Nigerian Journal of Science and Environment 2025 Volume 23 (2) 15 – 28 ISSN: 3043 – 4440
https://doi.org/10.61448/njse232252

SYNTHESIS OF GOLD NANOPARTICLES FROM LEAF EXTRACT OF *Vitex grandifolia* AND EVALUATION OF ITS ANTIBACTERIAL ACTIVITY AGAINST MULTI DRUG RESISTANT BACTERIA

Thonda, O.A.[1] Fagbemi, K.O.*[1] and Okunlola, O.I[1]
[1] *Department of Microbiology, school of science and technology, PMB 4005. Babcock University, Ilisan Remo Ogun State*
**Corresponding Author: Fagbemik@babcock.edu.ng*

ABSTRACT

The alarming prevalence of multidrug-resistant (MDR) bacteria threatens global public health. Current research has investigated the use of gold nanoparticles (AuNPs) as a potential solution. As a result, this study tends to establish that gold nanoparticles (AuNPs) synthesised from *Vitex grandifolia* leaf extract can be effective against these pathogens. Sunlight-driven synthesis was used for the gold nanoparticle synthesis. The application of techniques such as ultraviolet-visible-spectroscopy (UV-Vis), Fourier transform infrared spectroscopy (FTIR), X-ray diffraction (XRD,) and Transmission electron microscopy (TEM) were used for the detailed characterisation of the synthesised nanoparticles. The antimicrobial efficacy of the AuNPs against these multidrug-resistant pathogens was accessed using the agar well diffusion method at various concentrations that range between 10µg/ml -100µg/ml. The obtained UV-Vis result indicated that the absorbance peak of the synthesised nanoparticle was between 400nm and 600nm of visible light region, with a band gap at 3.5eV. Also, the FTIR results showed peaks that ranged between 470.96cm^{-1} and 3433.17c,m^{-1} which are functional groups such as alkenyl C=C stretch, OH stretches, and polysulfides. To validate its antibacterial activity, AuNPs exhibited a zone of inhibition that ranges between 7mm and 13mm against various pathogens such as *Pseudomonas aeruginosa*, *Salmonella typhi*, *Streptococcus pyogenes* and *Klebsiella pneumoniae* at different concentrations. Thus, this study offers a rapid and cost-effective method for synthesising AuNPs using *Vitex grandifolia.* This indicates positive potential in tackling multidrug-resistant pathogens, reducing the milestone in this research study.

Keywords: Antimicrobial resistance; gold nanoparticles; multidrug-resistant pathogens; *Vitex grandifolia*; sunlight-driven synthesis

INTRODUCTION

The alarming prevalence of multi-drug resistance in pathogenic microorganisms poses a significant hazard to worldwide wellness and security (Sarma *et al.*, 2024). Studies by the World Health Organisation (WHO) indicate that antimicrobial resistance (AMR) ranks among the foremost global public health threats, directly resulting in approximately 1.27 million deaths and contributing to over 4.95 million fatalities (WHO, 2023). This multi-drug resistance may occur due to the production of enzymes such as beta-lactamases and aminoglycosides, a decrease in the antibiotic's intracellular concentration, as well as expression of efflux pumps that displaces the antibiotics, which are capable of inactivating several metabolic activities, (Shaikh *et al.*, 2019; Giráldez-Pérez *et al.*, 2023).

Recent advances in scientific research, most notably the concept of nanotechnology, have significantly contributed to tackling this threatening challenge. Nanotechnology consists of techniques for producing and controlling nano-sized materials, usually ranging from 1 to 100 nanometers (Bobokulova, 2024). Some nano-sized materials, often considered nanoparticles, have been significantly recognised for their enormous beneficial properties such as antimicrobial, drug delivery, and antioxidant. Several approaches are used to synthesise nanoparticles, among which, biological methods are most preferred due to their less hazardous and environmentally friendly nature (Saravanan *et al.,* 2020). This involves synthesising nanoparticles by using microorganisms, plants, bio-molecules, and other natural raw materials. They are utilised as special reducing and capping agents for effectively converting metallic ions into nanoparticles, which intricately bind to the characteristics of the raw materials, thus creating a strong synergy between both materials (Sathiyaraj *et al.,* 2021). *Vitex grandifolia* leaves were utilized in this study due to their numerous therapeutic potentials and less rigid requirements (Oluwaseun *et al.,* 2021). *Vitex grandifolia* is a shrub that grows in the seasonally dry tropical biome of the Lamiaceae family (Bello *et al.,* 2018). Furthermore, several studies conducted have shown that several parts of *Vitex grandifolia* possess beneficial medicinal properties used for the treatment of bronchial complaints, rheumatism, umbilical cord infections and fever (Amo-Mensah *et al.,* 2020: Bello *et al.,* 2023: Sharifah & Hassan 2016). Gold nanoparticles (AuNPs) have attracted significant attention among the diverse nanoparticles because of their higher bio-compatibility and versatile physiochemical properties. Also, for its easy functionalisation by integrating antibiotics and bioactive compounds into it, which are essential for improving their antimicrobial properties to combat multi-drug resistance (Hussein *et al.,* 2021). In addition, many authors have documented that surface-modified plant-gold nanoparticles have been utilised in biological research and treatment of acute myeloid leukaemia (Zhang *et al.,* 2019; Ahmeda & Zanganeh, 2019; Acharya *et al.,* 2021; Yun *et al.,* 2019).

Moreover, these antibiotic-conjugated AuNPs enhance the concentration of the antibiotics in bacterial sites where antibacterial interact, thus aiding the binding of antimicrobial agents to bacteria (Shaikh *et al.,* 2019). Therefore, the main objective of this study is to synthesise gold nanoparticles utilising *Vitex grandifolia* leaf extract, characterise it, and evaluate the antibacterial activity against some multidrug-resistant pathogens.

EXPERIMENTAL PROCEDURE

Materials

Freshly harvested leaves of *Vitex grandifolia* were obtained from Ilishan, Remo, located in Ikenne Local Government Area of Ogun State, Nigeria (6.8932° N, 3.7105° E), Nigeria on January 2023. The sampled leaves were identified and authenticated at the Microbiology department, Babcock University, Ilishan-Remo Ogun State, Nigeria. The media used during this study were purchased from Himedia Laboratories Private Ltd, Thane, India. Bacterial strains of notably *Escherichia coli, Salmonella typhi, Pseudomonas aeruginosa*, *Staphylococcus aureus*, and *Streptococcus pyogenes* were obtained from stock culture in the Microbiology department of Babcock University, Ilishan-Remo, Ogun state, Nigeria. Gold nitrate ($AuNO_3$) was used for the study. All glassware utilised during this study underwent a thorough sterilisation process before usage.

Plant extracts preparation

The leaves were oven-dried, pulverised, and subsequently stored at room temperature in a sterile air-tight container, 5g of the powdered leaves was introduced into 50 ml of deionised water and heated for an hour at 60 ^oC. On cooling, the mixture was filtered using a NO. 1 Whatman filter membrane paper and centrifuge (Gallenkomp Model 80-2 England) at 3000 rpm for 2 minutes. The supernatant was conserved in an air-tight container at 4 ^oC for future reference.

Preparation of Gold nitrate solution

Gold nitrate ($AuNO_3$) solution of 1mM concentration was prepared by dissolving 0.2589g in 1000ml distilled water.

Gold nanoparticles Biosynthesis

The synthesis of gold nanoparticles involved dispersing 1g of the leaf extract into 10 ml of water. Thereafter. 1ml of resulting mixture was introduced into 40ml of 1mM concentrated $AuNO_3$. The mixture was gently mixed and exposed to sun radiation for 30 minutes, during which changes to a brownish colour were observed. This colour change ascertains that the gold nitrate has undergone a bio-reduction reaction, thus facilitating the green synthesis of gold nanoparticles. The AuNPs were washed with water and recovered after being centrifuged for 15 minutes at 10,000 rpm ((Hassanisaadi *et al*., 2021).

Characterisation of Gold nanoparticles

Several analytical techniques were applied to observe the synthesised gold nanoparticles' formation and the chemical, morphological and physical characteristics. These techniques include Fourier transform infrared spectroscopy (FT-IR), ultraviolet-visible spectroscopy (UV-VIS), energy-dispersive X-ray (EDX), X-ray powder diffraction (XRD) analysis and transmission electron microscopy (TEM).

FTIR analysis

The FITR techniques were conducted to identify the potential biomolecules in the *V. grandifolia* extract that are capable of capping effects, thus causing the metallic nanoparticles to be efficiently stabilised. The AuNPs were separated from the organic compounds by centrifuging the reaction mixture for 10 minutes at 10,000 rpm. The resulting pellets were lyophilised and diluted with KBr (Potassium bromide) at a ratio of 1:100. This analysis was conducted by a software attached to the instrument (Nicolet iS10 FT-IR spectrometer) (Adeoye-Isijola *et al*., 2025).

UV-VIS spectra analysis

The UV-VIS analysis is a popular characterisation technique conducted to evaluate the absorbance, which is a function of the wavelength of the synthesised nanoparticle in an aqueous suspension since some possess special absorption peaks and are different under microscopic scale. This characterisation of the synthesised AuNPs was authenticated using the Milipore spectroquant Pharo 300 Spectrophotometer. The biological reduction of Au ions to facilitate the production of AuNPs was analysed using the UV-visible absorption spectrophotometer (UV-1800) at a 2nm resolution between 200 and 800nm. Millipore water was used as a blank for baseline adjustment during this analysis (Adegoke *et al*., 2024).

.

XRD analysis

The crystalline structure of the biosynthesised AuNPs extracts was evaluated by the XRD system (Bruker - D8 Advanced Germany instrument) at an angle of 2θ with Cu Kα radians. During this analysis, a wavelength of 0.15418 nm was utilized (Olowe *et al*., 2025).

TEM and EDX analysis

Transmission electron microscopy (TEM) was used to determine the size and shape of the nanoparticles. A tiny portion

Nigerian Journal of Science and Environment 2025 Volume 23 (2) 15 – 28 ISSN: 3043 – 4440
https://doi.org/10.61448/njse232252

of the washed sample was dropped on Formvar carbon-coated 200-mesh copper grids to conduct the analysis. After air-drying the grid, electron micrographs of the gold nanoparticles were acquired using a JEOL TEM 1010, 60 kV. An energy-dispersive X-ray spectrometry system (TEM. EDAX DX4) was utilised to identify the biosynthesised AuNPs' elemental composition (Singh *et al*., 2015).

Antibacterial activity screening

The antibacterial activity of AuNPs was studied by utilising the standard Kirby Bauer diffusion method against pathogenic strains of *Staphylococcus aureus, Escherichia coli, Salmonella typhi, Pseudomonas aeruginosa,* and *Streptococcus pyogenes*. The Muller Hinton agar was used in culturing these pathogens by utilising a sterile swab stick for inoculation at concentrations between 10^5-10^6 CFU/ml. Thereafter, wells of diameter 8mm were aseptically bored on the agar plates using a sterile cork borer and labelled appropriately. The respective wells were filled with various concentrations of the biosynthesised gold NPs at intervals of 20 µg/mL. In addition, standard antibiotics such as Augmentin (30 µg), Gentamicin (10 µg), Ciprofloxacin (5 µg), Ofloxacin (5 µg), Cefuroxime (30 µg), Nitrofurantoin (300 µg), Ceftazidime (30 µg) and Cefixime (30 µg) of different concentrations were used as control to determine the antibiotic resistance potential of these pathogens. The plates were subsequently incubated at 37 °C for 24 hours in a DNP-9162 Thermostat incubator. The zone of inhibition was measured around the wells loaded with AuNPs (Fgabemi *et al*., 2024).

RESULT AND DISCUSSION

UV analysis

A popular technique used in determining the synthesis of metallic NPs is UV–vis spectroscopic analysis, which evaluates their unique optical properties that depend directly on the surface plasmon resonance (Nizamov *et al.,* 2022). The synthesised AuNPs were identified by a conspicuous surface plasmon resonance (SPR) band, reading 533 nm, as shown in the UV-visible spectra (Fig 1). The SPR band appeared when free electrons in AuNPs were triggered while absorbing visible light (Sathiyaraj *et al.*, 2021). The single band seen on the UV spectra corroborates Mie's hypothesis, which states that spherical nanoparticles exhibit a single SPR band in their absorption spectra (Dehdari *et al.*, 2024). A similar UV absorption peak at 533nm was reported by Abd El-Aziz et al. (2018) for AuNP nanoparticles synthesised using *Lawsonia inermis*. The change in the colour of the mixture from brown to dark brown confirms the synthesis of AuNPs (Fig. 1 Insert).

Nigerian Journal of Science and Environment 2025 Volume 23 (2) 15 – 28 ISSN: 3043 – 4440
https://doi.org/10.61448/njse232252

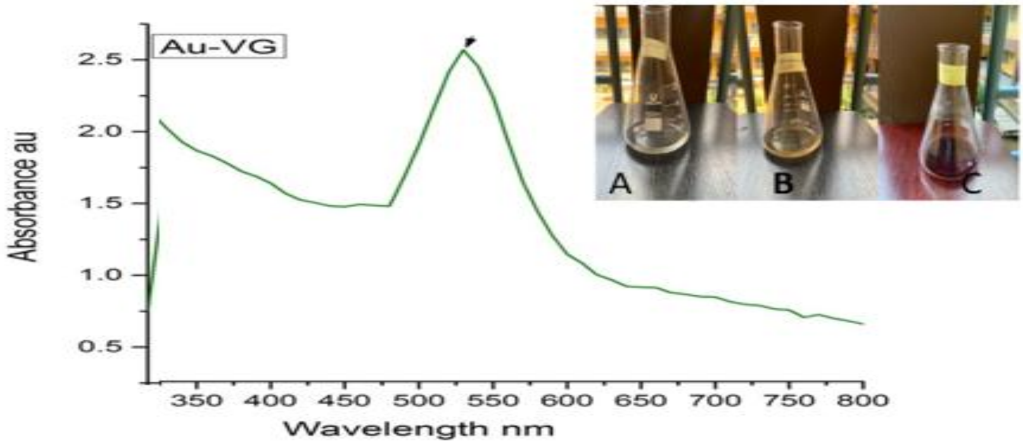

Figure 1: UV–vis spectrum of AuNPs mediated from *Vitex gradifolia*. Insert: A; $AuNO_3$ B Mixture of Plant extract and AuNo3 C: AuNPs synthesised

The bandgap energy was measured via UV spectroscopy (Fig 2) using the Tauc plot approach (Jubu *et al.,* 2024) and was found to be 3.15 eV, and this is confirmed by earlier report (Antony *et al.*, 2023).

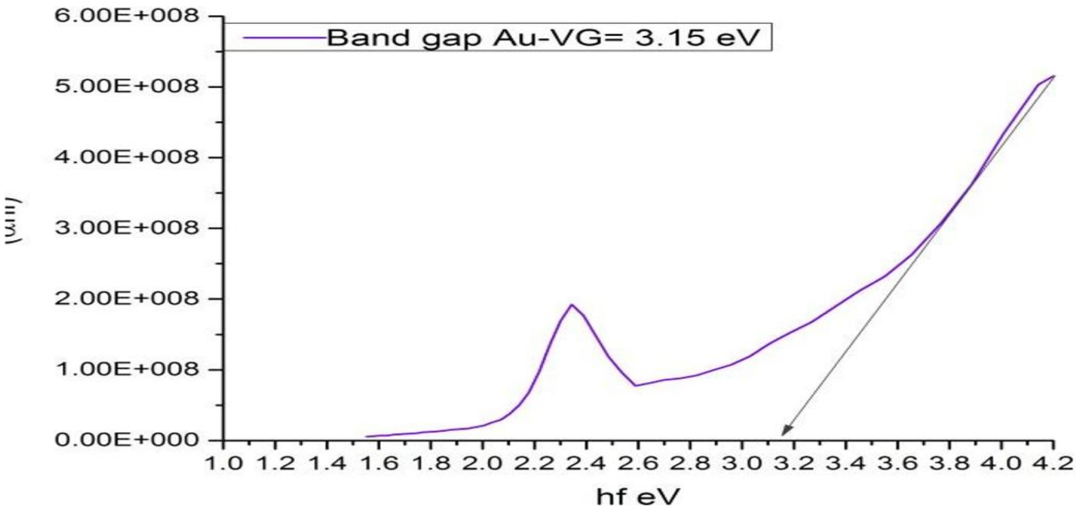

Figure 2. Energy bandgap of *Vitex gradifolia* mediated AuNPs.

FTIR analysis

FTIR spectroscopy was the technique applied to determine the role of various chemical groups of phytochemicals found in the *Vitex grandifolia* leaf that are involved in the reduction of $AuNO_3$. Several peaks were observed in the FTIR spectra at 3452 cm^{-1}, 2985 cm^{-1}, 2863 cm^{-1}, 2375 cm^{-1}, 1676 cm^{-1}, 1375 cm^{-1}, 1010 cm^{-1}, 857 cm^{-1} and 502 cm^{-1}. The distinctive robust band at 3452 cm^{-1} corresponds to the stretching vibration of -OH groups; the two bands showing low intensity at 2985 cm^{-1} to 2863 cm^{-1} signify elongation of the C-H band (Xu *et al.*, 2023). The penetrating deep band at 2375 cm^{-1} indicates the existence of C-N stretching of aliphatic primary amine. The vibrating band denoting 1613.27 cm^{-1} shows the presence of chemical compounds, such as aldehydes, carboxylic, or ketones (Fagbemi *et al.,* 2024). Absorption peaks around 1375 cm^{-1}, corresponding to alkanes or alkyl groups of protein.

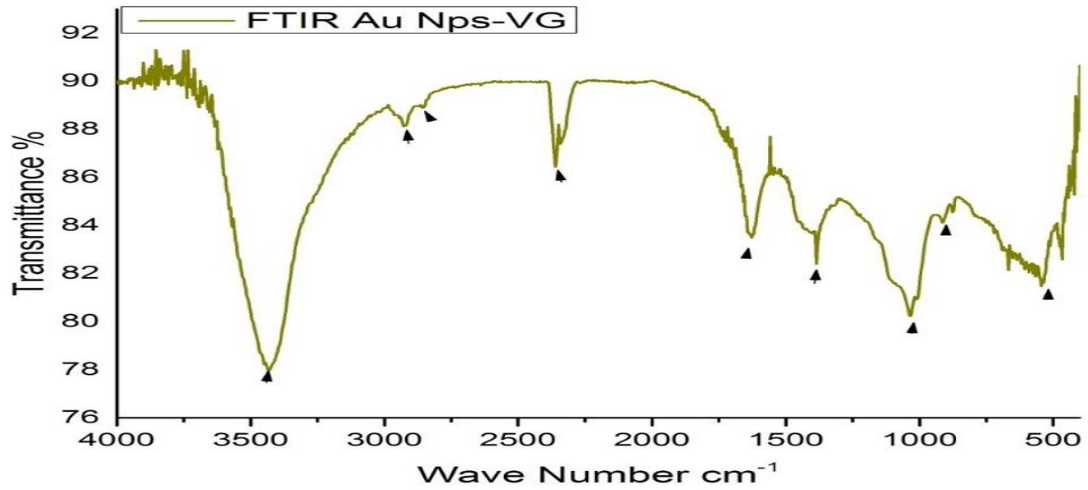

Figure 3. FTIR spectrum of *Vitex gradofolia* mediated AuNPs.

XRD analysis
XRD is primarily used for recognising phases and characterising the crystal structure of synthesised nanoparticles. Fig 4 shows the face-centred cubic (FCC) AuNPs based on XRD analysis; this agrees with the FCC structure shown on card number 04-0784 (Min *et al.*, 2024). Moreover, the XRD peaks denoting 2θ of 27.35, 36.05, 40.05. 56.35 and 70.05 corresponds to (1 1 0), (111), (121), (200) and (311). These Bragg's reflection planes observed suggest that the synthesised AuNP are cubical in shape with a crystalline nature. These results further corroborate previous reports regarding the synthesis of gold nanoparticles (Khatami *et al.*, 2021).

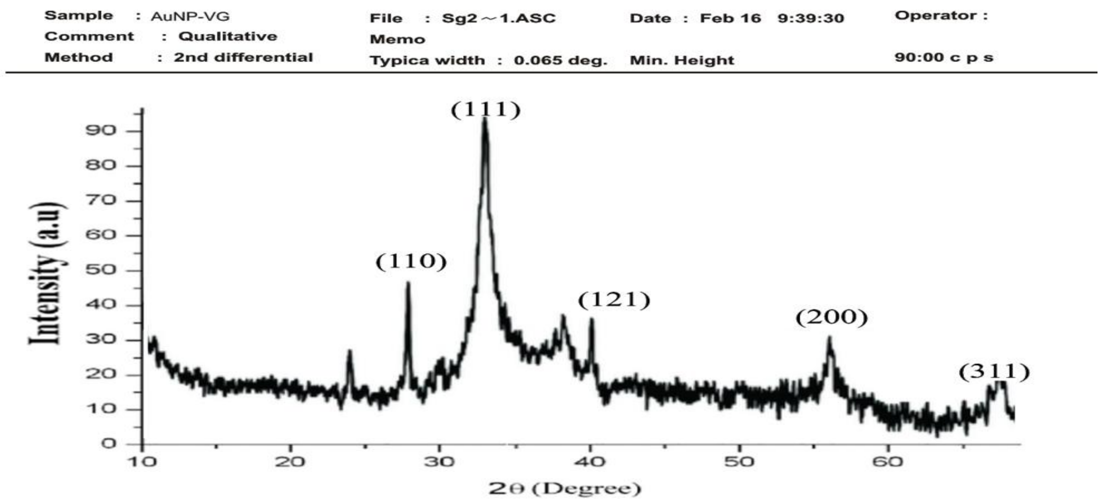

Figure 4. XRD spectrum of *Vitex gradofolia* mediated AuNPs.

EDX analysis
The biologically synthesised AuNP using *Vitex gradifolia* extract was further verified through EDS, as displayed in Figure 5. A substantial gold signal (72.94%) was observed in the EDS analysis, alongside weak oxygen (20.66) and carbon peaks (6.30%). The weak signals originate from macromolecules in *Vitex gradifolia* extract, including proteins, enzymes, and salts (Sathiyaraj *et al.*, 2021). The findings are consistent with previous reports of gold NPs synthesised using biological methods (Correa *et al.*, 2016; Erasmus *et al.*, 2024).

Nigerian Journal of Science and Environment 2025 Volume 23 (2) 15 – 28 ISSN: 3043 – 4440
https://doi.org/10.61448/njse232252

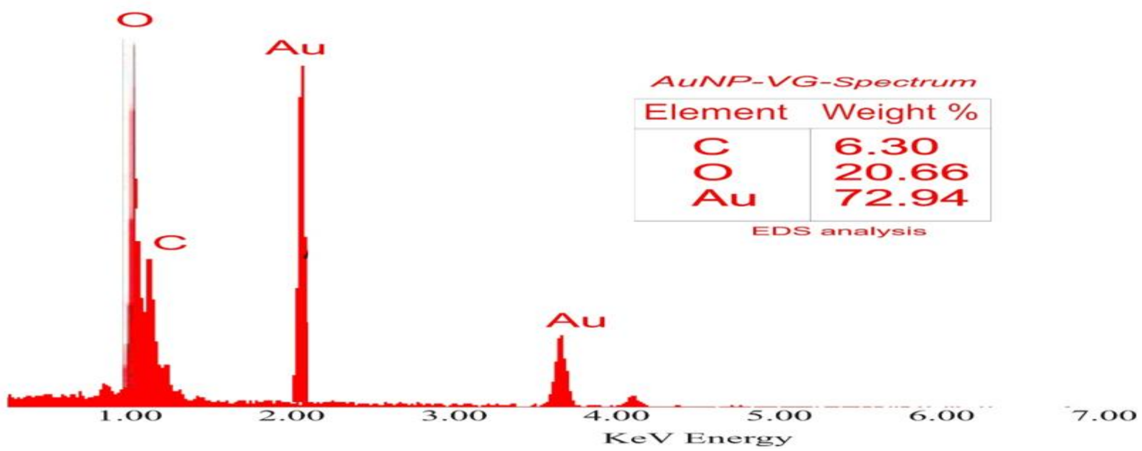

Figure 5. EDX spectrum of *Vitex gradofolia* mediated AuNPs.

TEM Analysis

The morphology of the synthesised AuNPs were measured by the use of TEM and ImageJ software. Figure 6 displays the micrographs of TEM as well as the particle size distribution of the gold nanoparticles that were synthesised. Utilising a voltage of 15 kV and a magnification of 1000, the resultant size fell within the range of 0 and 100 nm. It shows that the gold nanoparticle synthesised is mainly spherical in shape and are between the size of 1-12 nm. The morphology observed in the TEM micrographs confirms the preliminary results from the UV study, indicating that particles exhibiting a single SPR band predominantly had a spherical form.

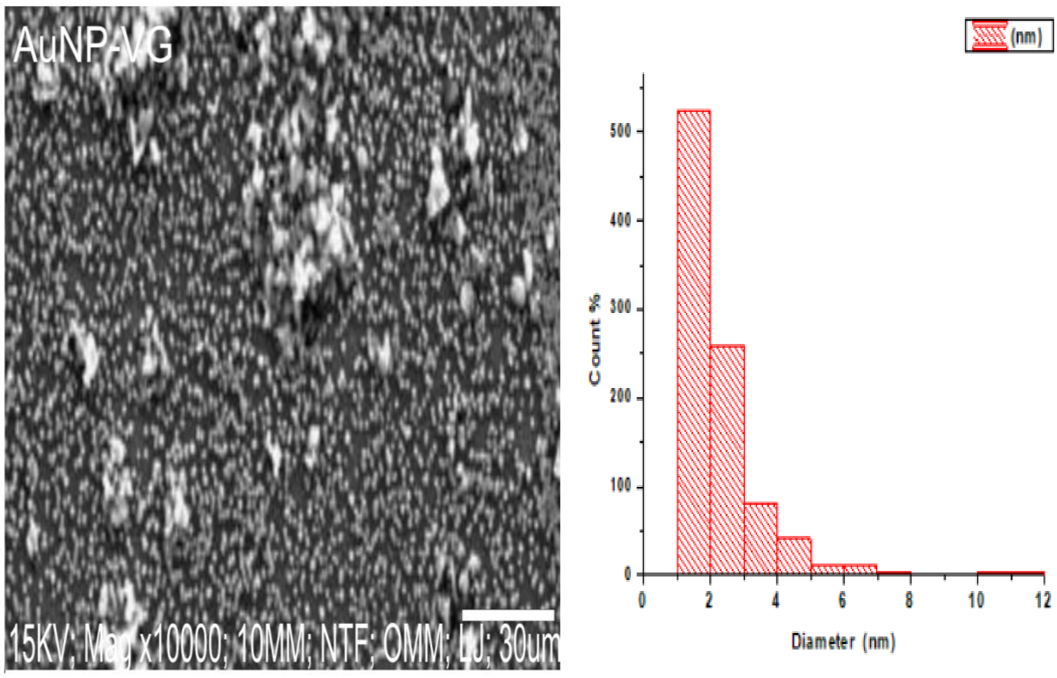

Figure 6. SEM Microgram and particle distribution of the *Vitex gradofolia* mediated AuNPs.

Nigerian Journal of Science and Environment 2025 Volume 23 (2) 15 – 28 ISSN: 3043 – 4440
https://doi.org/10.61448/njse232252

Antibacterial Activities

This research was conducted to determine the efficacy of gold NPs against multidrug-resistant bacteria, as displayed in Table 2. This shows the various zones of inhibition exhibited by each isolate tested, and it demonstrated that the nanoparticle had no potent effect at doses below 20 µg/mL, underscoring concentration-dependent characteristics. These findings align with previous research outcomes demonstrating a link between the concentration of extract and antibacterial activity, thereby contributing to the current evidence in this field (Fagbemi *et al.*, 2024; Baalousha *et al.*, 2015; Fagbemi *et al.*, 2023).

An additional evaluation of the antibacterial properties of AuNP at a concentration of 60 µg/mL, compared to traditional pharmaceuticals, was performed against various isolated bacterial strains, as illustrated in Table 1. These bacteria include Gram-negative species such as *Pseudomonas aeruginosa, Salmonella typhimurium and Klebsiella pneumoniae,* as well as Gram-positive strains like *Staphylococcus aureus* and *Streptococcus pyogenes*. All examined organisms exhibited susceptibility to some commercially available antibiotics, except for Cefutrizine, Cefraxone, and Cefuroxime, indicating the isolates' multidrug-resistant potential, following other studies (Terreni *et al.*, 2021; Mba & Nweze, 2021).

Table 1
Zone of inhibition (mm) displayed by gold NPs and other standard antibiotics against the selected bacterial isolates

ANTIBIOTICS ORGANISMS	GEN 10µg	CXM 30µg	OFL 5µg	AuNPs 100µg	AUG 30µg	NIT 300µg	CPR 5µg	CAZ 30µg	CRX 30µg
Klebsiella pneumoniae	0	0	17	12	0	20	24	0	0
Salmonella typhi	15	0	16	10	0	17	26	0	0
Pseudomonas aeruginosa	20	0	17	13	0	20	14.5	0	0
Streptococcus pyogenes	17	0	18	11.5	0	0	9	0	0
S. aureus	0	0	0	10	7	7	8	0	0

Key: Augmentin (AUG), Gentamicin (GEN), Ciprofloxacin (CPR), Ofloxacin (OFL), Cefuroxime (CXM), Nitrofurantoin (NIT), Ceftazidime (CAZ) and Cefixime (CPX)

On the other hand, the antibiotics used exhibit diverse actions on the Gram-positive and Gram-negative bacteria, which are distinguished by the thick layer known as peptidoglycan. Table 1 shows that all Gram-negative bacteria were more susceptible than the Gram-positive bacteria tested. This phenomenon can be linked to the differences in their cell wall composition. Gram-positive bacteria possessed thick peptidoglycan layers preventing the penetration of antibacterial agents. While Gram-negative has a very thin peptidoglycan layer, allowing the passage of material resulting in cell lysis (Riu, *et al.*, 2022) The results revealed that the gold nanoparticles were toxic to all standardised bacterial strains at varying dosages. Of all the bacterial strains analysed, AuNPs demonstrated the most potent inhibitory effect against *Pseudomonas aeruginosa,* followed by *K. pneumoniae* and *Staphylococcus aureus*, with zones of inhibition measuring 12, 11, and 10 mm, respectively, at the maximum dose of 80 µg/mL (Table 2).

Table 2:
Zones of inhibitions in diameter (mm) displayed by AuNPs on the isolates

ORGANISMS	20µG/ML	40µG/ML	60µG/ML	80µG/ML	100µG/ML	GEN10µG
Klebsiella pneumoniae	0	7	10.5	11	12	0
Salmonella typhi	0	0	9	9	10	15
Psedomonas aeruginosa	8	8	9	12	13	20
Streptococcus pyogenes	0	0	8	9.5	11.5	17
Staphylococcus aureus	0	9	9	10	10	0

AuNPs demonstrated extensive antibacterial efficacy against both Gram-negative and Gram-positive bacteria. However, it was not as effective as the silver nanoparticles mediated from this same plant, as reported by Fagbemi *et al.*, (2024). This finding corroborates previous reports on the efficacy of silver over gold nanoparticles (Sher *et al.,* 2022; Soliman *et al.,* 2023).

Several mechanisms of action of AuNPs on bacteria have been reported by several authors (Aguilar-Garay *et al.,* 2024; Soliman *et al.*, 2022; Sher *et al.*, 2022. Tian *et al.,* 2022). Some reported that AuNPs disrupt the bacterial cell membrane or cell wall, resulting in bacterial lysis. Another study found that when AuNPs are administered to cells, they penetrate the cell and disrupt its metabolism (Gouyau *et al.*, 2021; Timoszyk & Grochowalska, 2022). Chahardoli et al. (2018) also documented that AuNPs adhere strongly to the surface of bacteria thereby causing disruption of cell wall structure and causing respiratory malfunctioning.

Another further accepted explanation is that intracellular AuNPs bind to the Sulphur moieties in cells, namely the thiol groups in enzymes, resulting in an abrupt disruption of the respiratory chain due to the formation of a substantial quantity of free radicals, ultimately leading to cell death (Gupta *et al.,* 2020).

CONCLUSION

The concerning increase in infections due to multidrug-resistant (MDR) microorganisms has emerged as a significant global health issue, necessitating the immediate exploration of alternate therapeutic approaches beyond traditional antibiotics. In addressing this menace, researchers have increasingly focused on the use of nanotechnology. Gold nanoparticles (AuNPs) are a popular nanomaterial due to their unique physicochemical features, biocompatibility, and simplicity of functionalisation. Recent research has focused on establishing environmentally friendly ways for synthesising these nanoparticles, bringing scientific innovation in line with green chemistry principles.

Using *Vitex gradifolia* leaf extract as a natural reducing and stabilising agent, gold nanoparticles were effectively synthesised in this work. This green synthesis process helps lessen the environmental effect of producing nanoparticles while providing a safer and more sustainable substitute for traditional chemical procedures. More significantly, the biosynthesised AuNPs demonstrated their strong antimicrobial qualities by displaying exceptional antibacterial activity against every tested MDR pathogen. As evidenced by existing literature, this study is the first to explore the antibacterial potential of AuNPs synthesised from *V. grandifolia* leaf extract against multidrug-resistant microorganisms. The observed inhibitory effects across multiple MDR strains provide compelling evidence for the utility of these biosynthesised nanoparticles as promising antimicrobial agents.

These findings highlight the significant potential of plant-mediated AuNPs as an innovative component in the fight against antimicrobial resistance. Further research and development in this direction could pave the way for the effective integration of green-synthesised nanoparticles into mainstream antimicrobial therapies, ultimately contributing to global efforts to curb the spread of drug-resistant infections.

REFERENCES

Abate, L., Bachheti, A., Bachheti, R. K., & Husen, A. (2021). Antibacterial properties of medicinal plants: Recent trends, progress, and challenges. in A, Hussen (Ed,). *Traditional herbal therapy for the human immune system*, pp, 13-54. CRC Press

Abd El-Aziz, A. R., Al-Othman, M. R., & Mahmoud, M. A. (2018). Degradation of DDT by gold nanoparticles synthesised using *Lawsonia inermis* for environmental safety. *Biotechnology & Biotechnological Equipment*, 32(5), 1174-1182.

Acharya, D.; Mohanta, B.; Pandey, P. (2021) Green synthesis of Silver and Silver-gold core-shell nanoparticles using Pineapple leaf extract (*Ananas comosus*) and study of their antibacterial properties. *International Journal of Nano Dimension*., 12, 203–210.

Aguilar-Garay, R., Lara-Ortiz, L. F., Campos-López, M., Gonzalez-Rodriguez, D. E., Gamboa-Lugo, M. M., Mendoza-Pérez, J. A., & Nicolás-Álvarez, D. E. (2024). A comprehensive review of silver and gold nanoparticles as effective antibacterial agents. *Pharmaceuticals*, 17(9), 1134.

Ahmeda, A.; Zangeneh, M.M. (2019) Novel green synthesis of *Boswellia serrata* leaf aqueous extract conjugated gold nanoparticles with excellent anti-acute myeloid leukemia property in comparison to mitoxantrone in a leukemic mice model: Introducing a new chemotherapeutic drug. *Applied Organometallic Chemistry*., 34, e5344.

Adeoye-Isijola, M. O., Olajuyigbe, A. A., Fagbemi, K. O., Naidoo, K. K., Coopoosamy, R. M., and Olajuyigbe, O. O. (2025). Chemical compounds, FTIR and in vitro antibacterial analyses of the acetone stem bark extract of *Ziziphus mucronata* subsp. *mucronata* (Buffalo Thorn) against potential nosocomial bacterial pathogens. *Journal of Biological Research-Bollettino della Società Italiana di Biologia Sperimentale*. https://doi.org/10.4081/jbr.2025.10408

Adegoke O. M., Fagbemi K.O, Nathaniel, J. P, and Aina D.A.(2025). An assessment of the antibacterial efficacy of methanol extract of *Mitracarpus scaber* and its biosynthesised silver nanoparticles *Thomas Adewumi University Journal of Innovation, Science and Technology* 1 (1) pp 1-8

Amo-Mensah, J., Darko, G., & Borquaye, L. S. (2020). Anti-inflammatory and antioxidant activities of the root and bark extracts of *Vitex grandifolia* (Verbanaceae). *Scientific African,* 10, e00586

Antony, J., Bandyopadhyay, S., Yang, J., & Rønning, M. (2023). Optimizing the shape anisotropy of gold nanoparticles for enhanced light harvesting and photocatalytic applications. *Photochemical & Photobiological Sciences*, 22(4), 773-781.

Baalousha, M., Sikder, M., Prasad, A., Lead, J., Merrifield, R., & Chandler, G. T. (2015). The concentration-dependent behaviour of nanoparticles. *Environmental Chemistry*, 13(1), 1-3.

Bello, M. O., Zaki, A. A., Aloko, S., Fasinu, P. S., Bello, E. O., Ajao, U. L., & Oguntoye, O. S. (2018). The genus Vitex: An overview of iridoids as chemotaxonomic marker. *Beni-Suef University journal of basic and applied sciences*, 7(4), 414-419. https://doi.org/10.1016/j.bjbas.2017.07.004

Bello, O. M., Saulawa, A. I., & Ogbesejana, A. B. (2021). Insight in the Phytochemistry of Wild Vegetable *Vitex grandifolia* GÃrke with its Biological and Nutritional Importance "A Review. Discovery Phytomedicine. *Journal of Natural Products Research and Ethnopharmacology*, 8(3).

Bobokulova, M. (2024). The role of nanotechnology in modern physics. *Development and innovations in science,* 3(1), 145-153. https://www.econferences.ru/index.php/dis/article/view/12085

Chahardoli A., Karimi N., Sadeghi F., Fattahi A. (2018) Green approach for synthesis of gold nanoparticles from *Nigella arvensis* leaf extract and evaluation of their antibacterial, antioxidant, cytotoxicity and catalytic activities. *Artificial Cells, Nanomedicine, and Biotechnology*. ;46:579–588. doi: 10.1080/21691401.2017.1332634.

Correa, S. N., Naranjo, A. M., & Herrera, A. P. (2016). Biosynthesis and characterization of gold nanoparticles using extracts of *Tamarindus indica* L leaves. *In Journal of Physics*: Conference Series (Vol. 687, No. 1, p. 012082). IOP Publishing.

Dehdari, M., Jazi, B., & Khosravi, F. (2024). A Theoretical Explanation for the Existence of Certain Maxima in the Visible Spectrum Pattern of Wave Scattering from Spherical Metal-Dielectric-Janus Nanoparticles Based on Surface Plasmon Excitation. *Plasmonics*, 1-14.

Erasmus, M., Idris, O. A., Adetunji, A. I., & Cason, E. D. (2024). Biogenic synthesis and characterization of gold nanoparticles using transformed mesophilic *Escherichia coli* BL21 and thermophilic *Thermus th7ermophilus* HB27. *Biologia*, 79(8), 2605-2619.

Fagbemi, K. O., Olajuyigbe, O. O., & Coopoosamy, R. (2023). Biogenic synthesis, characterization, antibacterial and antioxidant activities of silver nanoparticles mediated from *Tamarindus indica* Linn fruit pulp extract. *Journal of Herbmed Pharmacology*, 12(4), 459-468.

Fagbemi, K. O., Thonda, O. A., Daramola, O. O., Oyewole, T., Adeduro, O. O., Samuel, A., ... & Aina, D. A. (2024). Antibacterial Activity of Silver Nanoparticles Synthesized Using *Vitex grandifolia* Against Multidrug-Resistant (MDR) Pathogens. *Tropical Journal of Natural Product Research*, 8(8).

Giráldez-Pérez, R. M., Grueso, E. M., Carbonero, A., Álvarez Márquez, J., Gordillo, M., Kuliszewska, E., & Prado-Gotor, R. (2023). Synergistic Antibacterial Effects of Amoxicillin and Gold Nanoparticles: A Therapeutic Option to Combat Antibiotic Resistance. *Antibiotics*, 12(8), 1275. https://doi.org/ 10.3390/ antibiotics12081275

Gouyau J., Duval R.E., Boudier A., Lamouroux E. (2021) Investigation of nanoparticle metallic core antibacterial activity: Gold and silver nanoparticles against *Escherichia coli* and *Staphylococcus aureus*.*International Journal of Molecular Sciences*.; 22:1905. doi: 10.3390/ijms22041905.

Gupta, A., Pandey, S., & Yadav, J. S. (2020). A review on recent trends in green synthesis of gold nanoparticles for tuberculosis. Advanced Pharmaceutical Bulletin, 11(1), 10. https://doi.org/10.1016/j.sciaf.2020.e00586

Hassanisaadi, M., Bonjar, G. H. S., Rahdar, A., Pandey, S., Hosseinipour, A., and Abdolshahi, R. (2021). Environmentally safe biosynthesis of gold nanoparticles using plant water extracts. Nanomaterials, 11(8), 2033.

Hussein, M. A. M., Grinholc, M., Dena, A. S. A., El-Sherbiny, I. M., & Megahed, M. (2021). Boosting the antibacterial activity of chitosan–gold nanoparticles against antibiotic–resistant bacteria by *Punicagranatum L.* extract. *Carbohydrate polymers*, 256, 117498. https://doi.org/10.1016/j.carbpol.2020.117498

Jubu, P. R., Danladi, E., Ndeze, U. I., Adedokun, O., Landi Jr, S., Haider, A. J., ... & Yam, F. K. (2024). Comment about the use of unconventional Tauc plots for bandgap energy determination of semiconductors using UV–Vis spectroscopy. *Results in Optics*, 14, 100606.

Khatami, M., Mosazade, F., Raeisi, M., Ghasemi, M., Fazli, Z., Arefkia, K., ... & Khatami, S. (2021). Simplification of gold nanoparticle synthesis with low cytotoxicity using a greener approach: opening up new possibilities. *RSC advances*, 11(6), 3288-3294.

Mba, I. E., & Nweze, E. I. (2021). Nanoparticles as therapeutic options for treating multidrug-resistant bacteria: research progress, challenges, and prospects. *World Journal of Microbiology and Biotechnology*, 37, 1-30.

Min, Y., Wu, S., Li, W., Ma, Y., Wang, Y., Zhang, P., & Zheng, Y. (2024). One-pot synthesis of multipod Au-Cu nanocrystals with tunable branching for efficient photothermal treatment against multidrug-resistant bacteria. *Journal of Alloys and Compounds*, 976, 172935.

Nizamov, S., Sazdovska, S. D., & Mirsky, V. M. (2022). A review of optical methods for ultrasensitive detection and characterization of nanoparticles in liquid media with a focus on the wide field surface plasmon microscopy. *Analytica Chimica Acta*, 1204, 339633.

Olowe, O. A., Adefisoye, M. A., Adeoye-Isijola, M. O., and Olajuyigbe, O. O. (2025). Characterization, Bioactive Profiling and Evaluation of the Pharmacological Activities of Ethanol Extract of *Lannea welwitschii (Hiern) Engl*. *European Journal of Medicinal Plants* Volume 36, Issue 1, Page 1-26,

Oluwasesan M, B., Saulawa, A. I., & Ogbesejana, A. B. (2021). Insight in the Phytochemistry of Wild Vegetable *Vitex grandifolia* Gürke with its Biological and Nutritional Importance--A Review. *Discovery Phytomedicine*, 8(3).

Riu, F., Ruda, A., Ibba, R., Sestito, S., Lupinu, I., Piras, S., ... & Carta, A. (2022). Antibiotics and carbohydrate-containing drugs targeting bacterial cell envelopes: an overview. *Pharmaceuticals*, *15*(8), 942.

Saravanan, M., Vahidi, H., Medina Cruz, D., Vernet-Crua, A., Mostafavi, E., Stelmach, R., ... & Barabadi, H. (2020). Emerging antineoplastic biogenic gold nanomaterials for breast cancer therapeutics: a systematic review. *International Journal of Nanomedicine*, 3577-3595. https://doi.org/10.2147/IJN.S240293

Sarma, P. P., Rai, A., & Baruah, P. K. (2024). Recent advances in the development of antibiotics-coated gold nanoparticles to combat antimicrobial resistance. *Antibiotics*, 13(2), 124. https://doi.org/10.3390/antibiotics13020124

Sathiyaraj, S., Suriyakala, G., Gandhi, A. D., Babujanarthanam, R., Almaary, K. S., Chen, T. W., & Kaviyarasu, K. (2021). Biosynthesis, characterization, and antibacterial activity of gold nanoparticles. *Journal of Infection and Public Health*, 14(12), 1842-1847. https://doi.org/10.1016/j.jiph.2021.10.007

Shaikh, S., Nazam, N., Rizvi, S. M. D., Ahmad, K., Baig, M. H., Lee, E. J., & Choi, I. (2019). Mechanistic insights into the antimicrobial actions of metallic nanoparticles and their implications for multidrug resistance. *International journal of molecular sciences*, 20(10), 2468.https://doi.org/10.3390/ijms20102468

Sharifah Raina, M., & Hassan, M. (2016). Screening of phytochemical properties and antimicrobial activity of Malaysian medicinal plants against aquatic bacteria. *Malaysian Journal of Microbiology*, 284-290.

Sher, N., Alkhalifah, D. H. M., Ahmed, M., Mushtaq, N., Shah, F., Fozia, F., ... & Aboul-Soud, M. A. (2022). Comparative study of antimicrobial activity of silver, gold, and silver/gold bimetallic nanoparticles synthesized by green approach. Molecules, 27(22), 7895.

Singh, V., Shrivastava, A., and Wahi, N. (2015). Biosynthesis of silver nanoparticles by plants crude extracts and their characterization using UV, XRD, TEM and EDX. *African journal of biotechnology*, 14(33), 2554-2567.

Soliman, M. K., Salem, S. S., Abu-Elghait, M., & Azab, M. S. (2023). Biosynthesis of silver and gold nanoparticles and their efficacy towards antibacterial, antibiofilm, cytotoxicity, and antioxidant activities. *Applied Biochemistry and Biotechnology*, 195(2), 1158-1183.

Terreni, M., Taccani, M., & Pregnolato, M. (2021). New antibiotics for multidrug-resistant bacterial strains: latest research developments and future perspectives. *Molecules*, 26(9), 2671.

Tian, E. K., Wang, Y., Ren, R., Zheng, W., & Liao, W. (2021). Gold nanoparticle: Recent progress on its antibacterial applications and mechanisms. *Journal of Nanomaterials*, (1), 2501345.

Timoszyk, A., & Grochowalska, R. (2022). Mechanism and antibacterial activity of gold nanoparticles (AuNPs) functionalized with natural compounds from plants. *Pharmaceutics*, 14(12), 2599.

World Health Organization. Antibiotic Resistance, Available: online: https://www. who.int/ news-room/fact-sheets/detail/antimicrobial-resistance (accessed on January 22, 2025).

Xu, J., Yıldıztekin, M., Han, D., Keskin, C., Baran, A., Baran, M. F., & Khalilov R. (2023). Biosynthesis, characterization, and investigation of antimicrobial and cytotoxic activities of silver nanoparticles using *Solanum tuberosum* peel aqueous extract. *Heliyon*, 9(8).

Yun, Z.; Chinnathambi, A.; Alharbi, S.A.; Jin, Z. Biosynthesis of gold nanoparticles using Vetex negundo and evaluation of pro-apoptotic effect on human gastric cancer cell lines (2019). *Journal of Photochemistry and Photobiology B: Biology* 203, 111749.

Zhang, T.; Dang, M.; Zhang, W.; Lin, X. Gold nanoparticles synthesized from *Euphorbia fischeriana* root by green route method alleviates the isoprenaline hydrochloride induced myocardial infarction in rats (2019). *Journal of Photochemistry and Photobiology B: Biology* 202, 111705.