Nigerian Research Journal of Chemical Sciences (ISSN: 2682-6054)
Volume 15, Issue 2, 2026

Antimicrobial Evaluation of Zinc Oxide Nanoparticles Synthesized Using *Irvingia gabonensis* Seed Shell Extract for Potential Paint Applications

*[1]Mercy E. Udezi, [2]Ikhuoria U. Esther, [2]Uwidia. E. Ita, [3]Ifijen H. Ikuazuagbe,
[4]Bamidele H. Akpeji
[1]Department Chemistry, College of Sciences,
Federal University of Petroleum Resources, Effurun, Delta State, Nigeria.
[2]Department of Chemistry, Faculty of Physical Sciences,
University of Benin, Benin City, Nigeria.
[3]Department of Chemistry, Edo State University, Iyamho, Edo State, Nigeria
[4]Department Science Laboratory Technology,
Federal University of Petroleum Resources, Effurun, Delta State, Nigeria.
*Corresponding Author: udezi.mercy@fupre.edu.ng

Accepted: *October 31, 2026* **Published Online***: November 5, 2026*

ABSTRACT

This study investigated the synthesis, characterization, and antimicrobial activity of zinc oxide nanoparticles (ZnO NPs) using *Irvingia gabonensis* seed-shell extract. Phytochemical screening was conducted using standard methods, and antimicrobial activity was evaluated against selected bacterial and fungal pathogens using agar diffusion. The synthesized material was characterized by Fourier-transform infrared (FTIR) spectroscopy, X-ray diffraction (XRD), and scanning electron microscopy (SEM). Phytochemical screening detected alkaloids, saponins, tannins, terpenoids, phenols, flavonoids, and reducing sugars. FTIR bands were assigned to O–H, C–H, C=O/C=C, N–H, and C–O-containing groups, which may reflect plant-derived species associated with nanoparticle formation and surface stabilization. XRD analysis gave an average crystallite size of approximately 60.19 nm. The nanoparticles showed concentration-dependent antimicrobial activity, with maximum reported inhibition zones of 29 mm against *Escherichia coli* and 26 mm against *Aspergillus niger*. The minimum inhibitory concentration was lowest for *Salmonella typhi* (5 mg/mL), while no inhibition was detected for *E. coli* in the MIC assessment. These results support further investigation of *I. gabonensis* seed-shell extract as a biomass resource for ZnO nanoparticle synthesis and potential antimicrobial paint formulations. Further work is required to establish safety, durability, and performance in finished coatings.

Keywords: Antimicrobial, nanoparticles, phytochemicals, *Irvingia gabonensis*

INTRODUCTION

Due to the demand of greener sustainable products, there has been a drive to develop sustainable green synthesis routes for functional nanomaterials [1]. Zinc oxide nanoparticles are among the nanomaterials that have gained much attention due to their antimicrobial activity, UV-absorbance, and prospective use as active components in protective coatings or paints [2-4]. The broad spectrum antimicrobial effect of ZnO-NPs has direct implications for the use of these in paint preparations, as microbial growth can lead to staining, surface degrading, and coatings' deterioration [5, 6].

Green synthesis has emerged as an alternative to conventional nanoparticle production, particularly where it involves biological products and minimizes the use of potentially toxic chemicals. Decay and processing of the seed and hard shell of the fruits of the native African deciduous tree *Irvingia gabonensis* (African mango) could generate waste material; using these seed shells as a precursor for ZnO-NP synthesis could take advantage of an underutilized biomass material in the production of environmentally friendly nanomaterials.

This work aims to synthesize Zinc oxide Nano particles using *Irvingia gabonensis* seed shell extract and test its antimicrobial activities against some selected microorganisms. The results obtained will shed light on the antimicrobial activity of the green synthesized Zinc oxide nanoparticles and its potential suitability to be incorporated into paint as antimicrobial coating material.

MATERIALS AND METHODS

Materials

All reagents were of analytical reagent (AR) grade and were used without further purification: zinc acetate dihydrate, sodium hydroxide, hydrochloric acid, Mayer's reagent, 5% $FeCl_3$, chloroform, concentrated tetraoxosulphate(VI) acid, acetic acid, Fehling's solutions A and B, and 10% ammonia solution. The solutions 2% HCl and 2 M NaOH were purchased from BDH Chemicals (England), and nutrient agar and Mueller–Hinton media were obtained from Sigma-Aldrich (USA).

Sample Collection and Preparation

Fresh *Irvingia gabonensis* (Ogbono in Igbo) seed shells were collected from households in Abraka town, located in the South-South region of Nigeria. The collected samples were cleaned to remove debris and air-dried before further processing. Botanical identification of the plant material was carried out and authenticated at the Department of Plant Biology and Biotechnology, University of Benin, Nigeria with voucher number **UBH-1153**. After it was dried, the shells were ground into fine particles using a mortar and pestle. The resulting dried shell particles were then sealed in polythene bags.

Extraction of *Irvingia gabonensis*

The aqueous extract of *Irvingia gabonensis* seed shell was prepared following the procedures described by Ikhuoria et al [7]. Exactly 10 g of the pulverized sample was measured into a 250 ml beaker containing 100 ml of water, the mixture were heated at 80 °C for 10 minutes and subsequently stirred for 5 minutes to ensure uniform extraction. After cooling to room temperature, the suspension were sieved through cotton wool and further filtered using Whatman No. 1 filter paper. The filtrate (aqueous extract) were collected and stored in a refrigerator at 4 °C until further use.

Qualitative Phytochemical Screening

The qualitative phytochemical screening of the leaf extracts was performed using the methods described by AOAC [8].

Test for Tannins

The solution of the extract was shaken with a small quantity of ferric chloride. The formation of a blue-green precipitate indicates the presence of tannins.

Test for Flavonoids

The solution of the extract was mixed with two drops of ammonia, resulting in a yellow-brown color, signifying the presence of flavonoids.

Test for Saponins

The solution of the extract was shaken with about 5 ml of distilled water and then heated to a boil. The formation of frothing indicates the presence of saponins.

Test for Alkaloids

The solution of the extract was warmed with 1% HCl for two minutes, filtered, and a few drops of Dragendorff's reagent were added. A reddish-brown color and turbidity with the reagent indicate the presence of alkaloids.

Test for Terpenoids

A mixture of 3 ml of various solvent extract, 1 ml of chloroform, and 1.5 ml of concentrated H_2SO_4 was created. The formation of a reddish-brown coloration at the interface indicates the presence of terpenoids.

Green Synthesis of Zinc Oxide Nanoparticles

The green synthesis of ZnO nanoparticles were carried out following the methodology of Ikhuoria et al [7] and Otabor et al [9], with slight modifications to improve yield and stability. A 200 mL solution of zinc acetate precursor was measured into a clean 500 mL conical flask. To this, 15 mL of freshly prepared *Irvingia gabonensis* seed shell extract was added under continuous stirring. The phytochemicals acted as both reducing and stabilizing agents during nanoparticles formation.

To maintain an alkaline environment conducive to nanoparticles nucleation, five drops of 0.5 mol dm^{-3} NaOH were introduced into the reaction mixture. The solution was then heated and stirred at 70 °C for 1 hour using a magnetic stirrer to promote complete reduction and stabilization of the zinc precursor. During this process, a gradual change in the mixture's turbidity was observed, indicating nanoparticles formation. The reaction mixture was centrifuged at 5000 rpm for 30 minutes to separate the solid nanoparticles from the supernatant. The pellet obtained was collected and washed several times with distilled water until the pH of the wash solution is neutral, ensuring the removal of excess precursors and unbound phytochemicals.

Finally, the purified ZnO nanoparticles was dried in a laboratory drying oven at 60 °C to obtain a fine Nano powder. The dried ZnO nanoparticles was stored in airtight sample containers for subsequent characterization and application studies.

Characterization of the Synthesized Zinc Oxide Nanoparticles

To ensure that ZnO nanoparticles was synthesized successfully, characterization techniques and analysis were conducted. Ultraviolet-Visible Spectrometer (Cary Series, Agilent Technology) was used for scanning the sample with a wavelength range of 200 nm – 800 nm with $BaSO_4$ as a

reference material. X-ray diffractometer (Bruker D8, Advance diffractometer, Coventry, UK) was used for analyzing the crystalline material with Cu k-alpha radiation of wavelength 1.5402 nm. Fourier-transform infrared spectrometer (Perkin Elmer FT-IR) was employed to detect the functional groups of the synthesized nanoparticles. The scanning was conducted within a wavenumber range of 500–4000 cm^{-1}. Scanning electron microscopy with a Nova Nano SEM 450 analyzer was used to give a high-resolution images of the synthesized nanoparticles. The SEM images were captured with an acceleration voltage of 40 KV.

Test Microorganisms and Growth Conditions

Seven bacterial and three fungal strains were used to assess the antimicrobial activity of the synthesized ZnO NPs. The Gram-positive bacteria were *Bacillus cereus, Staphylococcus aureus,* and *Streptococcus pneumoniae*; the Gram-negative bacteria were *Escherichia coli, Klebsiella pneumoniae, Salmonella typhi,* and *Pseudomonas aeruginosa*. The fungi were *Candida albicans, Trichophyton rubrum,* and *Aspergillus niger*. Bacteria were maintained on Mueller–Hinton agar (MHA) and grown in Mueller–Hinton broth (MHB), while fungi were maintained on potato dextrose agar (PDA).

Antimicrobial Susceptibility Testing

Antibacterial and antifungal activities were determined by the agar well diffusion method. Suspensions of each test organism were inoculated onto the appropriate agar medium, wells were filled with ZnO NP dispersions at 40, 20, 10, 5, and 2.5 µg/mL, and the plates were incubated under standard conditions. Ciprofloxacin (30 µg/mL) and fluconazole (30 µg/mL) served as positive controls for bacteria and fungi, respectively, and each test was performed in triplicate.

Zones of inhibition were measured in millimetres (mm) and recorded as mean values. Minimum inhibitory concentrations (MICs) were subsequently determined by broth microdilution following standard MIC methodology [10-11] with the MIC defined as the lowest concentration at which no visible growth was observed.

RESULTS AND DISCUSSION

Phytochemicals

The phytochemical analysis of *Irvingia gabonensis* seed shell revealed the presence of several bioactive secondary metabolites, as shown in Table 1. The sample appeared as a liquid with a dark-brown coloration, which is consistent with extracts obtained from seeds rich in oils and phenolic compounds. Such coloration often indicates the presence of oxidizable phytochemicals, particularly tannins and phenols, which are known to impart dark hues to plant extracts. The qualitative screening showed that alkaloids, saponins, tannins, terpenoids, phenols, flavonoids, and reducing sugars were all detected in the sample. The presence of these phyto-constituents suggests that *Irvingia gabonensis* possesses a diverse chemical profile that may contribute to its traditional medicinal and nutritional applications. However, these correspond to the earlier findings [12-14].

Alkaloids are known for their wide range of pharmacological activities, including analgesic and potential antimicrobial properties. Saponins that were present are associated with cholesterol-lowering, immune-boosting, and anti-inflammatory effects. The detection of tannins and phenols emphasizes the antioxidant potential of the sample, however, these compounds are capable of scavenging free radicals thereby protecting biological systems from oxidative damage. The presence of these compounds aligns with reports that *Irvingia gabonensis* possesses antioxidant and antimicrobial activities. Flavonoids is another important group of polyphenolic compounds found in the extract, it contributes additional antioxidant, anti-inflammatory, and cardioprotective properties. The presence of terpenoids suggests potential therapeutic value, as this class of compounds is known for anti-malarial, anti-cancer, and anti-microbial activities.

On the other hand, anthraquinones were not detected in the sample. This may be attributed to the fact that anthraquinones are more commonly found in the leaves and bark of certain plants rather than in seeds. Their absence therefore suggests that *Irvingia gabonensis* seed shells may not be associated with laxative or irritant properties typically linked to anthraquinone derivatives. Phlobatannins were also not detected, which is consistent with many edible seeds where these condensed tannins are usually present in very low concentrations or absent. The detection of reducing sugars indicates the presence of simple carbohydrates, suggesting that the extract contains nutritional components that may contribute to its caloric and metabolic value.

Overall, the phytochemical profile obtained aligns with previous scientific findings on *Irvingia gabonensis* seed shell as reported by Mgbemena et al [14] indicating that the seed is rich in health-promoting bioactive compounds. The presence of multiple classes of secondary metabolites supports the plant can serve as bio-reducing and stabilizing agents in the green synthesis of nanoparticles, as has been observed in studies by Agarwal et al [15] and Ramesh et al [16].

Table 1: Phytochemical characterization of *Irvingia gabonensis* seed shell

Phytochemical	Results
Alkaloids	+
Saponins	+
Tannins	+
Terpenoids	+
Phenols	+
Flavonoids	+
Anthraquinones	_
Phlobatannins	_
Reducing sugar	+

Keys; (+) detected, (-) not detected

XRD

The XRD pattern of the synthesized ZnO nanoparticles shown in Figure 1 presents several sharp and intense diffraction peaks, indicating high crystallinity. The peaks corresponding to the (100), (002), (101), (102), (110), (103), (200), and (112) planes are intense and narrow, with the (101) reflection, which is typical of the hexagonal wurtzite structure of ZnO, being the most intense. The appearance and position of these peaks confirm the formation of phase-pure ZnO nanoparticles, and the identical positions of all peaks with those of the standard JCPDS for metallic zinc oxide confirm the absence of any secondary phases such as zinc hydroxide or zinc carbonate [15]. The

high intensity and narrow width of the peaks indicate good crystal quality and small particle size. Furthermore, the lack of any extra peaks and the sharpness of the peaks across the spectrum support the high stability and purity of the green-synthesized ZnO nanoparticles.

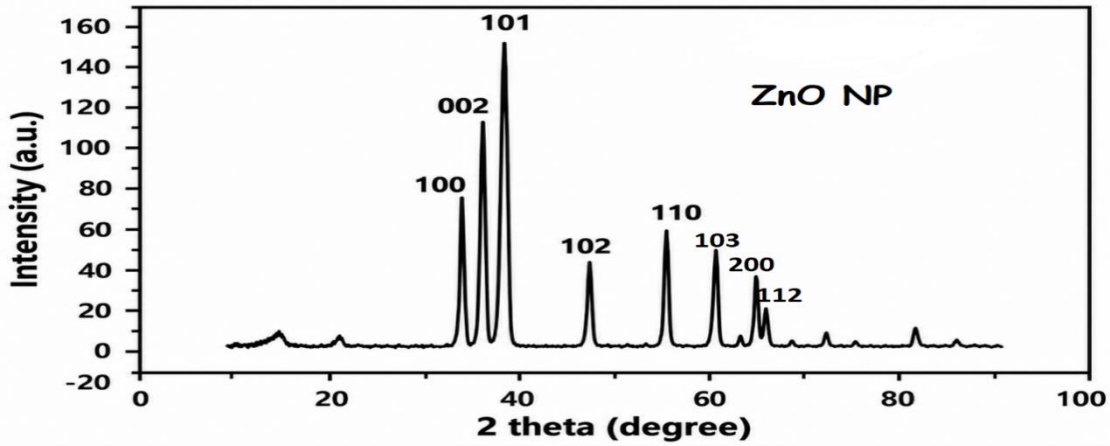


Figure 1: X-ray diffraction pattern for ZnO nanoparticles of *Irvingia gabonensis* seed shell

The crystallite size of the synthesized ZnO nanoparticles was analyzed using the Scherrer equation, as shown in Table 2. XRD reflections appeared at 2 θ values of 31.77°, 34.42°, 36.25°, 47.54°, 56.60°, 62.86°, 66.38°, and 67.96°, which correspond to the (100), (002), (101), (102), (110), (103), (200), and (112) crystal planes, respectively. Full Width Half Maximum (FWHM) values were determined with OriginLab software and ranged from 0.140° to 0.155°, or 0.002443 – 0.002705 radians. These Full Width Half Maximum (FWHM) values were used in the Scherrer equation to calculate crystallite sizes. The resulting crystallite sizes ranged from 55.73 to 66.07 nm, with the (101) plane showing the smallest size at 55.73 nm and the (112) plane showing the largest at 66.07 nm. These findings indicate that the ZnO nanoparticles have fairly uniform crystallite sizes, with only minor variation across different diffraction planes. The average crystallite size was 60.19 nm, confirming that the synthesized ZnO nanoparticles are in the nanoscale range.

$$D = \frac{K\lambda}{\beta cos\theta}$$ Equation 1

where λ is the X-ray wavelength (0.15406 nm for Cu Kα), β is the FWHM in radians, θ is the Bragg angle in radians, D is the crystallite size (nm), and K is the shape factor (usually 0.9).

Table 2: Average crystallite size for ZnO nanoparticles

Peak	2θ (°)	θ (°)	FWHM β (°)	β (rad)	D (nm)	Average crystallite size(nm)
(100)	31.77	15.88	0.145	0.002531	56.96	
(002)	34.42	17.21	0.140	0.002443	59.40	
(101)	36.25	18.12	0.150	0.002618	55.73	
(102)	47.54	23.77	0.145	0.002531	59.87	**60.19**
(110)	56.60	28.30	0.150	0.002618	60.15	
(103)	62.86	31.43	0.155	0.002705	60.07	
(200)	66.38	33.19	0.150	0.002618	63.29	
(112)	67.96	33.98	0.145	0.002531	66.07	

Functional Group Analysis

The FTIR spectrum of the biosynthesized ZnO NPs (Figure 2), recorded over 4000–500 cm^{-1}, shows distinct absorption bands near 3350, 2150, 2050, 1605, 1550, 1450, 1260, and 1050 cm^{-1}, confirming that phytochemical-derived functional groups are attached to the nanoparticle surface.

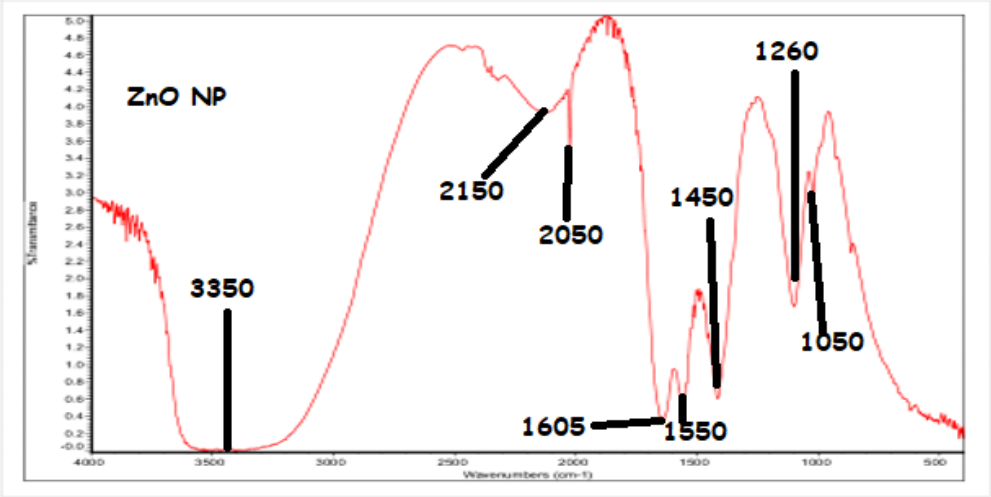


Figure 3: FTIR spectrum of biosynthesized ZnO nanoparticles of *Irvingia gabonensis* seed shell

The broad band near 3350 cm^{-1} is assigned to O–H stretching of hydroxyl groups from phenolic compounds, flavonoids, alcohols, or adsorbed water in the extract. Comparable broad O–H bands in the 3300–3400 cm^{-1} region have been reported for other plant-mediated ZnO NPs [17], indicating that hydroxyl-containing metabolites participate in the reduction and complexation of zinc ions and in stabilizing the nanoparticles. The weak bands near 2150 and 2050 cm^{-1} fall in a crowded region of the fingerprint area and may arise from minor residual organic or surface-bound species; because of their low intensity, their assignment remains tentative. The bands near 1605 and 1550 cm^{-1} are attributed to carbonyl (C=O) or aromatic C=C vibrations and to amide II/N–H bending or aromatic skeletal vibrations, respectively; bands in the 1500–1650 cm^{-1} range are commonly taken as evidence of biomolecules capping plant-mediated ZnO NPs [18], pointing to proteins and polyphenols as surface-stabilizing agents. The band near 1450 cm^{-1} lies in the region of C–H bending and aromatic-ring vibrations of residual plant organics, which persist on the surface of green-synthesized nanoparticles [19].

The bands at approximately 1260 and 1050 cm^{-1} correspond to C–O and C–O–C stretching of residual plant biomolecules, consistent with comparable bands reported for green-synthesized ZnO NPs [20]. Collectively, these spectra confirm that phytochemicals from the seed shell extract cap the nanoparticles, which corroborates the phytochemical profile in Table 1 and explains the stability of the synthesized ZnO NPs. The surface morphology of these capped nanoparticles was then examined by SEM.

Morphological Analysis

SEM images of the biosynthesized ZnO NPs at magnifications of 2000× and 15,000× (Figure 3) show agglomerated particles with irregular, granular surface features. This morphology is typical of plant-mediated ZnO, in which capping biomolecules promote clustering of the particles. The clustered grains indicate a polycrystalline structure consistent with the XRD results, and the rough, porous surfaces provide abundant adsorption sites — a property that is advantageous for antimicrobial action and for interaction with paint binders. Together, the XRD, FTIR, and SEM results confirm the successful green synthesis of capped, nanoscale ZnO, and the nanoparticles were next evaluated for antibacterial and antifungal activity.

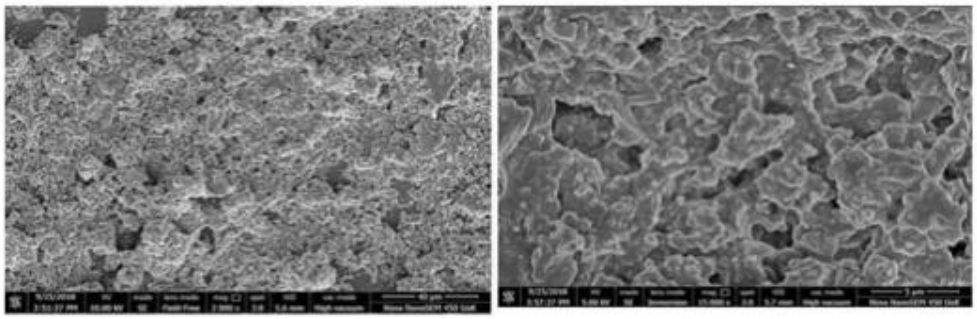


Figure 3: SEM images of the ZnO nanoparticles synthesized using *Irvingia gabonensis* seed shell extract: (a) 2000×; (b) 15,000× magnification

Antimicrobial Analysis

The antimicrobial analysis of the synthesized ZnO nanoparticles were evaluated against gram-positive and gram-negative bacteria as well as fungi. The experiment were conducted using agar well diffusion method [10] and all result obtained was observed by measuring the zones of inhibition in milliliters. In other to provide comparison, ciprofloxacin were employed as positive control for Ntibacterial activity was determined against a panel of three gram-positive bacteria, which are: *Bacillus cereus, Staphylococcus aureus and Staphylococcus pneumonia,* and four gram-negative bacteria which includes: *Escherichia coli, Klebsiella pneumonia, Salmonella typhi,* and *Pseudomonas aeruginosa.* These microorganisms were grown on Muller Hinton Agar (MHA) and Muller Hinton broth (MHB) medium. While the disc diffusion method was employed to evaluate the inhibitory effects of the seed shell extracts and ZnO nanoparticles. The zones of inhibition, indicating the regions where bacterial growth was suppressed, were measured in milliliters. The assessment was carried out in triplicate to ensure the reliability of the results. Similarly, the antifungal activity of the seed shell extracts and nanoparticles was tested against three fungi species which are *Candida albicans*, *Chrysosporium merdarium* and *Trichophyron rubrum.* Zones of inhibition, representing areas where fungal growth was hindered, were measured in milliliters. Similarly, the antifungal tests were also conducted in triplicate to enhance consistency and accuracy of the results obtained.

Table 2: Antibacterial activity of zinc oxide nanoparticles synthesized using *Irvingia gabonensis* seed shell, evaluated by zones of inhibition against selected bacterial pathogens at different concentrations, with ciprofloxacin as the reference control.

Test pathogens	**Zone of inhibition**					**Control (µg/ml) Cipro.**
	40 µg/ml	**20 µg/ml**	**10 µg/ml**	**5 µg/ml**	**2.5 µg/ml**	**30 µg/ml**
B. cereus	26	18	16	16	11	25
S. aureus	24	22	16	15	11	30
S. pneumonia	25	18	16	14	10	25
E. coli	29	25	24	16	15	26
K. pneumonia	24	22	19	15	13	29
S. typhi	23	26	22	15	14	29
P. aeruginosa	26	23	19	14	13	26

Key: Cipro.30 µg/ml (Ciprofloxacin) is the positive control for the bacteria

All measurements were carried out in milliliter (mm), the results were recorded. The results for the antibacterial susceptibility of the synthesized ZnO nanoparticles, as shown in Table 2, indicate that the ZnO NPs possess moderate antibacterial activity against the test bacterial organisms. The highest inhibition area of 29 µg/ml, was recorded for *Escherichia coli* at a nanoparticle concentration of 40 µg/ml.

These findings are consistent with those of Mohammed et al [21] and Naseer et al [22] who conducted a study on the antimicrobial activity of Zinc oxide nanoparticles against numerous bacterial strains, including both gram-positive (*Staphylococcus aureus* and *Bacillus subtilis*) and gram negative bacteria (*Escherichia coli, Klebsiella Pneumoniae,* and *Pseudomonas aeruginosa*). Mohammed and Naseer also observed significant antibacterial activity on all the tested bacterial strains, supporting the effectiveness of ZnO nanoparticles in inhibiting bacterial growth.

Table 3. Antifungal activity of zinc oxide nanoparticles synthesized using *Irvingia gabonensis* seed shell, evaluated by zones of inhibition against selected fungal pathogens at different nanoparticle concentrations, with fluconazole as the positive control.

Test pathogens	**Zone of inhibition**					**Control (µg/ml) Cipro.**
	40 µg/ml	**20 µg/ml**	**10 µg/ml**	**5 µg/ml**	**2.5 µg/ml**	**30 µg/ml**
C. albicans	25	23	17	15	13	25
T. rubrum	25	20	23	19	14	26
A. niger	26	18	16	16	12	25

Key: Fluc. 30 µg/ml (Flucunazol) is the positive control for the fungi

All measurements were carried out in milliliter (mm), the results were recorded. The results for the antibacterial susceptibility of the synthesized ZnO nanoparticles, as shown in Table 3, indicate that the ZnO NPs possess moderate ameliorating effect on all the tested fungal organisms. The highest inhibition area of 26 µg/ml was recorded for *Aspergillus niger* at a nanoparticle concentration of 30 µg/ml.

These results align with those of Mohammed et al [21] and George et al [23], that investigated the antimicrobial activity of Zinc oxide nanoparticles against various microorganisms, including both gram-positive (*Staphylococcus aureus and Bacillus subtilis*) and gram-negative bacteria (*Escherichia coli* and *Pseudomonas aeruginosa*), as well as fungi (*Aspergillus niger* and *Candida albicans*). George and Mohammed observed notable antifungal activity against the tested fungal strains, supporting the potential of ZnO NPs in inhibiting fungal growth.

Antimicrobial activities of biosynthesized ZnO nanoparticles were tested for the pathogenic microorganisms by minimum inhibitory concentration (MIC). It was observed that the synthesized nanoparticles exhibit broad spectrum activity against all microbial strains with different concentration.

The lowest MIC value of 5 mg/mL was observed for the gram-negative bacteria *S. typhi,* so it has maximum antibacterial activity among all tested pathogens. Moderate activity was noted for *P. aeruginosa* (10 mg/mL), while low activity was checked with *S. aureus, S. pneumoniae, K. pneumoniae*, and C. albicans at 20 mg/mL. High MIC values of 40 mg/mL for *B. Cereus* and *T.*

Rubrum indicates that test microbial strains are not so susceptible to the synthesized nanoparticles. The microorganism *E. coli* was found to be non-susceptible (ND) which is supported by the complex structure of the gram-negative bacteria, especially cell membrane constituents of microorganism which includes lipopolysaccharide layer.

Table 4. Minimum inhibitory concentrations (MICs) of zinc oxide nanoparticles synthesized using *Irvingia gabonensis* seed shell against selected bacterial and fungal pathogens.

Test Pathogens	**NPs**
B. cereus	40
S. aureus	20
S. pneumonia	20
E. coli	ND
K. pneumonia	20
S. typhi	5
P. aeruginosa	10
C. albicans	20
T. rubrum	40
A. niger	20

Key: ND = Not detected, *B. cereus= Bacillus cereus, S. aureus= Staphylococcus aureus, S. pneumonia= Streptococcus pneumonia, , E. coli= Escherichia coli, K. pneumonia= Klebsiella pneumonia, S. typhi= Selmonella typhi, P. aeruginosa= Pseudomonas aeruginosa, C. albicans= Candida albicans, T. rubrum= Trichophyton rubrum, A. niger= Aspergillus niger*

The bacteria are Gram-positive (*B. cereus, S. aureus, S. pneumoniae*), which were slightly more susceptible than Gram-negative bacteria, except for *S. typhi*, which exhibited the highest degree of susceptibility across all bacterial strains. This is consistent with previous research conducted by Naseer et al [22] that found ZnO nanoparticles have a higher tendency to interact with the exposed peptidoglycan layers present in Gram-positive bacteria.

A further implication is the demonstrated antifungal efficacy of these nanoparticles against *C. albicans* and *T. rubrum* demonstrates the anti-fungal spectrum of these particles. It is worth noting that the higher MIC of *T. rubrum* indicates that filamentous fungi may be more resilient than their yeast-like counterparts as they may have a different cell wall composition and grow faster. These results, along with reported studies [22-23] further strengthen the potential environmental and antimicrobial application of green-synthesized ZnO nanoparticles.

CONCLUSION

The research provides evidence that the seed shell of Irvingia gabonensis can be exploited as a sustainable raw material for the green synthesis of ZnO NPs. The biogenic synthesis of the ZnO NPs using the extract as well as its phytochemical screening was confirmed via FT-IR, XRD, and SEM analyses. The measured antibacterial and antifungal activities of the ZnO NPs toward the tested microbial isolates showed only moderate activity, with the larger average zones of inhibition measuring 29 mm against *Escherichia coli* and 26 mm against Aspergillus niger. The MIC profiles showed that different microbial isolates exhibited different levels of sensitivity to the green ZnO NPs with *Salmonella typhi* being the most sensitive at an MIC of 5 mg/mL. The study indicated that green ZnO NPs could potentially be exploited as antimicrobial coatings and in paints in the future. However, further research must be done on the antimicrobial mechanisms, safety, durability, and performance of these ZnO NPs in paints and coating formulations before their applicability in the open market can be determined.

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