A, Vijayakumar A. Minimum Inhibitory Concentration (MIC) and Minimum Bacterial Concentration (MBC) evaluation of green synthesised silver nanoparticles on *Staphylococcus aureus* and *Streptococcus agalactiae*. Int J Vet Sci Anim Husb. 2023; 8(4):244–249. https://doi.org/10.22271/veterinary.2023.v8.i4d.604
18. Sun Y, Mayers B, Herricks T, Xia Y. Polyol synthesis of uniform silver nanowires: a plausible growth mechanism and the supporting evidence. Nano Letters. 2003; 3(7):955-960. https://doi.org/10.1021/nl034312m
19. Scherrer PJ. Estimation of the size and internal structure of colloidal particles by means of röntgen. Nachr Ges Wiss Göttingen. 1918; 2:96-100.
20. Osman AI, Zhang Y, Farghali M, Rashwan AK, Eltaweil AS, Abd El-Monaem EM, *et al*. Synthesis of green nanoparticles for energy, biomedical, environmental, agricultural, and food applications: a review. Environ Chem Lett. 2024; 22(2):841–887. https://doi.org/10.1007/s10311-023-01682-3
21. Supriya G, Kumari S. Green synthesis of silver nanoparticles using *Aloe vera* extract and assessing their antimicrobial activity against skin infections. Int J Sci Res Biol Sci. 2019; 6(1):60-65. https://ijsrbs.isroset.org/index.php/j/article/view/296
22. Alwhibi MS, Soliman DA, Awad MA, Alangery AB, Al Dehaish H, Alwasel YA. Green synthesis of silver nanoparticles: characterization and its potential biomedical applications. Green Process Synth. 2021; 10(1):412–420. https://doi.org/10.1515/gps-2021-0039
23. Mojela NL, Pillay K, Komane PP. Synthesis and application of silver nanoparticles from lemon peel extract and other local plant extracts for detection of "blood" at crime scene. Forensic Sci Int. 2024; 365:112257. https://doi.org/10.1016/j.forsciint.2024.112257 PMid: 39486255.
24. Mikhailova EO. Silver nanoparticles: mechanism of action and probable bio-application. J Funct Biomater. 2020; 11(4):84. https://doi.org/10.3390/jfb11040084 PMid: 33255874 PMCid: PMC7711612
25. 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 Environ Microbiol. 2007; 73(6):1712–1720. https://doi.org/10.1128/AEM.02218-06 PMid: 17261510 PMCid: PMC1828795.
26. Al-Hada NM, Kasmani RM, Kasim H, Al-Ghaili AM, Saleh MA, Banoqitah EM, *et al*. The effect of precursor concentration on the particle size, crystal size, and optical energy gap of $Ce_xSn_{1-x}O_2$ nanofabrication. Nanomaterials. 2021; 11(8):2143. https://doi.org/10.3390/nano11082143 PMid: 34443973 PMCid: PMC8401046.
27. Ahmad N, Ang BC, Amalina MA, Bong CW. Influence of precursor concentration and temperature on the formation of nanosilver in chemical reduction method. Sains Malaysiana. 2018; 47(1):157–168. https://doi.org/10.17576/jsm-2018-4701-19
28. Htwe YZN, Chow WS, Suda Y, Mariatti M. Effect of silver nitrate concentration on the production of silver nanoparticles by green method. Mater Today Proc. 2019; 17:568–573. https://doi.org/10.1016/j.matpr.2019.06.336
29. Wypij M, Jędrzejewski T, Trzcińska-Wencel J, Ostrowski M, Rai M, Golińska P. Green synthesized silver nanoparticles: antibacterial and anticancer activities, biocompatibility, and analyses of surface-attached proteins. Front Microbiol. 2021;

12:632505. https://doi.org/10.3389/fmicb.2021.632505 PMid: 33967977 PMCid: PMC8100210.
30. 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):217–227. https://doi.org/10.1016/j.jrras.2015.10.002
31. Siddiqi KS, Husen A, Rao RAK. A review on biosynthesis of silver nanoparticles and their biocidal properties. J Nanobiotechnology. 2018; 16(14). https://doi.org/10.1186/s12951-018-0334-5 PMid: 29452593 PMCid: PMC5815253.
32. Banala RR, Nagati VB, Karnati PR. Green synthesis and characterization of *Carica papaya* leaf extract coated silver nanoparticles through X-ray diffraction, electron microscopy and evaluation of bactericidal properties. Saudi J Biol Sci. 2015; 22(5):637–644. https://doi.org/10.1016/j.sjbs.2015.01.007 PMid: 26288570 PMCid: PMC4537873.
33. Ginjupalli K, Shaw T, Tellapragada C, Alla R, Gupta L, Perampalli NU. Does the size matter? Evaluation of effect of incorporation of silver nanoparticles of varying particle size on the antimicrobial activity and properties of irreversible hydrocolloid impression material. Dent Mater. 2018; 34(7):e158–e165. https://doi.org/10.1016/j.dental.2018.03.016 PMid: 29706228.
34. Ershov VA, Ershov BG. Effect of silver nanoparticle size on antibacterial activity. Toxics. 2024; 12(11):801. https://doi.org/10.3390/toxics12110801 PMid: 39590981 PMCid: PMC11598259.

Author Contribution

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