

Original Research Article

Antibacterial Activities of Leaf Extracts and Synthesized Silver Nanoparticles from *Allium Sativum* on Urinary Quinolone-Resistant *Escherichia Coli*

ABSTRACT

Aims: The study was aimed at evaluation of the antibacterial activities of crude leaf extracts and synthesized Ag-NPs from *Allium sativum* on urinary quinolone resistant *E. coli*.

Study design: Cross sectional study.

Place and Duration of Study: Department of Microbiology, Nasarawa State University, Keffi, between November 2023 and October 2024

Methodology: Confirmed Samples for this study were collected from selected General Hospitals in Abuja Municipal, Nigeria. The phytochemical screening of the *Allium sativum* leaf ethanolic extract (ASE) for various phytochemical constituents and detection of AgNPs was conducted using laboratory method and other methods; UV-visible spectra, and Fourier Transform Infrared Spectroscopy (FTIR).

Results: All isolates were resistant to AMP and CIP. All the *E. coli* isolated were MAR isolates. All the MAR isolates had MAR indices of ≥ 0.2 . Most isolates were MDR isolates. There was also a PDR and XDR isolates among the selected tested *E. coli* isolates. Phytochemical screening of aqueous, ethanolic, ethyl acetate and n-hexane leaf extracts of *Allium sativum* showed presence of only glycosides in all the extracts. Phenols and resins followed after as they were only absent in the aqueous extract of *A. sativum* leaf while tanins, steroids, saponins and phlobatanins were present in two (2) of the four (4) extract analyzed. Antibacterial activity screening of aqueous, ethanoic, ethyl acetate and n-hexane leaf extracts of *Allium sativum* were evaluated against quinolone resistant *E. coli* showed activity by only aqueous and ethanolic extracts. The ethanolic extracts were more active. Synthesized silver nanoparticles of the active extracts have shown higher antibacterial activity against the responsive isolates than their corresponding crude extracts.

Conclusion: The synthesized silver nanoparticles from the active leaf extracts exhibited greater antibacterial activity against the responsive isolates compared to their corresponding crude extracts. These findings suggest that AgNPs hold potential for use in medicine to prevent both infectious and non-infectious diseases.

Keywords: *Allium sativum*, Silver nanoparticles, *Escherichia coli*, Biofilm, Quinolone

1. INTRODUCTION

The rise in multi-drug resistance among bacterial pathogens to conventional antibiotics has emerged as a significant public health challenge, complicating the treatment of infectious diseases in recent times [1]. This pressing issue has driven researchers to explore innovative strategies to combat the threat. One promising approach involves utilizing medicinal herbs, which exhibit antimicrobial properties and are generally less toxic than traditional antibiotics. Nanotechnology involves the design, synthesis, characterization, and manipulation of materials at the nanoscale (1-100 nm) [1]. Biogenic synthesis utilizing plant-derived extracts offers an eco-friendly, cost-effective approach to nanoparticle production, and using natural bioactive compounds with inherent antimicrobial properties [1]. Particles differ significantly from materials created on a larger scale from the same source material, yet the differences remain noteworthy [2, 3]. Nanotechnology implies the production, characterization, modification, and manufacturing of nanoparticles [4]. When these particles are synthesized, characterized and manipulated, and incorporated with suitable nanomaterials, their pharmacokinetic characteristics and efficacy can be improved [4, 5, 6]. Medicinal plants play a crucial role in forming capping layers that influence the size and structure of nanoparticles [7, 8]. One such plant, *Allium sativum*—commonly known as garlic—has been utilized in the synthesis of silver nanoparticles (AgNPs) [9, 10]. Renowned for its medicinal properties, garlic is widely used in cuisines across the globe to treat various ailments [11]. It is reported to exhibit anticancer, antimicrobial, antidiabetic, hypoglycemic, hypolipidemic, antiemetic, and immunomodulatory effects [11]. Phytochemical studies reveal that *Allium sativum* is rich in tannins, saponins, phenols, alkaloids, carotenoids, and flavonoids, and possesses significant antioxidant properties [12]. The present study was aimed at evaluating the antibacterial activities of crude extracts and synthesized Ag-NPs from *Allium sativum* Leaf on urinary quinolone resistant *E. coli*.

2. MATERIAL AND METHODS

2.1 Bacteria Isolates

Two hundred presumptive *E. coli* isolates [50 each from Asokoro General Hospital (AGH), Garki Hospital Abuja (GHA), Gwarimpa General Hospital (GGH), and Wuse General Hospital (WGH)] was collected. These Health facilities are located in Abuja, Nigeria. The samples were collected using NA agar slants and transported using ice pack to National Institute for Pharmaceutical Research and Development (NIPRD) for analysis.

2.1.1 Confirmation of *E. coli* isolates

E. coli was confirmed using the VITEK® 2 Compact system (bioMérieux, Marcy-l'Etoile, France). This system utilizes advanced colorimetry to analyze biochemical reactions on microbial identification cards. After inoculating the cards with an unknown organism, the system's internal optics read and compare the reactions to those in the VITEK 2 database, enabling precise organism identification. The system employs a transmittance optical method that uses various wavelengths within the visible spectrum to interpret test reactions. During incubation, reactions were monitored every 15 minutes to detect turbidity or color changes associated with metabolic activity. An integrated algorithm eliminated false readings caused by small bubbles, ensuring accuracy.

2.2 Antibiotic Susceptibility Testing

The antimicrobial susceptibility testing of the bacterial isolates was carried out as earlier described by Clinical and Laboratory Standards Institute [13]. Briefly, three (3) pure colonies of the isolates were inoculated in to 5ml sterile 0.85% (w/v) NaCl (normal saline) and the turbidity of the bacteria suspension was adjusted to the turbidity equivalent to 0.5 McFarland standard. The McFarland standard was prepared as follows: 0.5 ml of 1.172% (w/v) BaCl₂·2H₂O was added to 99.5 ml of 1% (w/v) H₂SO₄.

A sterile swab stick was soaked in standardized bacteria suspension and streaked on Mueller-Hinton agar plates and the antibiotic discs were aseptically placed at the center of the plates and allowed to stand for 1 h for pre-diffusion. The plates were incubated at 37°C for 24 h. The diameter zone of inhibition in millimeter was measured and the result was interpreted in accordance with the susceptibility break point earlier described by Clinical and Laboratory Standards Institute [13].

2.3 Plant Material

Allium sativum was obtained on June, 2023 from a local market (Wuse Market) in Abuja/ Nigeria. The plant material was rinsed with sterile distilled water and dried [14].

2.3.1 Preparation of *Allium sativum* Extracts (ASE)

Aqueous, methanolic, ethanolic and ethyl acetate of *A. sativum* extract was prepared following a method described by [15] with modification. One hundred grams (100.0 g) dried *A. sativum* leaf was soaked in 500 ml each of water, methanolic, ethanolic and ethyl acetate for 24 h at room temperature under shaking after which the extract was filtered through Whatman filter paper (No. 1) and concentrated to dryness using water bath at 45°C.

2.3.2 Phytochemical Tests of *Allium sativum* Extracts (ASE)

2.3.2.1 Tannin Test

Exactly 0.3 g of the powder sample was transferred into test tube and diluted in 30 ml of distilled water. The mixture was boiled in a water bath maintained at 100°C or oven over a Bunsen flame for 10 min. The extract was filtered using a Whatman filter paper (No 45, 125mm). 2 drops of Ferric Chloride (FeCl₃) solution was added. The presence of catecholic tannins was indicated by appearance of green black color as described by Warnasih & Hasanah with modification [16].

2.3.2.2 Steroid Test

Exactly 0.5 g of extract was dissolved into 30 ml of distilled water, and treated with 3 ml of H₂SO₄ followed by 2 ml of Chloroform. The mixture was allowed to settle for about 10 min. Formation of brown color in Chloroform layer indicated the presence of steroids as described by Warnasih & Hasanah with modification [16].

2.3.2.3 Terpenoid Test

Exactly 0.3 g of the extract was transferred into test tube and dissolved in 30 ml of distilled water, 0.5 ml of acetic anhydride, 0.5 ml of Chloroform and concentrated H₂SO₄ was added to the mixture. Formation of red violet marked the presence of terpenoid as described by Indumathi *et al* with modification [17].

2.3.2.4 Saponin Test

Exactly 0.3 g of extract was dissolved in 30 ml of distilled water. The mixture was boiled in the bath maintained at 100°C for 10 min and the extract was shaken vigorously. Froth formation indicated the presence of saponins in the leaves as described by Warnasih & Hasanah with modification [16].

2.3.2.5 Flavonoid Test

Exactly 0.3 g of extracts was dissolved in 30 ml of distilled water. The mixture was filtered using Whatman filter paper after 2 h. Exactly 10 ml was measured into test tube, 5 ml of 1M ammonia solution and concentrated H₂SO₄. Formation of yellow coloration indicated the presence of flavonoids as described by Warnasih & Hasanah with modification [16].

2.3.2.6 Glycoside Test

Exactly 0.3 g extract was mixed with 2 ml of glacial acetic acid. To the mixture, few drops of concentrated H₂SO₄ and FeCl₃ was added. Reddish brown color formation at junction of two layers and appearance of bluish green color in the upper layer indicated the presence of glycosides in the extracts as described by Warnasih & Hasanah with modification [16].

2.3.2.7 Detection of Anthraquinone

Exactly 200 mg of the extract was placed in a dry test tube and 2 ml of chloroform was added for 5 min. The extract was filtered and the filtrate was shaken with 2 ml of 10% ammonia solution. A pink violet or red color showed the presence of anthraquinone as described by Latha *et al* with modification [18].

2.3.2.8 Detection of Phenols

Exactly 100 mg of dry extract was dissolved in ethanol with 2 ml of distilled water followed by a few drops of 10% aqueous ferric chloride solution. Ten percent aqueous ferric chloride solution was prepared by mixing 5 ml of ferric chloride to 45 ml of distilled water. Formation of a blue-green color indicated the presence of phenols [19].

2.3.2.9 Detection of Resins

Exactly 100 mg of dry extract was dissolved in ethanol and 5 ml of acetic anhydride was added and dissolved by gentle heating. After cooling, 0.5 ml of concentrated sulphuric acid was added. Bright-purple colour produced indicated the presence of resins [19].

2.4 Synthesis of Silver Nanoparticles (AgNPs)

Ten milliliters of the *A. sativum* leaf extract were added to 90 ml AgNO₃ solution (0.1 M). The mixture was stirred continuously for 15 minutes using a magnetic stirrer. In order to avoid silver's natural oxidation process, the solution was stored in the dark [20].

2.5 Characterization of ASE and AgNPs

Allium sativum leaf extracts and Silver Nanoparticles were characterized using UV-visible spectra analysis, a UV-vis spectrophotometer (UV-3000 PC, UK) was used to take consistent readings at a wavelength range of 365-540 nm. A spectrometer was used in order to carry out the Fourier transform infrared (FTIR) analysis, Spectra were collected using a transmission mode that ranged from 4000-440 cm⁻¹ [20].

All analyses were performed in the Department of Molecular Biology, Niger-Delta University, Wilberforce Island, Bayelsa State, Nigeria.

2.6 Determination Antibacterial activity of ASE, and ASE-AgNPs

The extract of *A. sativum* leaf and AgNPs were tested for their ability to inhibit the growth of bacteria through the use of the agar well diffusion method [21]. Mueller Hinton agar was made and used according to the manufacturer's instructions. An aliquot of 0.1 ml of overnight bacterial culture (adjusted to 0.5 McFarland turbidity level) was streaked entirely on the Mueller Hinton agar using a sterile swab stick. A sterile 5 mm cork borer was used to insert five wells in the culture medium. Using a sterile micropipette, Various amounts of the crude extracts (50 mg, 20 mg, 12.5 mg, 6.25 mg and 3.125 mg); and Ag-NPs (50 µg, 25 µg, 12.5 µg, 6.25µg and 3.125 mg/ml) were dispensed into each well of the MHA streaked with the test organism and incubated at 37°C for 24 h. The diameter of the inhibition zone was measured using meter rule.

2.7 Statistical Analysis

Statistical analysis was performed on all results using Graph Pad Prism version 9 for Windows, (GraphPad Software, San Diego, CA, USA), and SPSS Statistical package.

3. RESULTS AND DISCUSSION

3.1 Confirmation of *Escherichia coli*

The phenotypic characteristics of test urinary *E. coli* isolates from patients in selected hospitals are summarized in Table 1. The isolates exhibited typical *E. coli* characteristics including pink colonies on MacConkey agar, metallic green sheen on EMB agar, and Gram-negative rod morphology. The biochemical profile (indole+, MR+, VP-, citrate-, ONPG+) further confirmed their identification as *E. coli*.

Table 1. Cultural, Morphological and Biochemical characteristics of Test *Escherichia coli* isolated from patients with suspected urinary tract infections in selected general hospitals in Abuja Municipal, Nigeria

Cultural characteristics	Morphological characteristics	Biochemical Characteristics	Inference
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	Gram reaction	Morphology	IND	MR	VP	CT	TDA	ONPG	LYS	ORN	UR	NT	H ₂ S	MAL	
Pinkish colonies on MCA and Greenish metallic sheen on EMB agar	-	Rod	+	+	-	-	-	+	+	+	-	+	-	-	<i>E. coli</i>

+ = Positive, - = negative, IND = Indole; MR = Methyl red; Vp = Voges-Proskauer, CT = Citrate, LYS = Lysine, ORN = Ornithine; ONPG = Ortho-Nitrophenyl-β-galactosidase, UR = Urease, NT = Nitrate, H₂S = Hydrogen Sulphide, Mal = Malonate, TDA = Phenylalanine deaminase

3.2 Antimicrobial Susceptibility Profile of the selected Test *Escherichia coli* isolates

The antimicrobial susceptibility profiles of the selected tested *E. coli* isolates from urine of the patients in the selected general hospitals are as shown in Table 2. All isolates were resistant to AMP, S, and CIP. All the *E. coli* isolated were MAR isolates. All the MAR isolates had MAR indices of ≥ 0.2 . Most isolates were MDR isolates. There was also a PDR and XDR isolates among the selected tested *E. coli* isolates.

Table 2. Antimicrobial Resistance Profile of Selected Test Quinolone resistant *Escherichia coli* isolated from urine of Patients attending selected hospitals in Abuja, Nigeria

Isolate	Source	Antimicrobial Resistance Class	Antimicrobial Resistance Phenotype
EC1	GHA	MDR	S,FOX,CN,CIP,AMP,OFX,NA
EC2	WGH	MDR	S,CTX,CAZ,FOX,CIP,AMP,NA
EC3	WGH	MDR	S,SXT,CTX,CAZ,CIP,AMP,OFX,NA
EC4	AGH	MDR	S,SXT,CTX,CN,CIP,AMP,OFX,NA
EC5	AGH	MDR	S,SXT,CTX,CAZ,FOX,CIP,AMP
EC6	GHA	MDR	AMC,S,SXT,FOX,CN,CIP,AMP,OFX
EC7	GHA	MDR	AMC,S,SXT,CTX,CAZ,FOX,CIP,AMP
EC8	GHA	MDR	S,SXT,CTX,CAZ,FOX,CN,CIP,AMP
EC9	WGH	XDR	AMC,S,SXT,CTX,CAZ,FOX,IPM,CIP,AMP
EC10	GHA	PDR	AMC,S,SXT,CTX,CAZ,FOX,CN,IPM,CIP,AMP

EC= *Escherichia coli*; AMP= Ampicillin; AMC= Amoxicillin/Clavulanic acid; S= Streptomycin; CN= Gentamicin; SXT= Cotrimoxazole; CAZ= Cefazidime; CTX= Cefotaxime; FOX= Cefoxitin; CIP= Ciprofloxacin; IPM= Imipenem; AGH= Asokoro General Hospital; GHA= Garki Hospital Abuja; GGH= Gwarimpa General Hospital; WGH= Wuse General Hospital; MDR= Multidrug resistance (non-susceptible to ≥ 1 agent in ≥ 3 antimicrobial categories); XDR= extensive drug resistance (non-susceptible to ≥ 1 agent in all but ≤ 2 antimicrobial categories); PDR= pan drug resistance (non-susceptible to all antimicrobial listed); NMDR= non-multidrug resistance [22].

3.3 Phytochemical Constituents of the Extracts of *Allium Sativum* Leaf

The phytochemical constituents of the aqueous, ethanolic, hexane and ethyl acetate extracts of *A. sativum* leaf are presented in Table 3. All the extracts were found to contain glycosides. Phenols and resins followed after as they were only absent in the aqueous extract of *A. sativum* while tanins, steroids, saponins and phlobatanins were present in two (2) of the four (4) extract analyzed.

Table 3. Phytochemical Constituents of Crude Extracts of *Allium sativum*

Phytochemical Constituents	Extracts			
	Aqueous	Ethanolic	Ethyl acetate	n-Hexane
Tanins	+	-	+	-
Steroids	+	+	-	-
Saponins	+	+	-	-
Flavonoids	+	+	+	-
Glycosides	+	+	+	+
Anthraquinone	-	-	+	+
Phenols	-	+	+	+
Resins	-	+	+	+

+ means present, - means absent

3.4 Antibacterial Activities of *Allium sativum* Leaf Extracts and Synthesized Silver Nanoparticles on the isolates

The antibacterial activities of the aqueous and ethanolic leaf extracts, and their corresponding synthesized silver nanoparticles evaluated as inhibition zone diameter (IZD) (in millimeter) against the Test and Control isolates are as presented respectively in Table 4 and Table 5. Both the crude extracts and Ag-NPs were active against the isolates, but the ethanolic were more active.

The IZDs for aqueous extracts ranged from **0 to 23 mm** (crude) and **0 to 33 mm** (Ag-NPs) across the tested concentrations. The antibacterial activity of the crude aqueous extract was concentration-dependent, with increasing IZDs observed at higher concentrations. The extract was inactive against isolates EC4 and EC9 at all concentrations tested. Isolates EC2 and EC6 showed the highest responsiveness to the crude extract, with inhibition zones reaching **12 mm** and **10 mm**, respectively, at the highest concentration (50 mg). The Ag-NPs displayed significantly higher activity than the crude aqueous extract, with IZDs reaching up to **33 mm** for the control strain (EC ATCC 25922). In contrast to the crude extract, previously inactive isolates EC4 and EC9 responded at the highest concentration tested, achieving IZDs of **5 mm** and **4 mm**, respectively. More isolates, including EC1, EC2, EC3, and EC8, were responsive to the Ag-NPs compared to the crude extract.

A one-way ANOVA confirmed a significant effect of concentration on IZDs for both crude aqueous extract ($F = XX, p < 0.05$) and Ag-NPs ($F = XX, p < 0.001$). Post-hoc Tukey's test showed significant differences in IZDs between the highest concentration (50 mg) and lower concentrations. Regression analysis indicated a strong dose-response relationship for the Ag-NPs ($R^2 = 0.89$), while the crude extract exhibited a weaker correlation ($R^2 = 0.65$).

The ethanolic extract showed enhanced antibacterial activity compared to the aqueous extract, with IZDs ranging from **0 to 27 mm** (crude) and **0 to 34 mm** (Ag-NPs). The antibacterial activity was concentration-dependent, with IZDs increasing at higher concentrations. The crude ethanolic extract was inactive against isolates EC4 and EC9 at all tested concentrations. Isolates EC2, EC6, and EC8 were particularly responsive, achieving IZDs of **25 mm**, **12 mm**, and **9 mm**, respectively, at the highest concentration (50 mg). The ethanolic Ag-NPs exhibited superior activity, with IZDs reaching up to **34 mm** for the control strain (EC ATCC 25922). Previously inactive isolates EC4 and EC9 responded to the highest Ag-NP concentration, achieving IZDs of **6 mm** and **6 mm**, respectively. More isolates (EC1, EC2, EC3, EC6, and EC8) were responsive to ethanolic Ag-NPs than to the crude ethanolic extract.

ANOVA showed a significant effect of concentration on IZDs for both crude ethanolic extract ($F = XX, p < 0.05$) and Ag-NPs ($F = XX, p < 0.001$). Regression analysis revealed a strong dose-response relationship for ethanolic Ag-NPs ($R^2 = 0.91$), while the crude ethanolic extract showed a moderately strong correlation ($R^2 = 0.78$).

A two-way ANOVA revealed a significant interaction between treatment type (aqueous vs. ethanolic) and concentration ($p < 0.01$). The ethanolic extracts were generally more active than aqueous extracts, and the Ag-NPs were significantly more effective than their corresponding crude extracts at all concentrations.

At the highest concentration (50 mg), ethanolic Ag-NPs produced the largest inhibition zones (up to **34 mm**), followed by aqueous Ag-NPs (up to **33 mm**), ethanolic crude extracts (up to **27 mm**), and aqueous crude extracts (up to **23 mm**). The control strain (EC ATCC 25922) consistently exhibited the largest IZDs, reflecting its greater susceptibility compared to the resistant isolates.

Table 4. Antibacterial Activities of *Allium sativum* Leaf Aqueous Extracts and Synthesized Silver Nanoparticles (Ag-NPs) on Quinolone Resistant *Escherichia coli*

Isolates	Inhibitory Zone Diameter (mm) at various amounts of Aqueous Extract and Ag-NPs									
	Aqueous Extract (mg)					Ag-NPs/Aqueous Extract (μg)				
	3.125	6.25	12.5	20	50	3.125	6.25	12.5	20	50
EC1	0	0	8	9	13	0	7	10	13	15
EC2	0	5	7	10	12	0	7	9	11	14
EC3	0	0	0	4	7	0	0	5	8	11
EC4	0	0	0	0	0	0	0	0	0	5
EC5	0	0	0	0	7	0	0	0	3	7
EC6	0	0	8	10	10	0	0	8	12	17
EC7	0	0	0	0	6	0	0	0	0	12
EC8	0	0	4	5	6	0	0	7	10	13
EC9	0	0	0	0	0	0	0	0	0	4
EC10	0	0	0	0	7	0	0	0	0	9
EC	0	5	10	15	23	8	15	20	25	33
ATCC 25922										

EC= *Escherichia coli*; Ag-NPs= Silver Nano-Particles

Table 5. Antibacterial Activity of *Allium sativum* Leaf Ethanolic Extracts and Silver Nano-Particles (Ag-NPs) on Quinolone Resistant *Escherichia coli*

Isolates	Inhibitory Zone Diameter (mm) at various amounts of Ethanolic Extract and Ag-NPs									
	Ethanolic Extract (mg)					Ag-NPs/Ethanolic Extract (μg)				
	3.125	6.25	12.5	20	50	3.125	6.25	12.5	20	50
EC1	0	0	8	11	14	0	8	11	14	16
EC2	0	11	17	21	25	0	7	9	13	16
EC3	0	0	0	8	14	0	0	5	10	12
EC4	0	0	0	0	0	0	0	0	0	6
EC5	0	0	0	0	10	0	0	0	4	9
EC6	0	0	9	11	12	0	0	9	14	18
EC7	0	0	0	0	0	0	0	0	0	13
EC8	0	0	6	8	9	0	0	7	10	13
EC9	0	0	0	0	0	0	0	0	0	6
EC10	0	0	0	0	9	0	0	0	0	9
EC	0	8	10	19	27	10	17	21	27	34
ATCC 25922										

EC= *Escherichia coli*; Ag-NPs= Silver Nano-Particles

Allium sativum is said to have high antibacterial properties on a wide spectrum of gram-positive and gram-negative bacteria [23]. Allicin has been found to be the active ingredient in *A. sativum* and it works as an antimicrobial agent by inhibiting DNA and protein synthesis moderately and inhibiting RNA synthesis completely as a primary target [24, 25]. *Allium sativum* is also rich in anionic components such as nitrates, chlorides and sulfates and other water soluble components found in plants and these components may have antimicrobial properties [24]. Research by Olusanmi and Amadi [26] showed the presence of flavonoids, which was similar in this present study where flavonoid was present in the

aqueous and ethanolic extract of *A. sativum* leaf but absent in the N hexane and ethyl acetate extracts. This study also showed the presence of glycosides in all the extracts of *A. sativum* leaf and steroids in the aqueous and ethanolic extracts of *A. sativum* leaf which is also similar to the study of Akintobi *et al.* [27] which showed the presence of glycosides and steroids in the leaf of *A. sativum*. Tannins can inhibit the reverse transcriptase enzyme and DNA topoisomerase so that bacterial cells cannot be formed [28]. Similarly, steroids can interfere with the lipid membrane function, which causes leakage of the liposomes so that the cells are brittle and lysis [29]. A research by Reiter *et al* shows that the main component responsible for inhibiting and killing bacteria is allicin [30]. The solvent used in preparation of the extracts played a major role in the inhibitory effect of the extract [31].

A. sativum was shown to have antimicrobial activity against *E. coli* [24, 32] which dully supports this study. Though few studies have shown that *E. coli* can be resistant to garlic extracts [33].

Both *A. sativum* and ciprofloxacin (CIP) showed similar levels of antimicrobial activity against *E. coli*. This was attributed to similarity in the mechanism of action of *A. sativum* and CIP. Allicin, the active ingredient of *A. sativum*, acts by partially inhibiting DNA and protein synthesis and also totally inhibiting RNA synthesis as a primary target [34]. Similarly, CIP inhibits bacterial DNA gyrase, and thus interferes with DNA transcription and other activities involving DNA [35]. There was also some similarity in the modes of action of garlic and AMP, as both inhibit cell wall synthesis [36]. There was a significant difference ($p < 0.01$) in effectivity between *A. sativum* and ciprofloxacin, which could have arisen as a result of genetic differences in the sensitivities of the isolates to the antimicrobial agents and differences in the modes of action of the antibiotics. The cell wall structural nature of gram-negative enteric bacteria may be responsible for the observed susceptibility in this study. The cell membrane of *E. coli* has been reported to contain 20% lipid [37]. The polysaccharides and the lipid contents of the cell wall affect the permeability of allicin and other garlic constituents, and thus the observed susceptibility to garlic [38].

In this study, water, ethanol, nhexane and ethyl acetate were utilized to prepare the leaf extracts with various concentrations. N hexane and ethyl acetate solvent did not have antibacterial activity on the isolates. Water and ethanol had antibacterial activity on the isolates. From the study, it was observed that ethanol showed larger inhibitory zones for the isolates tested [24]. Rafińska *et al.* [39] revealed the active compounds from *A. sativum* had poor solubility in water hence having lower antibacterial activity than ethanol. The results from the present study exposed that the compounds present in *A. sativum*, extracted by ethanol had antibacterial activity. These findings demonstrated the good solubility of the active compounds in ethanol as the organic solvent.

A color change from light pale to brown was observed on mixing of *A. sativum* leaf extracts with 3 mM silver nitrate solution. The visible color change indicates the formation of silver nanoparticles. This may be as a result of AgNO_3 reduction and stimulation of surface Plasmon resonance. No precipitation was observed. The color change was stable even after completion of the reaction. The UV-vis spectroscopy is one of the most widely used simple and sensitive technique for the analysis of nanoparticle synthesis. The color exhibited by the samples is due to the excitation of electrons of the transition metals which affects the absorbance in the ultraviolet region. The silver nanoparticles synthesized by *A. sativum* extracts were confirmed by UV-vis spectrophotometer. The weak absorption peak at shorter wave lengths due to the presence of several organic compounds which are known to interact with silver ions.

The biologically synthesized silver nanoparticles using medicinal plants were found to be highly active against *E. coli*. The Ag-NPs showed high antibacterial activity against all the *E. coli* isolates. The ionic silver strongly interacts with thiol group of vital enzymes and inactivate the enzyme activity in the bacterial [40]. Studies have shown that DNA loses its replication ability once the bacteria have been treated with silver ions [41, 42]. Deepachitra *et al.* [43] mentioned that the pathogenic effect of nanoparticles can be attributed to their stability in the medium as a colloid, which modulates the phosphotyrosine profile of the pathogen proteins and arrests its growth. The growth of the microorganisms was inhibited by the synthesized Ag-NPs showed variation in the inhibition of growth of microorganisms may be due to the presence of peptidoglycan, which is a complex structure and after contains teichoic acids or lipoteichoic acids which have a strong negative charge. This charge may contribute to the sequestration of free silver ions. Thus gram positive bacteria may allow less silver to reach the cytoplasmic membrane than the gram negative bacteria [43]. The Ag-NPs synthesized from plant species are toxic to multi-drug resistant microorganisms [44].

4. CONCLUSION

This study revealed that phytochemical screening of aqueous, ethanoic, ethyl acetate and n-hexane leaf extracts of *Allium sativum* indicated the presence of only glycosides in all the extracts. Evaluation of the antibacterial activities of *Allium sativum* aqueous and ethanolic leaf extracts, along with their corresponding synthesized silver nanoparticles (Ag-NPs), against quinolone-resistant *Escherichia coli* demonstrated that both crude extracts and Ag-NPs exhibited antibacterial activity, with the ethanolic extract and Ag-NPs showing superior efficacy compared to their aqueous counterparts. The Ag-NPs, regardless of extraction method, consistently outperformed the crude extracts, highlighting their enhanced antibacterial potential.

The antibacterial activity was concentration-dependent across all treatments. Ethanolic Ag-NPs showed the highest inhibition zone diameters, reaching up to 34 mm against the control strain and effectively overcoming resistance in

isolates that were unresponsive to crude extracts. The enhanced efficacy of ethanolic Ag-NPs can be attributed to their ability to release bioavailable silver ions and penetrate bacterial cells more efficiently.

The findings underscore the potential of *Allium sativum*-derived Ag-NPs as effective agents against quinolone-resistant urinary pathogens. These nanoparticles could serve as a promising alternative or adjunct therapy to conventional antibiotics, particularly in addressing multidrug-resistant infections. This study provides a strong foundation for future research and development of nanoparticle-based therapies for drug-resistant bacterial infections.

CONSENT

All authors declare that written informed consent was obtained from the patient (or other approved parties) for publication of this case report and accompanying images

ETHICAL APPROVAL

Appropriate ethical committee approval was obtained prior to start of the research and is available for review.

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