MICROBIOLOGY ARCHIVES
Original Research Article | ISSN: 3041-590X
Journal homepage: https://microjournal.researchfloor.org/

Antimicrobial Studies of Biosynthesized Zinc Oxide Nanoparticles

Ugosor, P. T*[1] and Wada, S. T[2]

[1]*Chemistry Department, College of Education, Katsina-Ala, Benue State, Nigeria*
[2]*Department of Chemistry, College of Education, Obudu, Cross River State, Nigeria*

ARTICLE INFO

Citation: Ugosor, P.T and Wada, S. T (2025). Antimicrobial Studies of Biosynthesized Zinc Oxide Nanoparticles. *Microbiology Archives, an International Journal.*
DOI: https://doi.org/10.51470/MA.2025.7.1.46

Received 28 February 2025
Revised 28 March 2025
Accepted 20 April 2025
Available Online 16 May 2025

Corresponding Author: **Ugosor, P. T**
E-Mail: **paulugosor@gmail.com**

ABSTRACT

Nanoparticles of zinc oxide (ZnO NPs) were synthesized through a sustainable chemistry approach using aqueous extracts from Colocasia esculenta leaves. Characterization was conducted using UV-Visible spectroscopy, X-ray diffraction (XRD), scanning electron microscopy (SEM), energy-dispersive X-ray spectroscopy (EDX), and Fourier-transform infrared spectroscopy (FTIR). Statistical analysis of antimicrobial activity data was carried out using Social Package for Social Sciences (SPSSS) version 20, with results reported as mean ± standard deviation (Mean ± SD). One-way Analysis of Variance (ANOVA) with Least Significance Difference (LSD) post hoc tests were performed at significance level ($p < 0.05$). Optimal nanoparticle formation occurred at 0.50 mol/dm^3 ZnO solution at 80 °C over a 4-hour reaction period. The synthesized ZnO NPs exhibited a hexagonal wurtzite crystal lattice structure with an mean particle size of approximately 12 nm. FTIR analysis showed phenolic compounds, amines, peptides, and amides, which facilitated reduction of zinc ions, capping, and stabilization of the ZnO NPs. The ZnO NPs demonstrated concentration-dependent antimicrobial effects against five fungal pathogens (Aspergillus niger, Rhizopus stolonifer, Aspergillus flavus, Fusarium oxysporum, and Botryodiplodia theobromae,) and three bacterial strains (Klebsiella oxytoca, Serratia marcescens, and Pseudomonas aeruginosa). Their inhibitory efficiency ranged from 32.22% to 89.95%, showing comparable performance to standard antimicrobial agents such as clotrimazole and ciprofloxacin. These findings suggest that ZnO NPs synthesized from Colocasia esculenta have promising applications in postharvest disease management and pharmaceutical development.

Keywords: *Phytochemicals, nanotechnology, biosynthesis, pathogens, antimicrobial activity.*

1.0 Introduction

Postharvest deterioration of agricultural produce remains a critical issue in developing nations, primarily due to inadequate storage infrastructure, limited access to technology, and microbial infestations. Fungal and bacterial pathogens, which produce various enzymes and mycotoxins [30,34,37], are among the leading causes of spoilage, especially in crops like white yam (*Dioscorea spp.*) [23,32,33].

Globally, it is estimated that over a quarter of yam harvests are lost annually due to microbial infections and pest attacks [27,29]. In Nigeria, postharvest losses can exceed 50%, with significant deterioration observed within three to six months of storage [27,30,32]. This high rate of spoilage poses a serious threat to food availability and economic sustainability. Conventional control strategies have included cultural practices and the use of synthetic chemicals such as borax, captan, benomyl, and sodium hypochlorite [1,5,9]. While effective, these chemical treatments often come with drawbacks such as environmental toxicity, non-biodegradability, pesticide resistance, and potential health hazards due to residual accumulation in the food chain [22,28,30]. Moreover, their high costs and improper usage further limit their effectiveness, particularly among small-scale farmers.

In response to these concerns, there is increasing interest in developing environmentally friendly alternatives. One promising approach is the use of plant-based materials in combination with metal or metal oxide nanoparticles [3,4,5]. These biosynthesized nanoparticles offer broad-spectrum antimicrobial activity and can function as preservatives by inhibiting microbial growth, prolonging shelf life, and protecting nutrient integrity [22,19,35].

Colocasia esculenta (commonly known as cocoyam) has been shown to possess numerous bioactive phytochemicals such as flavonoids, saponins, phenolics, alkaloids, and glycosides, which are associated with antibacterial, antifungal, antiviral, and antioxidant properties [20,22,36]. Meanwhile, zinc oxide (ZnO), a compound recognized as safe by regulatory authorities, is widely used in pharmaceutical and cosmetic products due to its antimicrobial and protective qualities [1,2,18]. When synthesized at the nanoscale, ZnO exhibits enhanced biological activity because of its large surface area and characteristic physicochemical qualities [6,11,13,38].

This research aims to prepare ZnO nanoparticles using *Colocasia esculenta* leaf extract and determine their antimicrobial efficacy against pathogens responsible for white yam rot. The goal is to develop an accessible, sustainable, and cost-effective strategy for disease management in agricultural systems, particularly for farmers in Benue State, Nigeria.

2.0 Materials and Methods (Rewritten)

2.1 Plant Material and Authentication

2.1.1 Collection

Fresh leaves of *Colocasia esculenta* were gathered from the Fr. Adasu University campus, Makurdi, Benue State, Nigeria, during January 2025. The leaves were labelled appropriately and stored in clean polyethylene bags for transport and analysis.

2.1.2 Identification

Botanical authentication of the plant material was conducted at the Department of Biological Sciences, Fr. Adasu University, Benue State, Nigeria.

2.2 Processing and Extraction

2.2.1 Drying and Pulverization

The *Colocasia esculenta* leaves were carefully washed with distilled water and ambient-dried (to preserve phytochemical integrity) for two weeks. Dried samples pulverized using an electric blender pestle and kept in airtight containers [6,9,10].

2.2.2 Aqueous Extraction

Aqueous extract of *Colocasia esculenta* leaves was obtained by boiling 200 grammes of the powdered leaves in 1000 mL of diemineralized water at 80 °C for one hour. The mixture was cooled, then filtered and the extract refrigerated at 4 °C until further use [15,16].

2.3 Microbial Culture Preparation

2.3.1 Source of Test Organisms

Microbial strains, comprising five fungal pathogens (*Aspergillus niger, Aspergillus flavus, Botryodiplodia theobromae, Rhizopus stolonifer, Fusarium oxysporum)* and three bacterial species *(Klebsiella oxytoca, Serratia marcescens,* and *Pseudomonas aeruginosa),* were sourced from the Department of Biological Sciences, Fr. Adasu University, Benue State, Nigeria.

2.3.2 Culture and Maintenance

Microbial isolates were revived in sterile distilled water and cultured on Potato Dextrose Agar, PDA (for fungi) and Nutrient Agar, NA (for bacteria). After incubation at 37 °C (24 hours for bacteria, 7 days for fungi), pure colonies were maintained on fresh media and preserved in 20% glycerol at –70 °C [17,33].
Microbial suspensions were standardized to an optical density of 0.144 at 550 nm (approximately 1.0×10^6 CFU/mL). All glassware and reagents used were sterilized or analytical grade, and aseptic conditions were maintained throughout the procedures [32,33].

2.4 Phytochemical Screening

Qualitative tests for phytochemicals (flavonoids, phenols, saponins, alkaloids, tannins, terpenoids, cardiac glycosides, and steroids) were performed using standard procedures of [16].

2.5 Preparation of ZnO Nanoparticles

Green route method was carried out by mixing 40 mL of 0.50 mol/dm^3 zinc ethanoate, $Zn(CH_3COO)_2$ solution with 20 mL of the *Colocaia esculenta* leaves extract. The pH was regulated to 12 by dropwise addition of 0.02 mol/dm^3 sodium hydroxide, NaOH. The reaction mixture was heated between 30 °C and 90 °C for four hours with continuous stirring. The resulting white product was cooled, centrifuged at 1200 rpm for 5 minutes, rinsed severally with demineralized water, dried at 80 °C for 24 hours, and kept in a desiccator for further analysis [7,14]. A modified schematic diagram of the process is as shown below:

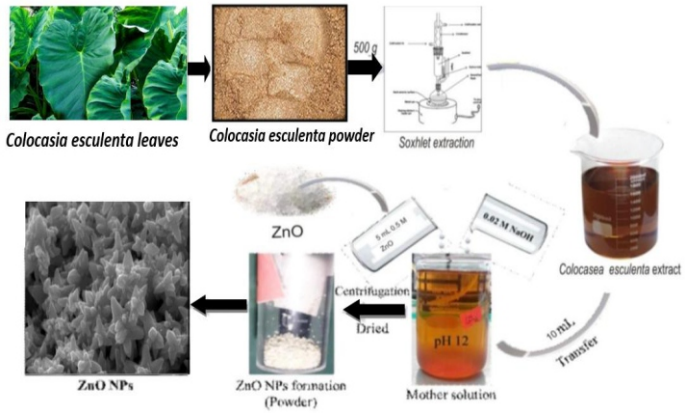


Fig. 1: A modified schematic diagram for the preparation of ZnO NPs using C esculenta leaves extract [7],

2.6 Characterization of ZnO Nanoparticles

Uv-3600 Plus, Shimadzu, Japan in the rage of 350–700 nm.was employedto monitor ZnO NP synthesis. XRD Analysis (XRD-6000, Shimadzu, Japan) was performed using Cu Kα radiation to determine crystal structure and average crystallite size. SEM hyphenated with Philips XL-30, Eindhoven, Netherlands was employed to observe nanoparticle shape, structure and component elements. Perkin Elmer FTIR Spectrophotometer-100 from of 500–4000 cm^{-1}.scale was carried out to identify the biomolecule which serve as reductant of zinc ions, capping, and stabilization of the zinc oxide nanoparticles [7].

2.7 Antimicrobial Activity Assay

A modified agar diffusion technique [29, 30, 32] was used to evaluate the antimicrobial efficacy of the nanoparticle against pure isolates. PDA (for fungi) and NA (for bacteria) were supplemented with different ZnO NP concentrations (25, 50, 75, and 100 mg/mL). Standard drugs (clotrimazole for fungi and ciprofloxacin for bacteria) served as positive controls. After incubation, inhibition zones were measured, and % inhibition zones were estimated as shown below:
% IZ = Mean diametre of pathogen colony / Mean diametre of pathogen in control x 100 % [19, 32, 33].
Percentage inhibition zones were graded as follows:
Highly effective = 100 %; effective = 50 – 99 %;; moderately effective = 20 – 49 %;
slightly effective = 0 – 19 %, and not effective (≤ 0 %) [32, 33].

2.8 Statistical Analysis

Experimental data were performed Version 20 of SPSS. Average values were reported with SD. Significance among groups was evaluated using ANOVA with LSD post hoc analysis. Results were significant at $p < 0.05$, and insignificant at $p > 0.05$.

3.0 Results and Discussion

3.1 Result of phytochemical Constituents

Table 1: Result of secondary metabolites screening

Secondary Metabolite	Test	Result
Tannins	Lead ethanoate Test	+
Alkaloid	Wagner's Test	+
Saponins	Foam Test	+
Quninone	Craven;s Test	-
Glycosides	Borntrager's Test	+
Steroids	Libbermann Burchard's Test	+
Flavoniods	Shinoda's Test	+
Starch	Lugol's iodine Test	+
Terpenoids	Libermann-Burchard's Test	+
Phenols	Bromine water Test	+

Key: + = Positive; - = Negative.

The phytochemical screening of *Colocasia esculenta* leaves extract revealed biocompounds, including tannins, alkaloids, saponins, glycoside, sreroids, flavonoids, starch, terpenoids, and phenols. These bioactive compounds are known for their antimicrobial, antioxidant, and reducing properties, making them ideal for nanoparticle biosynthesis and stabilization.

The presence of these metabolites supports the importance of the extract as reductants of zinc ions, and stabilizing agent of the nanoparticles, as confirmed by spectral analysis [7].

3.2 UV-Visible Spectrometry analyis

The synthesis of ZnO nanoparticles was affirmed by a distinct absorption intensity at 370 nm, which is characteristic of ZnO nanoparticles. The intensity and sharpness showed nanosized ZnO crystallite sizes. This peak intensified with increasing reaction time and temperature, suggesting enhanced nanoparticle formation as shown in spectrum below:

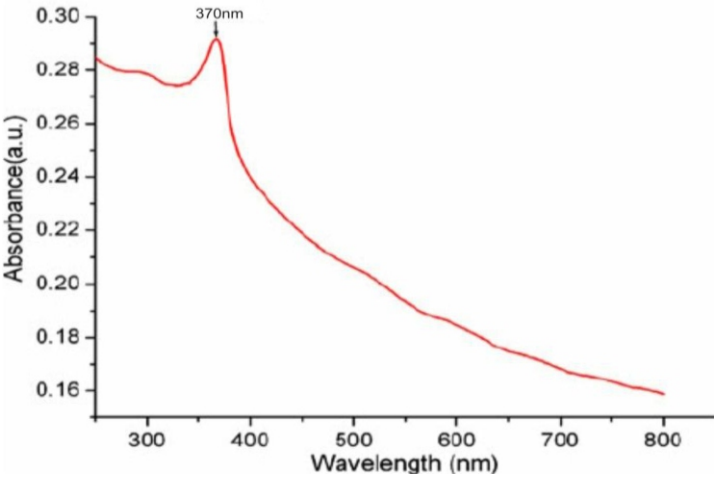


Fig. 2. UV-Vis spectra of the biosynthesized ZnO Nps.

3.3 XRD Analysis

X-ray diffraction pattern of the prepared nanoparticle displayed prominent intensities at 2θ values of 31.84°, 34.50°, 36.26°, 47.57°, and others relating to the (100), (002), (101), (102), and other crystal planes, matching hexagonal wurtzite structure (JCPDS Card No. 36-1451). The average crystallite size was calculated using the Debye–Scherer equation:

$$D = \frac{k\lambda}{\beta cos\theta} \quad \text{.....(1)}$$

Where d = crystallite size, K = Scherer constants with values from 0.9 to 1 (shape factor), β = width of XRD peak at half height, X = X-ray wavelength (1,5428 Å) and Θ = Diffraction angle.

Average crystallite size was estimated to be approximately 12 nm, with values ranging from 10.10 nm to 12.92 nm.

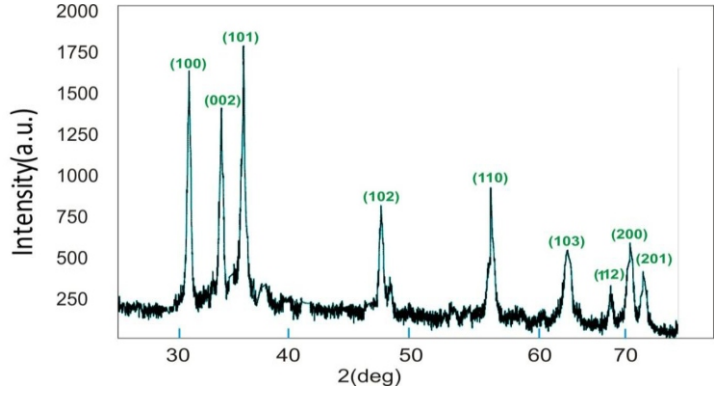


Fig. 3: XRD pattern of the biosynthesized ZnO Nps

3.4 Scanning Electron Microscope (SEM) and EDX Studies

SEM imaging revealed well-defined, segregated hexagonal nanoparticles with smooth surfaces, indicative of good crystallinity. Particle size analysis using ImageJ software estimated an average size of 11.99 nm, aligning well with XRD data. SEM image of the nanoparticles is presented in Figure 4.

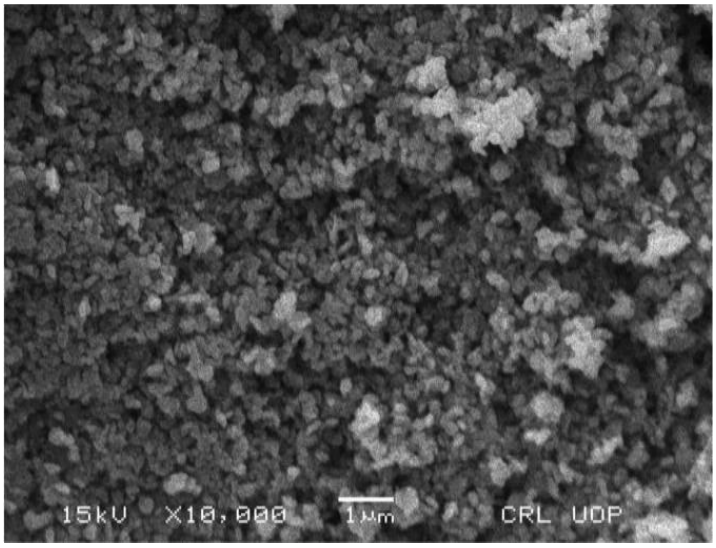


Fig. 4: SEM image of biosynthesized ZnO Nps

EDX spectrum affirmed the elemental makeup of the nanoparticles. Peaks corresponding to zinc (Zn) and oxygen (O) were dominant, with Zn constituting approximately 41.19 % and O about 51.58 %. with trace amounts of C (7.24%). This confirmed an approximate ratio of 1:1. The low levels C as impurity suggest high purity of the ZnO NPs as shown in Fig. 5.

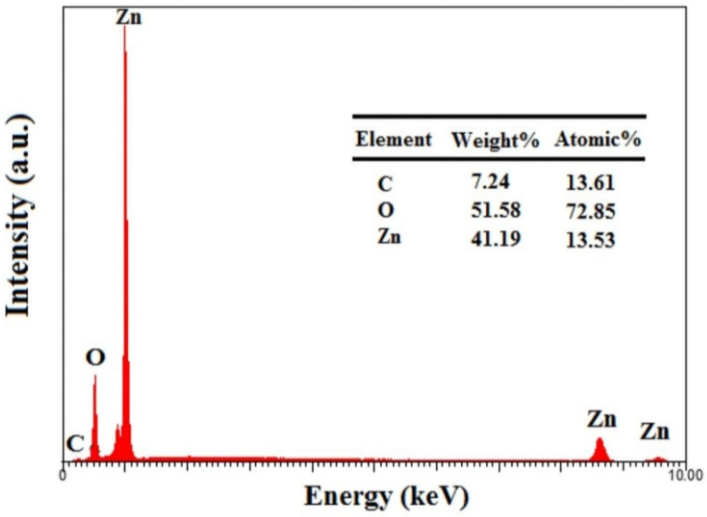


Fig. 5: EDX spectrum of the biosynthesized ZnO.

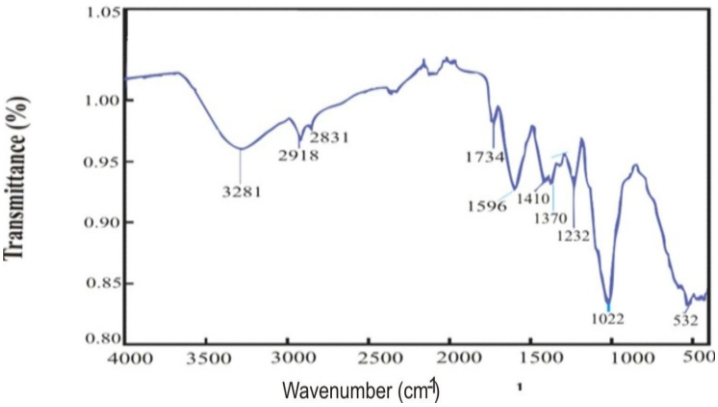


Figure 6: FTIR spectrum of ZNO NPS.

3.5 FTIR Spectroscopy

FTIR analysis presented in Fig. 6 reveals the chemical bonding between Zn and O. The spectrum identified a peak at 532 cm^{-1} corresponding to Zn–O stretching, characteristic of wurtzite-phase ZnO. Additional bands at 3382 cm^{-1}, 2374 cm^{-1}, 1656 cm^{-1}, and 1380 cm^{-1} were attributed to hydroxyl (–OH), water, C=C of aromatics, and alkane groups, respectively. These functional groups originate from the phytochemicals in the *Colocasia esculenta* extract and function as reductant of zinc ions, capping, stabilization and surface functionalization of the nanoparticles.

The plant extract spectrum reviewed peaks at 3281, 2918, 2831, and 1734 cm^{-1}, indicating O–H stretching, phospholipid content, aliphatic chains, and C=O stretching, respectively. These confirm the presence of bioactive molecules responsible for reducing and capping Zn^{2+} ions.

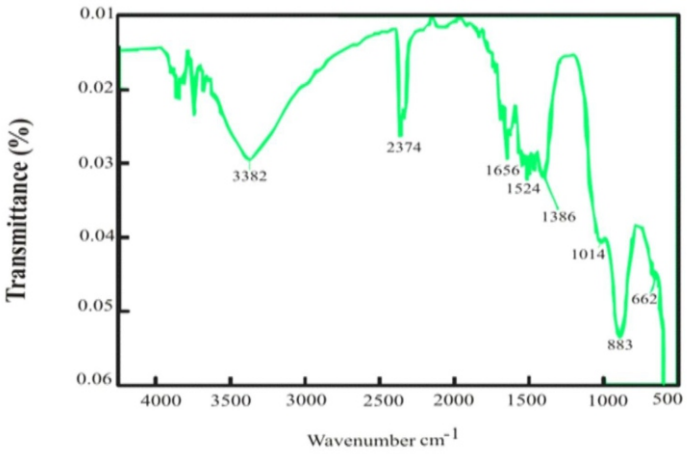


Figure 7: FTIR spectrum of Coocasia. Esculenta leaves.

3.6 Antimicrobial Activity of ZnO Nanoparticles

Table 2: Mean zone of inhibition (mm) for fungal and bacterial strains

Zinc Oxide Nanoparticles Concentration (mg/mL)					
	100	**75**	**50**	**25**	**Co Control**
Fungi					
A. niger	6.17 ± 0.01[b]	5.17± 0.01[c]	4.04 ± 0.01d	2.86 ± 0.13[e]	8.18 ± 0.01[a]
A. flavus	5.57 ± 0.32[b]	4.87± 0.07[c]	3.96 ± 0.04[d]	3.14 ± 0.01[e]	9.71± 0.04[a]
B. theobromae	6.78 ± 0.02[b]	5.82 ± 0.06[c]	4.99 ± 0.01[d]	4.58 ± 0.01[e]	10.99 ± 0.01[a]
R. stolenifera	10.16 ± 0.01[b]	9.27 ± 0.02[c]	6.78± 0.01[d]	5.03 ± 0.01e	18.08 ± 0.08[a]
F. oxysporum	19.73 ± 0.01[b]	18.16 ± 0.09[c]	17.52 ± 1.10[c]	9.05 ± 0.01d	29.67 ± 0.01[a]
Bacteria					
K. oxytoca	18.14 ± 0.05[b]	15.27 ± 0.40[c]	12.08 ± 0.08[d]	8.06 ± 0.01[e]	37.25 ± 2.20[a]
S. marcescens	17.24 ± 0.32[b]	15.12 ± 0.09[c]	12.82 ± 0.01[d]	9.08 ± 0.01e	40.32 ± 0.04[a]
P. aeruginosa	21.04 ± 0.01[b]	19.24 ± 0.11[c]	16.25 ± 0.03[d]	7.13 ± 0.01[e]	38.07± 0.54[a]

N= 5, values expressed as Mean ± SD. Values in the same row with different superscript (alphabetical letters) are significant at p <0.05.

Table 3: Percentage zone of inhibition of the ZnO Nps

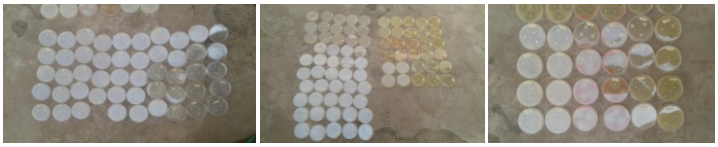
Fungi Concentration (mg/mL) 100 75 50 25				
Aspergillus niger	75.37	63.36	49.39	36.64
Aspergillus flavus	58.12	50.57	40.85	32.26
Botryodioplodia theobromae	61.55	53.45	45.36	41.45
Rhizopus stolenifera	56.39	51.39	37.67	27.89
Fusarium oxysporum	66.43	61.00	56.32	30.50
Bacteria				
Klebsiella oxytoca	51.97	43.30	34.74	23.11
Serratia marcescens	44.14	37.44	31.74	22.49
Pseudomonas aeruginosa	55.83	50.70	43.08	18.90

Key: *a = 100 % inhibition (highly effective); b = 50 – 99 % inhibition (effective); c = 20 – 49 % inhibition (moderately effective); d = 0 - 19 % inhibition (slightly effective); e = ≤ 0 % inhibition (ineffective) [26].*

The biosynthesized ZnO NPs displayed concentration-dependent antimicrobial effects against all tested pathogens. Inhibition zones increased with ZnO concentration, indicating enhanced antimicrobial potency at higher doses.

All the test microorganisms showed effective to moderately effective inhibition (75.37-22.11) % at 100 – 25 mg/mL, with the exception of *Pseudomonas aeruginosa* which indicated slightly effective inhibition (18.90%) at 25 mg/mL.

The ZnO NPs demonstrated broad-spectrum activity, particularly at 100 mg/mL, with inhibition percentages over 80 % for most pathogens. Their efficacy was statistically comparable ($p < 0.05$) to that of standard antimicrobial drugs, affirming their potential in disease management.



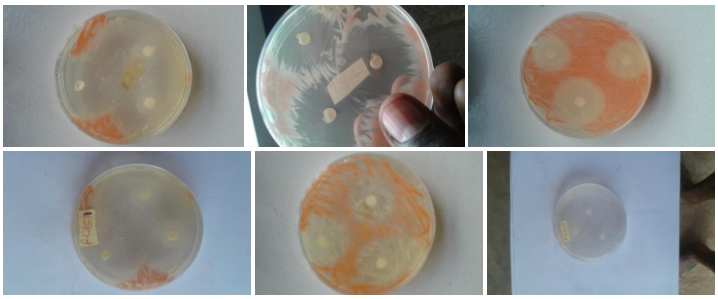


Figure 8: Antimicrobial sensitivity test plates.

4.0 Conclusion

This study prepared zinc oxide nanoparticles using aqueous leaves extract of *Colocasia esculenta* through sustainable approach. Synthesized nanoparticles exhibited well-defined hexagonal wurtzite crystal lattice structure with mean crystallite size of approximately 12 nm. Spectroscopic and microscopic analyses confirmed the involvement of plant-derived phytochemicals as reducing agents of zinc ions, capping, and stabilizing of the nanoparticles.

The nanoparticles showed significant antimicrobial action against microorganisms associated with postharvest white yam rot. The inhibition was concentration-dependent and comparable to standard antimicrobial agents such as clotrimazole and ciprofloxacin.

The result highlight the prospects of *Colocasia esculenta*-facilitated ZnO nanomaterials as eco-friendly and cost-effective antimicrobial agents. Their application could serve as a sustainable substitute to harmful chemicals substances in postharvest disease control and development of new antimicrobial formulations. This approach aligns with the goals of promoting food security and environmental sustainability, especially for resource-limited farming communities.

Acknowledgement
The authours appreciate the staff of the Departments of Chemistry and Biological Sciences, as well as CEFTER, Fr. Adasu University, Makurdi, Benue State for their support and access to facilities for the successful execution of this research.

Competing Interests
Authours have declared that no competing interests exist.

References

1. Ahmed, S.A., Taia, A., Ahmad, O.B., Samy, S., Abir, M.H. (2022). A.Green Synthesis and Characterization of ZnO Nanoparticles Using Pelargonium odoratissimum(L.) Aqueous Leaf Extract and Their Antioxidant, Antibacterial and Anti-inflammatory Activities. Antioxidants (Basel).2022;(8):1444.DOI:10.3390/antiox11081444.Ava ilable:https://doi.org/10.4236/fns.2017. 87051.

2. Amin, G., Asif, M.H., Zainelabidin, A., Zaman, S., Nur, O., Willander, M. (2011). Influence of Ph, precursor concentration, growth time, and temperature on the morphology of Zno nanostructures grown by the hydrothermal method. Journal of Nanomaterials. 2011;269692.

3. Divya, M.J., Sowmia, C., Joona, K., Dhanya, K.P. (2013). Synthesis of zinc oxide nanoparticle from Hibiscus rosa-sinensis leaf extract and investigation of its antimicrobial activity. Res; 2013.

4. Eleazu, C.0. (2016). Characterization of the natural products in cocoyam (Colocasia esculenta) using GC-MS. Pharmaceutical Biology. 2016;54(12):2880-2885.

5. Elumalai, K., Velmurugan, S. (2015). Green synthesis, characterization and antimicrobial activities of zinc oxide nanoparticles from the leaf extract of Azadirachta indica (L). Applied Surface Science. 2015;345:329-36.

6. Jha, A.K., Kumar, V., Prasad, K. (2011). Biosynthesis of metal and oxide nanoparticles using orange juice. J. Bionanoscience. 2011;5(2):162–166. Available:http://dx.doi.org/10.1166/jbns.2011.1053.

7. Farjana, R., Md Abdul M.P., Md Abu, B.S, Muhammad, S.B, Md. Aminul, H., Beauty, A., Rimi, R., Md. Anamul, H., Royhan, A.K.M. (2022). Green synthesis of ZnO nanoparticles using Cocos nucifera leaf extract: Characterization, antimicrobial, antioxidant, and photocatalytic activity; 2022. Available:https//doi.org/10.11012020.10.27.514023.

8. Jayanta, K. B. (2013). Synthesis and characteriztion of zno nanoparticles. a master of science dissertation of the department of physics. National Institute of Technology, Rourkela, Orissa, India; 2020.

9. Josef, J., Katarina, K. (2015). Application of nanotechnology in agriculture and food industry, its prospects and risks .Ecol chem Eng s. 2015;22(3):321-361.

10. Kharissova, O.V., Dias, H.V.R., Kharisov, B.I, Perez, B.O, Perez, V.M.J. (201). The greener synthesis of nanoparticles Trends in Biotechnology. 2013;31(4):240-48.

11. Kumar et al. (2019). Zinc oxide nanoparticles: A review of their antimicrobial activity and applications in medicine. Journal of Nanoparticle Research, 21(10).

12. Lakshmi, J.V., Sharath, R., Chandraprabha, M.N., Neelufar, E., Hazra, Abhishikta, Patra, Malyasree Synthesis, characterization and evaluation of antimicrobial activity of zincoxide nanoparticles. J. Biochem. Technology. 2012;3(5):S151–S154.

13. Mittal, A.K., Chisti, Y., Banerjee. U.C. (2013). Synthesis of metallic nanoparticles using plant extracts Biotechnol Adv; 2013. DOI: 10.1016/j.biotechadv.2013.01.003.

14. Moloto, N., Revaprasadu, N., Musetha, P.L, Moloto, M.J. (2009). The effect of precursor concentration, temperature and capping group on the morphology of CdS nanoparticles. Journal of Nanoscience and Nanotechnology. 2009;9:4760-66.

15. Nakade, D.B., Mahseh, S.K., Kiran, N.P., Vinayak, S.M. (2013) Phytochemical screening and Antibacterial Activity of Western Region wild leaf Colocasea esculenta. International Research Journal of Biological Science. 2013;2(10):1-6.

16. Official Methods of Analysis of AOAC International. (2023). 22nd ed. AOAC International, Gathersburg, MD, USA, Official Methods, 2023.005.

17. Padil, V.V.T, Cernik, M. (2013). Green synthesis of copper oxide nanoparticles using gum karaya as biotemplate and their antibacterial application. International Journal of Nanomedicine. 2013;8:889-98.

18. Parveen, K., Banse, V., Ledwani, L (2015). Green synthesis of nanoparticles: Their advantages and disadvantages 2nd International Conference on Emerging Technologies: Micro to Nano; 2015 (ETMN-2015). DOI: 10.1063/1.4945168.

19. Pritha, C., Papiya, D., Sudeshna, C., Bohniskilda, C., Jayantihi, A. (2015). Cytotoxicity and antimicrobial activity of Colocasea esculenta. Journal of Chemical and Pharmaceutical Research. 2015;7(12):627-635.

20. Priyatharesini, P.I., Ganesamoorthy, R., Sudha, R. (2020). Synthesis of zinc oxide nanoparticle using Cocos nucifera male flower extract and analysis of their antimicrobial Activity. J of Pharm and Tech. 2020;13:2151- 2154.

21. Rad, S.S., Sani, A.M., Mohseni, S. (2019). Biosynthesis, characterization and antimicrobial activities of zinc oxide nanoparticles from leaf extract of Mentha pulegium (L.). Microbial Pathogenesis. 2019;131(2019):239–245.

22. Rahayu, V., Wonoputri, V., Nad Samadhi, T.W. (2011). Plant extract-assisted biosynthesis of zinc oxide nanoparticles and their antibacterial applications. Material Science and Engineering. 2020;823;012-036.

23. Rajiv, P., Rajeshwari, S., Venckatesh, R.. Rambutan. (2013). Peels promoted biomimetic synthesis of bioinspired zinc oxide nanochains for biomedical applications. Spectrochim. Acta Part A Mol.Biomol.Spectros. 2013;112:384–387. Available:http://dx.doi.org/10.1016/j.saa.2014.08.022.

24. Ramesh, P., Rajendran, A., Meenakshisundaram, M. (2014). Green synthesis of zinc oxide nanoparticles using flower extract Cassia auriculata. J NS NT. 2014;1(1):41–45. ISSN 2279 – 0381.

25. Salam, A.H, Sivaraj, R., Venckatesh, R. (2014). Green synthesis and characterization of zinc oxide nanoparticles from Ocimum basilicum, L. var. purpurascens, Benth.-Lamiaceae leaf extract. Mater.Lett. 2014;131:16–18. Available:http://dx.doi.org/10.1016/j.matlet.2014.05.033.

26. Sadeghi, A., et al. (2019). "Antimicrobial effects of nanoparticles: A review." Journal of Microbial and Biochemical Technology. 10 (12): 12 -20.

27. Sangeetha, G., Rajeshwari, S., Venckatesh, R. (2011). Green synthesis of zinc oxide nanoparticles by aloe barbadensis miller leaf extract: Structure and optical properties. Mater. Res. Bull. 2011;46:2560–2566.

28. Sathishkumar, G., Rajkuberan, C., Manikandan, K., Prabukumar, S., DanielJohn, J., Sivaramakrishnan, S. (2017). Facile biosynthesis of antimicrobial zinc oxide (ZnO) Nano flakes using leaf extract of Couroupitaguianensis.Aubl, Mater. Lett. 2017;188:383–386.

29. Shiriki, D., Ubwa, S.T., Yusufu, M.I., Shambe, T. (2019). Extraction methods and inhibition studies of ten plant extracts on nine yam rot pathogenic microorganisms. Food and Nutrition Sciences; 2019. Available:https://doi.org10.4236/fns.2019.

30. Shiriki, D., Obochi, G.O., Eke, M.O, Shambe T. (2017). Postharvest Loss Control: Synergistic Plants Extract Inhibition of Ten Microbial Yam Rot Organisms. Journal of food science and nutrition.2017;8(7):25-732.

31. Sibiya, P.N, Moloto, M.J. (2014). Effect of precursor concentration and pH on the shape and size of starch capped silver selenide (Ag2Se) nanoparticles. Chalcogenide Letters. 2014;11(11):577-88.

32. Terngu, P.U., Anhwange, A., Okibe, F.G and Dooshima, S. (2024). Green synthesis of Zinc Oxide Naniparticles using Colocasia esculenta Tuber Peel Extract and Antimicrobial Studies Aganist White Yam Pathigens. Asian J. Food Res. & Nutri., vol. 3, no. 2, pp. 306-319, 2024; Article no.AJFRN.116492.

33. Terngu, P.U., Anhwange, A., Okibe, F.G and Dooshima, S. (2024). Isolation and Identification of Pathogens Associated with Posthharvest White Yam (Dioscorea rotundata L) Tuber Rot. Asian J. Food Res. & Nutri., 3(3): 689-701.

34. Vijayakumar, S., Vinoj, G., Malaikozhunddan, B., Shanthi, S., Vaseeharan, B. (2015). Plectranthus amboinicus leaf extract mediated synthesis of zinc oxide nanoparticles and its control of methacillin resistant Staphylococus aureus biofilm and blood sucking mosquito larva. Spectrochim. Acta Part Amol. Biomol. Spectrose. 2015; 137:886-891. Available:http://dx.doi.org/10.1016/j.saa.2014.08.064.

35. Wang, J.K. (2019). Taro-a review of Colocasia esculenta and its potentials. Journal of Biotechnology and Pharmaceutical Research, 2012;3:42-46.

36. Yasser, S., Nassim, S. (2019). Current advances in applications of chitosan based nanaometal oxides as food preservative materials. Nanomed J. 2019;4:122-129.

37. Zare, E., Pourseyedi, S., Khatami, M., Darezereshki, E. (2017). Simple biosynthesis of zinc oxide nanoparticles using nature's source, and it's in vitro bio-activity. Journal of Molecular Structure. 2017;1146:96-103.

38. Zhang et al. (2018). Zinc oxide nanoparticles: A review of their synthesis, properties, and applications. Journal of Nanomaterials, 22(12): 1-13