International Journal of Advances in Applied Sciences (IJAAS)
Vol. 13, No. 2, June 2024, pp. 313~324
ISSN: 2252-8814, DOI: 10.11591/ijaas.v13.i2.pp313-324

A review of the antimicrobial benefits of naturally extracted nanomaterials

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Article Info

Article history:

Received Sep 25, 2023
Revised Dec 17, 2023
Accepted Feb 28, 2024

Keywords:

Antimicrobial
Biomedical application
Gold nanoparticles
Green synthesis
Natural products
Silver nanoparticles

ABSTRACT

Nanotechnology finds immense potential due to the unique characteristics of nanomaterials. Though noble metal nanoparticles, particularly gold and silver nanoparticles possess advanced properties their conventional production methods pose environmental hazards. This paper explores the eco-friendly approaches using natural sources for synthesizing gold and silver nanoparticles. Rose and pomegranate extracts were used to synthesize gold nanoparticles. Evaluation using ultraviolet-visible (UV-Vis) spectroscopy confirmed the nanoparticle formation, and Fourier transform infrared spectroscopy (FT-IR) analysis recognized the presence of plant-derived compounds for stabilizing these particles. In-depth observations of their size and form were provided using electron microscopy, and these findings were aligned with the inferences made from the UV-Vis data. Silver nanoparticles were produced using *Ocimum gratissimum* leaf extract (OGE), exhibiting dose-dependent antimicrobial effects against bacterial strains. A comparative analysis demonstrated the distinct antibacterial characteristics of silver and gold nanoparticles against several bacterial strains. These nanoparticles demonstrated enhanced inhibitory effects when employed in combination with antibiotics, suggesting the possibility of dealing with antibiotic resistance. The study presents opportunities for producing nanomaterials with minimal impact on the environment and for addressing antibiotic resistance. Further research can enhance the process and find more useful applications as this green synthesis approach can bring about significant improvements in many areas.

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1. INTRODUCTION

Nanotechnology refers to the precise use of technology at nanoscale scale [1]. Nanotechnology has garnered significant attention from researchers owing to its potential use in several sectors like electronics, agriculture, magnetics, chemistry, biology, optics, geology, and more [2]. Nanomaterials, unlike their larger counterparts, exhibit distinct characteristics that may be manipulated to provide novel features. Nanoparticles possess exceptional qualities due to their small size at the nanoscale, molecule dispersion, and specific form. Nanomaterials provide significant advantages in several disciplines such as optoelectronics, photovoltaics, biomedicine, and thermos-electrics. Their tiny size and distinctive properties make them particularly suitable for applications in chip technology [3]. Nanomaterials have achieved amazing breakthroughs in electronics, with quantum dots in semiconductors serving as a notable example [4]. Utilizing nanoparticles instead of bulk materials to accomplish the same outcome requires much lower amounts of energy, financial resources, and raw materials [5].

Researchers have focused on noble metal nanoparticles because of their small dimensions, increased surface area, unique electronic arrangement, and quantum size effect, which increase their physical and chemical properties [6]. Palladium, platinum, gold, and silver, which are classified as major noble metals, possess the distinct characteristic of being non-reactive with other elements. By reducing them to nanoscale dimensions, their characteristics may be precisely adjusted by adjusting factors like size, shape, and composition [7]. Due to their optical, chemical, magnetic, and electrical features, which vary depending on their size, nanoparticles play a crucial role in several applications [8]. An atom positioned on the outermost surface of a nanoparticle exhibits more favorable characteristics in comparison to an atom of a bulk substance. As a result of quantum or surface effects, atoms located at different positions inside the crystal exhibit diverse features [9]. Typical methods for producing nanomaterials include pyrolysis, the sol-gel method, chemical vapor deposition (CVD), etching, and the use of supercritical fluids [10]. These synthesis procedures have many drawbacks, such as excessive energy utilization, chemical hazards, limited production rate, and the creation of unwanted waste products [5].

The development and testing of nanoparticles can pose environmental and health hazards due to their increased reactivity and flexibility. As these hazards are different from those of bulk substances, it is important to develop techniques that decrease risk and waste, as nanotechnology becomes commercially viable. Some techniques for producing nanomaterials without hazardous chemicals have been discovered [11]. Researchers have investigated novel synthesis methods based on green techniques to promote environmental conservation [12], [13]. The benefits of using green synthesis for nanomaterials are reduced manufacturing costs and decreased energy usage. These advantages make it a very desirable choice in the realm of nanotechnology [14]. Water is used as a solvent in this ecofriendly fabrication process which uses natural materials rather than harmful chemicals as reducing and stabilizing agents [15]. Scientists are dedicating significant efforts and resources towards the exploration of methods for producing nanomaterials by the utilization of biological sources, often referred to as "green synthesis" [16]. Bacteria [17], yeasts [18], fungi [19], and algae [20], [21] are often used in the biosynthetic production of nanomaterials and ensure minimal contamination. The current research field of synthesizing metal and metal-based hybrid nanoparticles utilizing plant or plant extracts is considered both innovative and well-accepted [22].

Research by Ramalingam *et al.* [23] delves into the synthesis and characteristics of silver nanoparticles (AgNPs) produced by reducing silver nitrate with Rhizopus oryzae's cell-free protein. The study explores the efficiency of AgNPs against two types of harmful bacteria. The AgNPs showed a dose-dependent ability to eliminate *Escherichia coli* and *Pseudomonas aeruginosa* within four hours. The study examines how AgNPs interact with these bacteria, focusing on their impact on the cell membrane, where they generate reactive oxygen species (ROS), modify membrane characteristics, and cause harm to the bacteria. This research focuses on the synthesis, activity, and possible applications of AgNps, emphasizing their antibacterial properties.

According to Elia *et al.* [24] extracts of various plant parts can act as effective reducing agents to manufacture gold nanoparticles in an ecofriendly friendly manner. The study highlights the possibility and ecological benefits of using plant-based methods for the production of nanoparticles, revealing their various potential uses [2]. According to Sharma *et al.* [25] primarily focused on producing AgNps utilizing Ocimum gratissimum leaf extract (OGE) in an ecologically friendly manner. The characterization of the synthesized nanoparticles, antibacterial characteristics, and toxicity analysis are all thoroughly investigated in this study. The work demonstrates how green synthesis methods may be successfully applied to produce silver nanoparticles with promising antibacterial properties.

Research by Basavegowda *et al.* [26] describes a novel method for synthesizing gold nanoparticles (AuNPs), which included using an extract from the pomegranate fruit. This study shows chloroaurate ions can be easily transformed into very stable AuNPs which exhibit a characteristic ultraviolet-visible (UV-Vis) absorption peak at 536 nm, indicating plasmon resonance. The investigation into the antibacterial activity of AuNPs against *Streptobacillus sp.* and *Escherichia coli* demonstrates their potential as effective agents against these bacteria. Overall, this paper provides new insights into an environmentally benign approach for synthesizing stable AuNPs using *Punica granatum* extract, emphasizing their characterization and prospective antibacterial capabilities, paving the way for further research.

This review paper contributes to the field through an extensive investigation into the environmentally friendly production of AuNP and AgNP, emphasizing the characteristics, effectiveness against microbes, and potential uses. Specifically, the novel aspect is the thorough comparison of these nanoparticles, which highlights their unique characteristics and emphasizes their function in addressing antibiotic resistance. These sections seek to emphasize the unique characteristics and prospective applications of these environmentally sensitive nanoparticles, highlighting their significance in a variety of disciplines and their capacity to address current issues.

2. GREEN SYNTHETIC APPROACH OF NANOMATERIALS

The new approach named "green nanotechnology" promises to attain molecular sustainability and limit dangers while producing safer, more sustainable chemicals and processes [5]. The green chemistry principles encompass “prevention, atom economy, less hazardous chemical synthesis, the use of safer chemicals, solvents, and auxiliaries, energy efficiency, renewable feedstock, derivative reduction, catalysis, design for degradation, and real-time analysis for pollution prevention”. These techniques have improved the design of nanomaterials and nanostructured goods by decreasing the consumption of hazardous chemicals and solvents and enhancing the synthesis processes in terms of materials and energy [27], [28]. Green synthesis is both environmentally friendly and biocompatible as it uses plant extracts or microbes [29] as a capping agent to control particle size and minimize agglomeration [16], [30]. Thus, green chemistry leads nanotechnology research to build items that benefit society and the environment [31]. This research outlines an environmentally friendly method for producing metal nanoparticles and its vital application.

3. GOLD NANOPARTICLE SYNTHESIS USING ROSE AND POMEGRANATE

Many physical and chemical approaches exist for synthesizing gold nanoparticles (AuNPs), but many of these methods are not preferred as they involve dangerous substances and extremely high temperatures that can harm human health and the environment [32], [33]. Using natural resources like plants and microorganisms provides a more environmentally friendly method of producing AuNPs [34]. The biosynthesis of AuNPs using plant materials is regarded as an environmentally beneficial process because different plant parts can be used as sources [35].

Natural products for the green syntheses of gold nanoparticles as shown in Figure 1. Leaves of rose (the scientific name is *pelargonium graveolens*) and fruit of pomegranate (the scientific name is *Punica granatum*) as shown in Figures 1(a) and (b) were used to prepare the extracts. A small amount of respective plant parts was cleaned thoroughly using normal water and then with double–distilled water (DDW). Subsequently, the ingredients were thoroughly combined till achieving a consistent texture, stirred for a brief duration, subjected to centrifugal force, and then passed through a filter. To create gold nanoparticles, 1.5 milliliters of plant extract were mixed with 20 milliliters of a gold ion solution. This solution was made by diluting chloroauric acid ($HAuCl_4$) with DDW until it reached a concentration of 0.1 g/l. As soon as gold nanoparticles begin to develop, the color of the mixture will change to a deep purple [24]. At 530 nm, UV-visible spectroscopy verified the existence of gold nanoparticles. The absorption peak of the AuNP was seen at 538±8 nm for PeG and somewhat higher at 568±12 nm for PuG, as shown in Figure 2 [24]. The larger absorption peak was caused by the large size dispersion of gold nanoparticles in PuG.

(a) (b)

Figure 1. Natural products for the green syntheses of gold nanoparticles (a) rose and (b) pomegranate

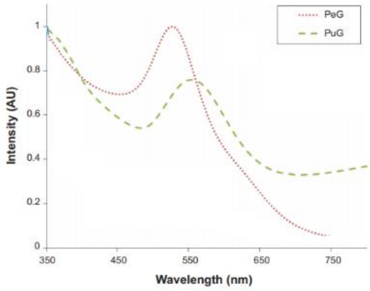
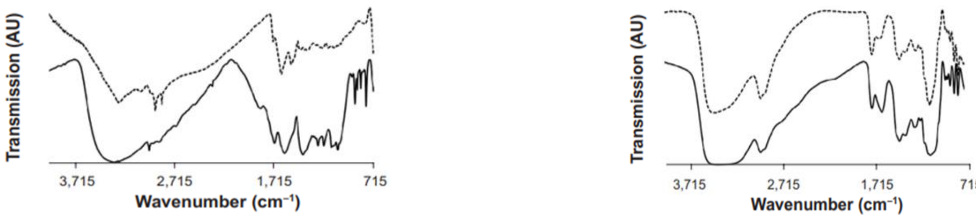


Figure 2. UV-visible spectra of the gold solutions prepared with extracts of rose and pomegranate

To determine the absorption peaks that exhibit a noticeable change in two distinct media, the Fourier transform infrared spectroscopy (FT-IR) spectra were obtained from both the pure natural extract and the colloidal solutions. The change in peak occurred due to the absorption of all extracted components onto the surfaces of gold nanoparticles. Both the extract and colloidal solution share identical components as shown by their spectra. Figure 3 illustrates the FT-IR spectra of the two phases [24]. The extract and colloidal solution spectra are the same, however the locations of some absorption peaks have changed significantly.



(a) (b)

Figure 3. Demonstrating FT-IR spectra of (a) *Pelargonium graveolens* and (b) *Punica granatum*

Energy dispersive spectroscopy (EDS) measurements use an electron beam with a larger diameter than the particle being analyzed. This allows for the determination of the composition of the elements of both the particle and the surrounding environment. Figure 4 displays the EDS spectra of the *Pelargonium graveolens* sample that was used to synthesize Au-NPs. The data indicate that the particle compositions are made of gold. Based on the typical EDS findings, the plant extracts included small quantities of other elements like carbon, oxygen, aluminum, sodium, magnesium, potassium, and calcium, in addition to their primary elemental composition. The results indicated a significant correlation between the EDS findings and the concentrations of different elements present in the plant extracts [24]. Dynamic light scattering (DLS) and nanoparticle tracking analysis (NTA) were used to measure gold nanoparticle sizes in samples and Table 1 summarizes the outcomes.

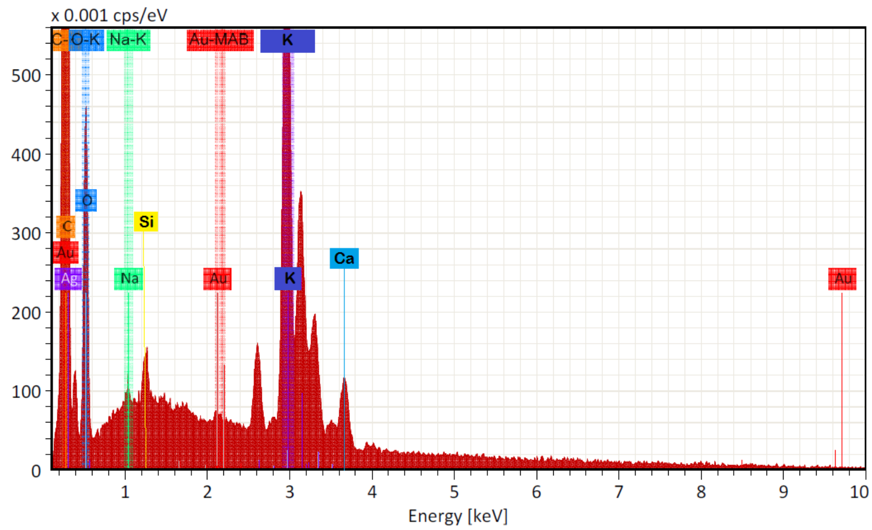


Figure 4. The EDS spectra of *Pelargonium graveolens*-mediated Au NP synthesis

Table 1. A detailed summary of the investigation of DLS and NTA of gold nanoparticles

Extract	Mean diameter (nm) ± standard deviation (SD)		
	DLS		NTA
	Peak of small particles	Peak of large particles	
PeG	6±3	78±30	75±35
PuG	34±18	312±46	127±57

The UV-visible spectra observations confirmed these findings. In the PeG sample, absorption occurred at wavelengths almost identical to those of the small particles, while in the PuG samples, absorption took place at a higher value suggesting a change to larger particles. NTA was used to verify particle size. Table 2 shows that the average gold nanoparticle diameter determined by NTA matches DLS for PeG but is substantially smaller for PuG. To understand the distribution of particles by size the SEM images were subjected to compute analysis. SEM results illustrated in Table 2 show that PuG and PeG extracts produce similar-sized particles. The apparent particle size variation in PuG colloids is due to gold nanoparticle clusters, which are significantly larger than the size of individual particles [24]. Repeated DLS tests on the same samples for three weeks confirmed the stability of the gold nanoparticle size distribution. Average particle sizes were constant in PeG and PuG peaks.

Table 2. Summary of the particle formation with PuG and PeG extracts

Extract source	Mean diameter (nm)			Mean (nm)
	By area	By perimeter	By dimensions	
PeG	30±6	56±8	50±8	45
PuG	16±6	50±6	30±4	32

The study shows that introducing a reducing agent into a solution containing chloroaurate ions ($AuCl4^-$) resulted in the formation of AuNP. Extensive research has revealed that antioxidants are the primary component in plant extracts that function as reducing agents. These antioxidants are crucial in the formation of gold nanoparticles [36]. This green synthesis process offers a direct, cost-effective, and eco-friendly approach to generating monodisperse gold nanoparticles with specific functions. This synthesis method is simple, economical, and capable of providing monodisperse, functional gold nanoparticles.

4. SILVER NANOPARTICLE SYNTHESIS EMPLOYING *OCIMUM GRATISSIMUM* LEAF EXTRACT

The development of nanoparticles through eco-friendly methods employing microbes [37], [38], enzymes [39], and extracts from plants [40], [41] is a substitute for conventional synthesis methods using chemicals. These approaches are cost-effective, and the resulting nanoparticles are reported to be more stable. Metallic nanoparticles, specifically AgNPs, are produced and stabilized by the utilization of plants like *Acorus calamus* [42], *Alternanthera dentate* [43], *Ocimum sanctum* [44], *Azadirachta indica* [25], and many others.

The green production of AgNP included thoroughly rinsing the *Ocimum gratissimum* plant leaves as shown in Figure 5, with purified water, then air-drying them in a shaded area, and finally grinding them into a fine powder. A quantity of 2.5 g of powder was then heated in 100 ml of distilled water for 20 minutes. Upon subjecting the extract to double filtration, clear liquid was obtained, and it was stored at a temperature of 40 °C.

Figure 5. The *Ocium gratissimum* is utilized as a natural product

Using laminar airflow and continuous stirring, different amounts of silver nitrate (ranging from 1 to 5 mm) were added gradually to OGE in varying proportions. To produce AgNPs at the optimal pH, a solution with a pH ranging from 4 to 9 was treated with 0.1 N HCl and 0.1 N KOH. The reaction mixture was incubated for a certain period. The silver nanoparticles (AgNPs) underwent centrifugation at an average rate of 20,000 rpm for a duration of 20 minutes, after being subjected to 15 minutes of gentle sonication.

Following the removal of the liquid portion, the AgNP particle underwent four rounds of washing with DDW followed by drying for an extended period at 600 °C [45].

UV–visible spectra of AgNP are illustrated in Figure 6. Figure 6(a) demonstrates the impact of varying silver nitrate concentrations on the synthesis of AgNPs using OGE. Detection of a surface plasmon resonance (SPR) peak in the visible region of the UV-Vis spectra between 400 and 500 nm verifies the existence of silver nanoparticles. Figure 6(a) shows that as the silver nitrate (AgNO3) concentration increases the height of the absorbance peak also increases. This indicates that an increase in AgNO3 concentration enhances the formation of silver nanoparticles.

Figure 6(b) illustrates how the pH influences the biogenic production of AgNPs. Changing the pH from 4 to 6 did not produce an SPR peak in the spectra, which is indicative of an acidic pH. However, an expanded SPR peak was seen when the pH was increased to 7, illustrating the beginning of AgNP formation. There is an observed blue shift in the maximum wavelength (Kmax) from 452 to 422 nm, along with a substantial rise in the absorbance peak at pH 9. Thus the results show that the synthesis of AgNPs by biological means was hindered by acidic medium and enhanced by alkaline pH [45].

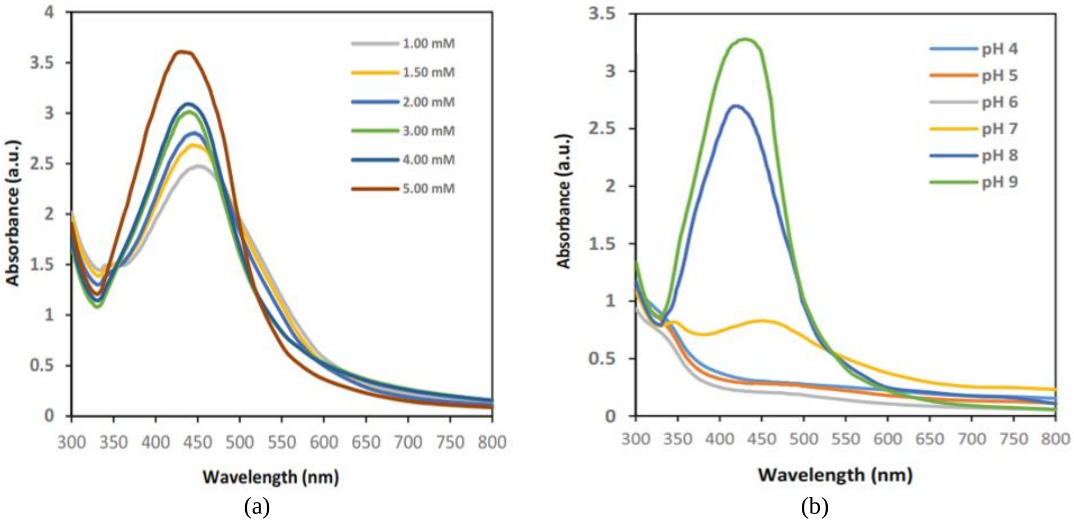


Figure 6. UV–visible spectra of AgNP (a) with various concentrations of silver nitrate and (b) at various pH levels of the reaction mixtures

The infrared (IR) spectrum was analyzed to investigate the surface characteristics and identify the biomolecule-related functional groups contributing stability and formation of AgNP. The existence of phenols and flavonoids, respectively, is indicated by the absorption bands at 3468.5 and 3417.56 cm-1 as indicated in Figure 7. Those bands of absorption are the vibrations caused by the stretching of O-H bonds. The presence of peaks at 1634.25 cm-1 and 1616.84 cm-1, respectively validates the occurrence of proteins. These peaks are the result of vibrations caused by the carbonyl group in the amide-I bond and the nitrogen-hydrogen (N-H) bond in the amide-II bond. Asymmetrical stretching of the C-H bond is shown by the distinctive bands of the alkenes, at 2924.72 cm-1 and 2853.53 cm-1. Owing to the uneven stretching of the C-H bond in alkanes, peaks are seen at 1384.53 cm-1 and 1354 cm-1. There are peaks at 1107.8 cm-1 and 1124.83 cm-1 that are caused by the stretching of carboxylic acid C-OH. Similarly, the aromatic C-H stretching peaks were observed at 780.76 cm-1 and 804.63 cm-1, and the phenol O-H bending peak was found at 521.22 cm-1. These various absorption peaks show that the nanoparticles contain phytochemicals on their surface. Phytochemicals have a major role in providing stability and capping of AgNPs, which prevents them from aggregating. Biomolecules that are used for capping and reduction have a significant impact on the shape and properties of the silver nanoparticles that are formed [46].

The dimensions and morphology of AgNPs were inspected using scanning electron microscopy (SEM). The SEM shown in Figure 8, especially at low resolution (see Figure 8(a)) and high resolution (see Figure 8(b)) confirms the development of evenly distributed AgNPs. Additionally, it was shown that the produced AgNPs exhibited consistent size and shape. The absence of nanoparticle aggregation indicated that the extract's capping and stabilizing component effectively regulated the stability of the NPs [47].

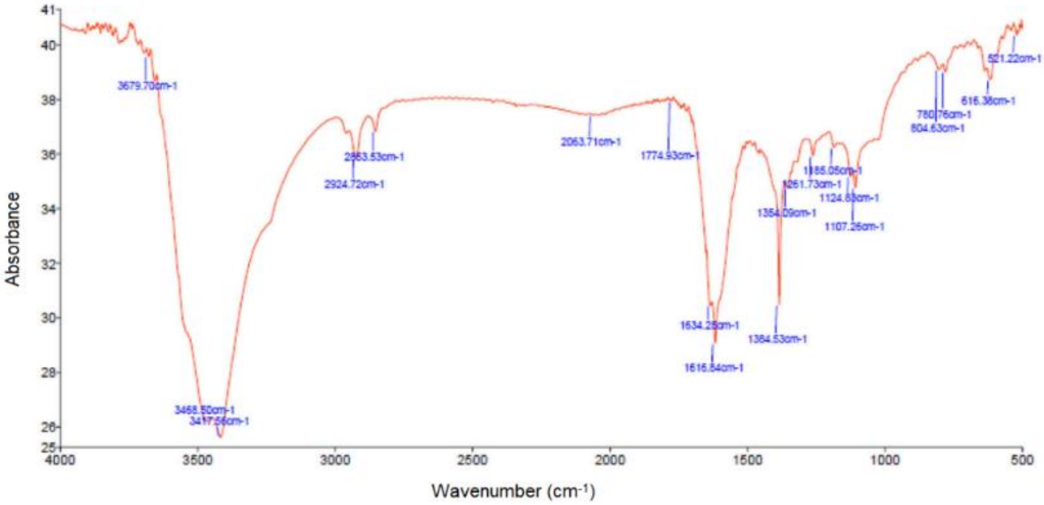
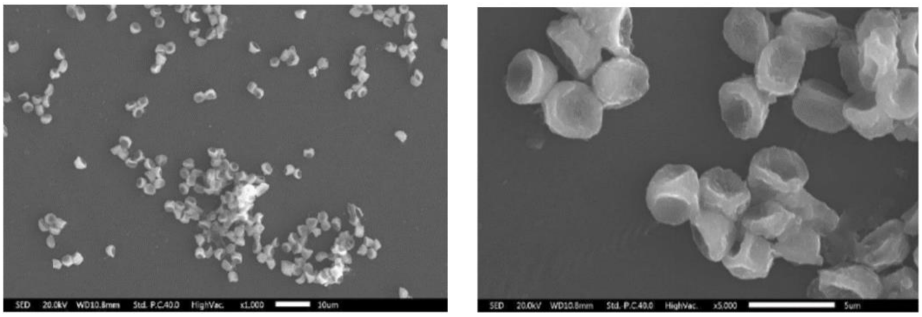


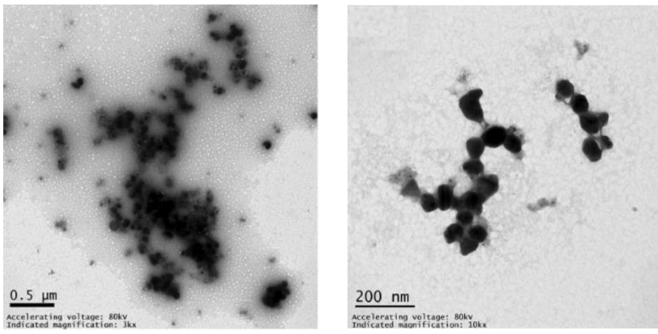
Figure 7. FT-IR analysis of AgNP produced from OGE



(a) (b)

Figure 8. SEM images of AgNPs (a) low-resolution and (b) high-resolution

The dimensions and morphology of AgNPs were thoroughly examined using transmission electron microscopy (TEM) as shown in Figure 9. At low magnification, a high concentration of nanoparticles was noted, indicating a mono-disperse synthesis with a size range of 12 to 60 nm as indicated in Figure 9(a). A high-resolution TEM image as indicated in Figure 9(b) shows that most of the nanoparticles appeared spherical [45].



(a) (b)

Figure 9. TEM images of OGE-synthesised AgNP (a) low-resolution TEM image indicating a mono-disperse synthesis with a size range of 12 to 60 nm (b) high-resolution TEM image indicating the spherical shape of the synthesized silver nanoparticles

5. ANTIMICROBIAL ACTIVITIES OF THE GREEN SYNTHESIZED NPs

In recent decades, the emergence of antibiotic-resistant bacteria poses a significant worldwide public health challenge, prompting a change in research focus toward other antimicrobial agents. The rising number of transmitted infections, mainly those induced by multi-drug resistant microorganisms and other antibiotic-resistant bacteria, has emerged as a significant issue. Due to the increasing occurrence of bacteria that are resistant to several drugs, environmentally friendly nanoparticles are being explored as an effective alternative to existing antibiotics [48], [49]. Smaller nanoparticles (NPs) have a bigger surface area, which allows for increased diffusion into cells. As a result, smaller NPs tend to have improved stability and stronger antibacterial effects [50].

5.1. Antimicrobial activity utilizing green synthesized gold nanoparticle

The agar well diffusion method was used to assess the antimicrobial activity against *Escherichia coli* and *Streptobacillus sp.* bacteria. The bacteria were cultured for a period of one night on Muller Hinton agar medium plates by placing a clean cotton swab on them. The wells were supplied with antibiotic solution and gold nanoparticles, each with a volume of 10 µl. Well-containing only antibiotic solution functioned as positive controls. After being incubated for a whole day at 37 °C, the petri plates were taken out.

A study of antibiotics indicated in Table 3 shows that standard antibiotics (A) alone had a smaller zone of inhibition compared to antibiotics including AuNP made from P. granatum (A + P). The impact of the antibiotics was evaluated by estimating the area of inhibition surrounding the colonies of bacteria. Antibacterial experiments targeting the specified pathogens were conducted using ampicillin and penicillin. Ampicillin and penicillin had an inhibitory effect on the development of *Streptobacillus sp.* and *Escherichia coli* [26]. Ampicillin has shown a greater efficacy against *Escherichia coli* compared to penicillin, however, it had a lesser impact on *Streptobacillus sp.* with diameters of 18 mm and 19 mm. Figure 10 demonstrates that the inhibitory effect of ampicillin and penicillin was intensified when they were combined with gold nanoparticles [26].

Table 3. Antimicrobial activity of pomegranate-derived gold nanoparticles

Antibiotics	Diameters of inhibition area bacterium (mm)			
	Escherichia coli		*Streptobacillus sp.*	
	A	A+P	A	A+P
Ampicillin	18.0	19.0	17.0	18.0
Penicillin	17.0	18.0	16.0	17.0

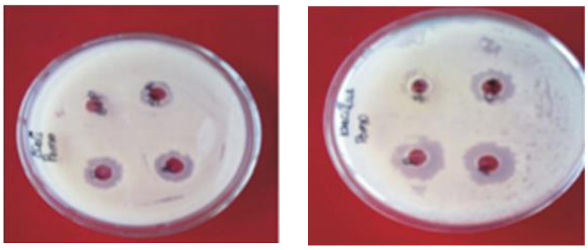


Figure 10. Antimicrobial effect of AuNPs against *Escherichia coli* and *Streptobacillus sp.*

5.2. Antimicrobial action using green synthesized silver nanoparticle

The antimicrobial efficacy of nanoparticles at varying concentrations (0.50, 1.0, 2.0, and 3.0 mm) was assessed against two gram-negative bacteria (*Escherichia coli* and *Klebsiella pneumoniae*) and three gram-positive bacteria (*Bacillus subtilis*, *Staphylococcus aureus*, and *Micrococcus luteus*) employing the agar well diffusion technique. Figure 11 especially in Figures 11(a)-(e) and Table 4 indicate the antimicrobial properties of OGE synthesised AgNPs. The inhibitory zones observed at concentrations of 0.50, 1, 2, and 3 millimolar indicate that the efficacy of AgNPs against gram-negative bacteria is dependent on dosage as well as greater than that against gram-positive bacteria. Nanoparticles may not be able to cross the cytoplasmic membrane of gram-positive bacteria due to the higher number of peptidoglycan layers seen in these bacteria compared to gram-negative bacteria. Pure *Ocimum gratissimum* leaf extract has no antibacterial activity. Silver nanoparticles (AgNPs) may kill bacteria because their positive charges may easily adhere to their negatively charged cell membranes, modifying their physical and chemical properties. Changes in membrane characteristics hinder osmoregulation, permeability, and respiration [45].

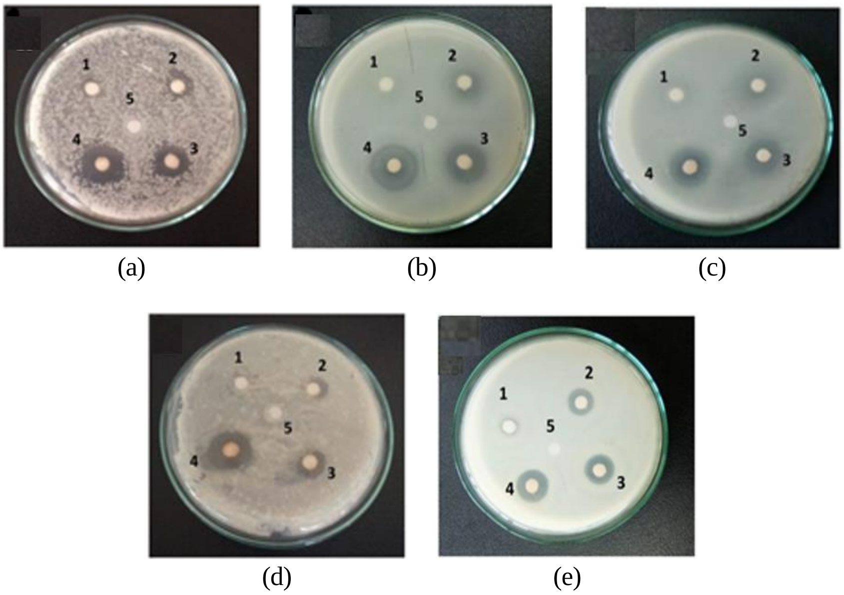


Figure 11. Testing five different bacterial strains for the antimicrobial activity of AgNP produced by OGE: (a) *Micrococcus luteus*, (b) *Escherichia coli*, (c) *Bacillus subtilis*, (d) *Staphylococcus aureus*, and (e) *Klebsiella pneumoniae*. Concentrations of 0.5, 1, 2, and 3 mm of AgNPs are denoted by the numbers 1-4. OGE is represented by the number 5

Table 4. Silver nanoparticle-induced inhibitory zone against five bacterial strains

AgNP concentration (mm)	Diameters of inhibition area (mm)				
	Gram-positive			Gram-negative	
	Staphylococcus aureus	*Bacillus subtillis*	*Micrococcus luteus*	*Escherichia coil*	*Klebsiella pneumoniae*
0.5	-	-	-	-	06±0.13
1.0	07.50±0.32	08±0.34	08±0.45	10±0.35	12.5±0.28
2.0	09.0±0.36	14±0.12	13±0.32	16±0.18	14.5±0.25
3.0	13.0±0.20	16+0.24	16±0.21	20±0.32	17±0.17

* Vlaues are average+SD

The free radicals generated by silver nanoparticles disrupt the bacterial cell membrane, allowing proteins and lipopolysaccharides contained inside to seep out. Membrane damage caused by AgNP interaction could be one of the solid reasons for their antibacterial activity. These results suggest that AgNPs made from *Ocimum gratissimum* leaf extract might be used to combat bacteria that have developed resistance to drugs and that the antimicrobic efficiency of these nanoparticles is dose-dependent.

6. COMPARATIVE ANALYSIS OF ANTIMICROBIAL ACTION OF GREEN SYNTHESISED NANOPARTICLES

The nanoparticle production utilizing natural and non-toxic materials has garnered substantial interest across several industries, including biomedicine, electronics, and catalysis. Green synthesized AuNP and AgNP offers numerous benefits. Au nanoparticles created using environmentally friendly processes have excellent biocompatibility, making them highly suitable for use in biomedical fields, including drug transport and cancer treatment. Additionally, using plant extracts or microorganisms as reducing agents in Au synthesis is more cost-effective compared to traditional chemical methods and eliminates the need for harmful chemicals, contributing to the overall environmental friendliness of the process.

Ag nanoparticles synthesized through green methods showcase remarkable antimicrobial activity and offer the same cost-effectiveness and environmental friendliness as Au nanoparticles. Biocompatibility, cost-effectiveness, and environmental friendliness are just a few of the benefits that green synthesis offers over traditional chemical processes for creating nanoparticles. These factors make green synthesized Au and Ag nanoparticles highly attractive for many applications. Nanoparticle size, shape, composition, and production methods are some of the variables that could affect the antibacterial properties of nanoparticles made of gold or silver. The antibiotic effectiveness of AuNPs produced from *Punica granatum* and silver nanoparticles derived from *Ocimum gratissimum* is assessed in sections 5.1 and 5.2, respectively. In each of the studies, a different method is used to assess the antimicrobial activity, but the overall approach involves testing the antibacterial activity against various strains of bacteria and measuring the area of inhibition.

Results showed that ampicillin and penicillin's inhibitory action against *Escherichia coli* and *Streptobacillus sp.* was enhanced by AuNPs produced from *Punica granatum*. When antibiotics were combined with gold nanoparticles, the zone of inhibition was much greater than when antibiotics were used alone. The silver nanoparticles synthesized from *Ocimum gratissimum* showed dose-dependent antimicrobial action over five different strains of bacteria, with gram-negative bacteria showing greater tolerance than gram-positive bacteria. An increase in the concentration of AgNP results in a corresponding rise in the size of the inhibitory zones. Silver nanoparticles exert their antibiotic effects by interacting with the negatively charged bacterial cell membranes, altering the characteristics of the bacteria and interfering with their operations. According to the results, AuNP and AgNPs produced from extracts of various plants show strong inhibition against several bacteria. The combination of nanoparticles with antibiotics and plant extracts enhances the inhibitory activity, making them potential candidates for developing new antibacterial agents. However, the specific activity and mechanism of action could differ according to the nature of the nanoparticle and the manufacturing procedures.

Further research is required to overcome the current limitations of green synthesis of metal nanoparticles, which include low yields, lengthy synthesis times, and limited control over particle size and shape. Efforts should be made to understand the impact of reaction conditions, reactants, and surfactants on the synthesis process. Despite the proven antibacterial and antifungal properties of metal nanoparticles, additional research is needed to determine their efficiency against a broader spectrum of microbes. Metal nanoparticles are increasingly being used with other treatments, such as antibiotics or photodynamic therapy, to boost their antibacterial action. More study, however, is required to discover the most effective combination tactics and to evaluate the safety and efficacy of these combined therapies.

7. CONCLUSION

The research highlights the promising capabilities of gold and silver nanoparticles synthesized by environmentally friendly techniques in biomedicine and antimicrobial applications. Using eco-friendly and biocompatible ingredients throughout the synthesis process enhances biocompatibility and offers cost-effectiveness and ecological benefits. The examination of green nanoparticles and the characteristics they possess shows significant possibilities for the advancement of novel and eco-friendly materials across various fields. The benefits of employing plant extracts are their ease of handling, widespread availability, and broad usage of metabolites. Despite these advancements, poor yields, lengthy synthesis periods, and insufficient control over particle properties remain the main challenges. To overcome these obstacles and to get deeper knowledge, further research is necessary to understand how different elements impact the synthesis process. Despite their antibacterial and antifungal properties, metal nanoparticles are efficient against a wider range of microbes. In addition, the results highlight the need for greater research on the ecological and physiological impacts of these nanoparticles. The demonstration of how amalgamation with gold nanoparticles can enhance the inhibitory activity of antibiotics in conjunction with the dose-dependent antimicrobial properties exhibited by silver nanoparticles against a wide variety of bacterial strains illustrates their potential as advanced antibacterial agents.

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