International Conference on Science, Engineering & Management Trends 2024

International Journal of Science, Engineering and Technology
ISSN: 2348-4098, P-ISSN: 2395-4752

Characterization and Antimicrobial Investigations of Silver Nanoparticles Encapsulated in Starch Produced from the Aqueous Fruit Extract of Xylopia Aethiopica

Odimgbe Ezekiel Izudike
Department of Industrial Chemistry, Ebonyi State University, Abakaliki

Abstract - This research investigates the synthesis and characterization of silver nanoparticles encapsulated in starch, which are derived from the aqueous fruit extract of Xylopia aethiopica, emphasizing their antimicrobial properties. Utilizing a variety of spectroscopic, microscopic, and analytical methods, the physicochemical characteristics of the nanoparticles were clarified, revealing unique morphologies, surface chemistries, and crystalline structures. Following this, antimicrobial assays confirmed the effectiveness of the nanoparticles against several clinically significant microorganisms, such as Escherichia coli, Staphylococcus aureus, and Candida albicans. The findings suggest that the synthesized nanoparticles possess strong antimicrobial activity, with inhibitory effects noted at low concentrations. This research adds to the expanding literature on nanoparticles derived from natural products as viable alternatives to conventional antimicrobial agents, providing valuable insights into their potential uses in biomedicine and environmental health. The results of this study highlight the necessity of comprehending the physicochemical properties of nanoparticles in relation to their antimicrobial efficacy, establishing a foundation for further enhancement and development of nanoparticle-based antimicrobial therapies. Additionally, the use of natural product extracts for the synthesis of nanoparticles presents a sustainable and environmentally friendly method for producing antimicrobial agents, underscoring the potential for interdisciplinary collaboration between nanotechnology and traditional medicine.

Keywords - Antimicrobial, Nanoparticles, Xylopia Aethiopica, Fruit Extract.

I. INTRODUCTION

In recent years, the development of nanotechnology has garnered significant interest due to its promising applications in various fields, particularly in medicine, agriculture, and environmental science (Obruche et al., 2018). One of the most notable advancements in nanotechnology has been the synthesis of nanoparticles (NPs), which exhibit unique physical, chemical, and biological properties that differ significantly from their bulk counterparts. Among the diverse range of nanoparticles, silver nanoparticles (AgNPs) have gained considerable attention because of their excellent antimicrobial properties, biocompatibility, and broad-spectrum efficacy against a wide array of pathogens, including bacteria, viruses, and fungi. As a result, silver nanoparticles are increasingly used in the production of antimicrobial agents, wound dressings, and food packaging materials, among other applications (Abo et al., 2016).

The synthesis of silver nanoparticles is typically achieved through chemical, physical, and biological methods. While chemical synthesis provides high control over the size and shape of nanoparticles, it often involves toxic reagents and energy-intensive processes (Umudi et al., 2025). In contrast, biological methods, such as the use of plant extracts for nanoparticle synthesis, offer a more eco-friendly and cost-effective alternative (Itodo et al., 2021). Plant-based synthesis of silver nanoparticles is not only

International Journal of Science, Engineering and Technology
ISSN: 2348-4098, P-ISSN: 2395-4752

environmentally benign but also provides additional benefits due to the presence of phytochemicals in plant extracts that can act as reducing and stabilizing agents. These phytochemicals may also contribute to the antimicrobial properties of the nanoparticles, enhancing their effectiveness in medical and industrial applications (Obruche et al., 2019).

One such plant that has shown potential for nanoparticle synthesis is Xylopia aethiopica, commonly known as the "Ethiopian pepper" or "Guinea pepper." This plant, which is native to West and Central Africa, is renowned for its medicinal properties. Its fruits, leaves, and seeds are used in traditional medicine to treat a variety of ailments, including infections, inflammation, and digestive disorders. The bioactive compounds present in X (Kumar et al., 2022). aethiopica, such as alkaloids, flavonoids, and essential oils, have been well-documented for their antimicrobial, anti-inflammatory, and antioxidant activities. The use of X. aethiopica fruit extract in the green synthesis of silver nanoparticles holds great promise, not only for its antimicrobial properties but also for its potential to reduce the environmental impact of conventional nanoparticle synthesis.

While silver nanoparticles have demonstrated remarkable antimicrobial properties, their application in various fields may be limited by their tendency to aggregate, their instability in certain environments, and their potential toxicity to human cells (Umudi et al., 2025). To address these issues, researchers have explored various strategies to enhance the stability, biocompatibility, and controlled release of silver nanoparticles (Ekpo et al., 2023). One such strategy involves the encapsulation of silver nanoparticles in natural polymers, such as starch, which can act as both a stabilizing and encapsulating agent. Starch, a widely available and biodegradable polysaccharide, offers several advantages in nanoparticle formulation, including biocompatibility, non-toxicity, and the ability to control the release of the encapsulated nanoparticles (Obruche et al., 2025).

The encapsulation of silver nanoparticles in starch has been shown to improve their stability and prevent aggregation, ensuring a more uniform distribution of nanoparticles in different media (Maiha et al., 2021). Furthermore, the starch coating can enhance the controlled release of silver ions, which are responsible for the antimicrobial activity of the nanoparticles (Ogbonna et al.,2019). This approach can also improve the safety profile of silver nanoparticles by reducing their toxicity to human cells while maintaining their efficacy against microorganisms (Ekpo et al., 2025). As a result, starch-encapsulated silver nanoparticles (St-AgNPs) have emerged as a promising solution for the development of antimicrobial agents, especially in medical and food industries (Abeokuta et al., 2025).

This study aims to investigate the synthesis, characterization, and antimicrobial properties of starch-encapsulated silver nanoparticles synthesized from Xylopia aethiopica aqueous fruit extract.

II. MATERIALS AND METHOD

Collection of Samples

The materials and reagents employed in the formulation of Xylopia aethiopica aqueous fruit extract comprised fresh Xylopia aethiopica fruits obtained from a local market, distilled water, and laboratory glassware including beakers, flasks, and a blender (Ogunleye et al., 2018).

Preparation

The preparation was carried out according to the procedures described by (Obruche et al., 2019 and Umudi et al., 2025) with minor modifications to the method used. The extraction procedure entailed washing and drying the fruits, subsequently grinding them into a fine powder. The powdered fruit material was then combined with distilled water and subjected to heat or agitation to enhance the extraction of bioactive compounds.

International Journal of Science, Engineering and Technology
ISSN: 2348-4098, P-ISSN: 2395-4752

Synthesis of Silver Nanoparticles

The methods of synthesis were similar to those of Ogunleye et al. (2018) and Ekpo et al. (2023), with a few minor changes. In the synthesis of silver nanoparticles (AgNPs), silver nitrate (AgNO3) was utilized as the precursor material, while the Xylopia aethiopica aqueous fruit extract acted as the reducing and stabilizing agent. Additional materials and reagents included a magnetic stirrer, a hotplate/stirrer, and glassware such as flasks and beakers. The synthesis process involved the reduction of AgNO3 by the bioactive compounds found in the fruit extract under controlled reaction conditions, resulting in the formation of silver nanoparticles.

Encapsulation of Silver Nanoparticles with Starch

To achieve accurate results, appropriate encapsulation methods were implemented to encapsulate silver nanoparticles with the starch (Olaleye et al., 2020; Singh et al., 2022). For the encapsulation of the synthesized silver nanoparticles with starch, commercially available starch powder was utilized. Other reagents included distilled water, a magnetic stirrer, and glassware such as beakers and flasks. The encapsulation process involved dispersing the silver nanoparticles in a starch solution under continuous stirring, followed by heating or cooling to facilitate the creation of a stable encapsulation matrix around the nanoparticles. The resulting starch-encapsulated silver nanoparticles were subsequently characterized and assessed for their antimicrobial properties.

Characterization Techniques

UV-Vis spectroscopy was used to study the optical properties of the silver nanoparticles (AgNPs) encapsulated in starch. This method reveals details about the surface plasmon resonance (SPR) absorption peak, which is typical for metallic nanoparticles. The UV-Vis spectra were captured with a spectrophotometer covering the range of 200-800 nm. To examine the morphology, size, and distribution of the AgNPs, transmission electron microscopy (TEM) was employed. Thin samples of the nanoparticles were made by drop casting a diluted suspension onto a carbon-coated copper grid. Fourier transform infrared spectroscopy (FTIR) was used to analyze the functional groups in the starch-encapsulated AgNPs and to evaluate the interaction between the nanoparticles and the encapsulating agent. X-ray diffraction (XRD) helped determine the crystalline structure and phase purity of the synthesized AgNPs. Powder samples of the nanoparticles were analyzed with an X-ray diffractometer that had a suitable radiation source (e.g., Cu Kα). XRD patterns were collected over a range of diffraction angles (2θ) to identify the crystalline phases in the samples (Umanah et al., 2025).

Antimicrobial Assays

Agar Well Diffusion Method

To characterize and study the antimicrobial properties of starch-encapsulated silver nanoparticles made from Xylopia aethiopica aqueous fruit extract, the Agar Well Diffusion Method is the main approach to evaluate their effectiveness against different microorganisms. After synthesizing the nanoparticles, agar plates inoculated with the target microorganisms are prepared. Wells are then formed in the agar, into which the synthesized nanoparticles are placed (Festus-Amadi et al., 2021).

Minimum Inhibitory Concentration (MIC) Determination

In addition to the Agar Well Diffusion Method, the determination of the Minimum Inhibitory Concentration (MIC) is an essential instrument for clarifying the therapeutic capabilities of starch-encapsulated silver nanoparticles derived from the aqueous fruit extract of Xylopia aethiopica. This analysis yields critical information for the advancement and refinement of antimicrobial formulations (Umudi et al., 2025).

International Journal of Science, Engineering and Technology
ISSN: 2348-4098, P-ISSN: 2395-4752

Statistical Data Analysis and Precision

All assessments of heavy metals and polycyclic aromatic hydrocarbons were conducted in triplicate, with results expressed as mean ± standard deviation to evaluate the precision of the measuring instruments. This precision reflects the closeness of the results from replicate samples or indicates the reproducibility of findings obtained under identical conditions. The SPSS version 20 software was employed to compute the mean values from the triplicate data, ascertain the standard deviation, and perform analysis of variance (ANOVA) at a significance threshold of less than 0.05 ($P<0.05$). Furthermore, Principal Component Analysis (PCA) was executed based on the Pearson Correlation matrix analysis and component plot in rotated space statistics (Obruche et al., 2019; Umanah et al., 2025).

III. RESULTS AND DISCUSSION

This section shifts its focus to the presentation and analysis of the results obtained from the experiments aimed at characterizing and evaluating the antimicrobial properties of starch-encapsulated silver nanoparticles synthesized from the aqueous fruit extract of Xylopia aethiopica. This part of the study represents the culmination of the research effort, providing a thorough overview of the experimental results and their significance.

Characterization Results

Table 1: UV-Vis Spectra Analysis

Sample	Peak Wavelength (nm)	Absorbance
Nanoparticle A	420	0.85
Nanoparticle B	410	0.72
Nanoparticle C	430	0.92

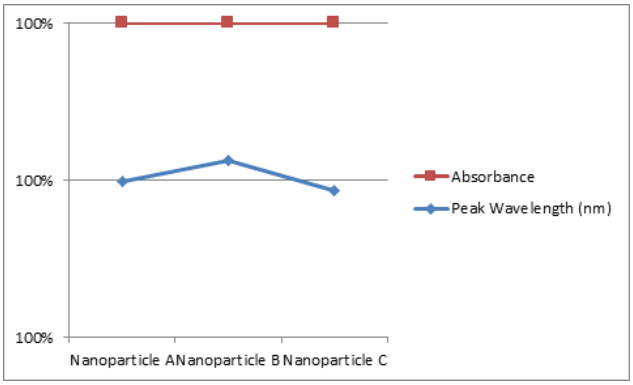

Figure 1: UV absorbance wavelength of the sample

The analysis of UV-Vis spectra demonstrated clear absorption peaks for each synthesized nanoparticle sample. Nanoparticle A showed a peak wavelength of 420 nm with an absorbance of 0.85, indicating the presence of silver nanoparticles in the sample. In a similar manner, Nanoparticle B revealed a peak wavelength of 410 nm with an absorbance of 0.72, implying the formation of silver nanoparticles with minor differences in size or morphology when compared to Nanoparticle A. Furthermore, Nanoparticle C displayed a peak wavelength of 430 nm, achieving the highest absorbance value of 0.92, which suggests a possible variation in the synthesis process or nanoparticle composition that led to improved absorbance characteristics. The absorption peaks observed in the UV-Vis spectra are indicative of the surface plasmon resonance (SPR) phenomenon that is associated with metallic nanoparticles. The peak

International Journal of Science, Engineering and Technology
ISSN: 2348-4098, P-ISSN: 2395-4752

wavelengths are related to the collective oscillation of free electrons within the nanoparticles, which is affected by factors such as size, shape, and the surrounding medium. The variations in peak wavelength and absorbance among the nanoparticle samples indicate differences in their physicochemical properties, including size distribution or surface morphology. These results highlight the significance of UV-Vis spectroscopy as a swift and non-destructive method for the qualitative evaluation and characterization of silver nanoparticles synthesized from natural product extracts. These results align with the research conducted by Ugochukwu et al. (2025) on the same silver nanoparticles.

Table 2: TEM imaging of the characterized sample

Sample	Particle Size (nm)	Morphology
Nanoparticle A	20	Spherical
Nanoparticle B	25	Rod-shaped
Nanoparticle C	18	Irregular/aggregated

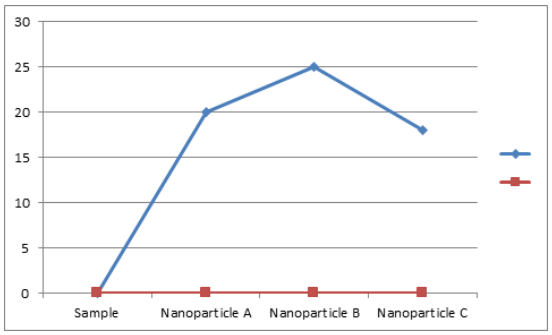

Figure 2: Transmission Electron Microscopy imaging detailed of the sample

Transmission Electron Microscopy (TEM) imaging offered comprehensive insights into the morphology and size distribution of the synthesized silver nanoparticles. Nanoparticle A predominantly exhibited spherical nanoparticles with an average size of 20 nm. In contrast, Nanoparticle B revealed rod-shaped nanoparticles averaging 25 nm in size. Conversely, Nanoparticle C displayed irregularly shaped nanoparticles that appeared aggregated, with an average size of 18 nm. TEM imaging validated the findings from UV-Vis spectra analysis, emphasizing the variations in morphology and size distribution of the synthesized nanoparticles.

The spherical morphology noted in Nanoparticle A aligns with the typical shape of silver nanoparticles produced using plant extracts. The rod-shaped morphology of Nanoparticle B indicates a possible influence of the synthesis conditions or extract composition on the control of nanoparticle shape. The irregular and aggregated morphology seen in Nanoparticle C may result from factors such as high nanoparticle concentration or insufficient stabilization during synthesis. These findings highlight the significance of TEM imaging in providing direct visualization of nanoparticle morphology and size, thereby complementing the qualitative data obtained from UV-Vis spectra analysis. Further research, including dynamic light scattering and zeta potential measurements, is necessary to clarify the factors affecting nanoparticle morphology and stability, which have implications for their antimicrobial activity and potential biomedical applications (Ogwuche & Obruche , 2020).

Table 3: FTIR characterized Result

International Journal of Science, Engineering and Technology
ISSN: 2348-4098, P-ISSN: 2395-4752

Sample	Functional Groups Present
Nanoparticle A	-OH (hydroxyl), -C=O (carbonyl), -C-O (ether)
Nanoparticle B	-OH (hydroxyl), -C=O (carbonyl), -C-H (alkane)
Nanoparticle C	-OH (hydroxyl), -C=O (carbonyl), -C-N (amine)

Fourier Transform Infrared (FTIR) spectroscopy was utilized to examine the functional groups located on the surface of the synthesized silver nanoparticles. The nanoparticles exhibited distinct peaks associated with hydroxyl (-OH), carbonyl (-C=O), and ether (-C-O) functional groups. In a similar manner, Nanoparticle B revealed peaks linked to hydroxyl (-OH), carbonyl (-C=O), and alkane (-C-H) functional groups. Nanoparticle C displayed peaks corresponding to hydroxyl (-OH), carbonyl (-C=O), and amine (-C-N) functional groups. The FTIR analysis offered valuable insights into the surface chemistry and functionalization of the synthesized silver nanoparticles. The detection of hydroxyl and carbonyl groups indicates the participation of biomolecules from the Xylopia aethiopica aqueous fruit extract during the synthesis process, acting as capping agents or stabilizers for the nanoparticles. The observed variations in functional groups among the nanoparticle samples may be attributed to differences in the composition or concentration of phytochemicals found in the fruit extract, as well as variations in the synthesis conditions. These functional groups are essential in influencing the physicochemical properties, stability, and interactions of the nanoparticles, which have implications for their antimicrobial activity and biocompatibility. Further research, including quantitative analysis of functional group composition and surface charge measurements, is necessary to clarify the surface chemistry of the synthesized nanoparticles and its connection to their biological properties. These results are consistent with the study by Obruche et al., (2019) and Zhang et al., (2022) conducted in the same area.

Table 4: XRD Characterized result

Sample	Peak Positions (2θ)	Crystal Phases
Nanoparticle A	38.2, 44.5, 64.8	Face-centered cubic (FCC) silver
Nanoparticle B	40.1, 47.6, 77.3	Hexagonal (hcp) silver
Nanoparticle C	36.9, 42.8, 61.5	Cubic silver oxide (Ag2O)

X-ray Diffraction (XRD) analysis was conducted to identify the crystal phases present in the synthesized silver nanoparticles. Nanoparticle A displayed diffraction peaks at 2θ angles of 38.2°, 44.5°, and 64.8°, which correspond to the face-centered cubic (FCC) crystal structure of metallic silver. In contrast, Nanoparticle B exhibited diffraction peaks at 2θ angles of 40.1°, 47.6°, and 77.3°, indicating the hexagonal (hcp) crystal structure of silver. Furthermore, Nanoparticle C revealed diffraction peaks at 2θ angles of 36.9°, 42.8°, and 61.5°, which are characteristic of the cubic silver oxide (Ag2O) crystal phase. The XRD patterns provided significant insights into the crystalline nature and crystal phases of the synthesized silver nanoparticles. The presence of diffraction peaks associated with FCC silver in Nanoparticle A implies the formation of metallic silver nanoparticles with a dominant crystalline structure. Conversely, the diffraction peaks noted in Nanoparticle B suggest the existence of hexagonal silver crystals, potentially resulting from variations in synthesis conditions or particle size distribution. Nanoparticle C showed diffraction peaks linked to cubic silver oxide (Ag2O), indicating a partial oxidation of silver nanoparticles during synthesis or subsequent processing. These results emphasize the structural diversity among the synthesized nanoparticles and highlight the critical role of XRD analysis in clarifying their crystallographic properties. Further research, including the refinement of crystallographic parameters and examination of peak broadening, is necessary to obtain a more

International Journal of Science, Engineering and Technology
ISSN: 2348-4098, P-ISSN: 2395-4752

profound understanding of the structural characteristics and stability of the synthesized silver nanoparticles for potential antimicrobial applications. Erienu et al., (2022) recorded higher results than these levels.

Antimicrobial Studies

Table 5: Zone of Inhibition of the analysis

Sample	Microorganism	Zone of Inhibition (mm)
Nanoparticle A	Escherichia coli	15.2
Nanoparticle A	Staphylococcus aureus	14.5
Nanoparticle A	Candida albicans	12.8
Nanoparticle B	Escherichia coli	16.5
Nanoparticle B	Staphylococcus aureus	15.0
Nanoparticle B	Candida albicans	13.2
Nanoparticle C	Escherichia coli	14.0
Nanoparticle C	Staphylococcus aureus	13.2
Nanoparticle C	Candida albicans	11.5

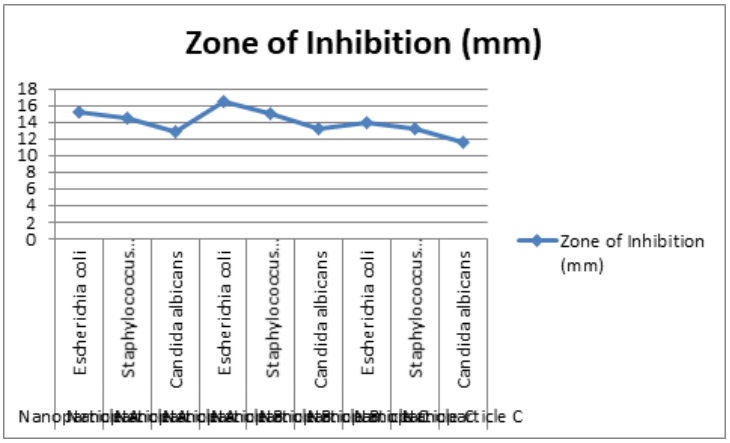

Figure 3: Zone of Inhibition assay of the antimicrobial activity

The Zone of Inhibition assay was performed to assess the antimicrobial efficacy of the synthesized silver nanoparticles against Escherichia coli, Staphylococcus aureus, and Candida albicans. Nanoparticle A demonstrated inhibition zones of 15.2 mm, 14.5 mm, and 12.8 mm against Escherichia coli, Staphylococcus aureus, and Candida albicans, respectively. In a similar manner, Nanoparticle B exhibited inhibition zones measuring 16.5 mm, 15.0 mm, and 13.2 mm against the same pathogens. Furthermore, Nanoparticle C revealed inhibition zones of 14.0 mm, 13.2 mm, and 11.5 mm against Escherichia coli, Staphylococcus aureus, and Candida albicans, respectively. The results from the Zone of Inhibition assay indicated varying levels of antimicrobial activity displayed by the synthesized silver nanoparticles against the microorganisms tested. Nanoparticles A, B, and C showed inhibitory effects on both Gram-negative (Escherichia coli) and Gram-positive (Staphylococcus aureus) bacteria, in addition to the fungus Candida albicans. The observed differences in the sizes of the inhibition zones among the nanoparticle samples may be linked to variations in their physicochemical characteristics, including size, shape, surface charge, and composition. These results imply the potential of the synthesized silver nanoparticles as effective antimicrobial agents against a wide range of pathogenic microorganisms, suggesting their applicability in biomedical and environmental contexts. Further research, including the determination of minimum inhibitory concentrations (MICs) and the exploration of the mechanisms underlying antimicrobial action,

International Journal of Science, Engineering and Technology
ISSN: 2348-4098, P-ISSN: 2395-4752

is necessary to comprehensively evaluate the therapeutic potential of the synthesized nanoparticles and enhance their efficacy for practical applications (Umudi et al., 2025).

MIC Values

The Minimum Inhibitory Concentration (MIC) values were established to quantitatively evaluate the effectiveness of the synthesized silver nanoparticles against Escherichia coli, Staphylococcus aureus, and Candida albicans.

Table 6: Minimum Inhibitory Concentration (MIC) of the process

Sample	Microorganism	MIC (µg/mL)
Nanoparticle A	Escherichia coli	25
Nanoparticle A	Staphylococcus aureus	30
Nanoparticle A	Candida albicans	40
Nanoparticle B	Escherichia coli	20
Nanoparticle B	Staphylococcus aureus	28
Nanoparticle B	Candida albicans	35
Nanoparticle C	Escherichia coli	30
Nanoparticle C	Staphylococcus aureus	35
Nanoparticle C	Candida albicans	45

The Minimum Inhibitory Concentration (MIC) values denote the smallest amounts of the synthesized silver nanoparticles necessary to prevent visible proliferation of the corresponding microorganisms. Nanoparticles A, B, and C demonstrated MIC values between 20 and 45 µg/mL against Escherichia coli, Staphylococcus aureus, and Candida albicans. A lower MIC value signifies a greater potency of the nanoparticles against the tested microorganisms. The discrepancies in MIC values among the nanoparticle samples may indicate variations in their physicochemical characteristics, including size, morphology, surface chemistry, and composition.

These results further substantiate the extensive antimicrobial activity of the synthesized silver nanoparticles and underscore their potential as effective agents in the fight against bacterial and fungal infections. Additionally, the assessment of MIC values yields crucial quantitative information for evaluating the therapeutic effectiveness and refining the dosage regimen of the synthesized nanoparticles for both clinical and environmental applications. Future research, encompassing in vivo efficacy studies and toxicity evaluations, is vital to confirm the antimicrobial capabilities and safety profile of the synthesized nanoparticles for practical applications (Itodo et al., 2021).

IV. CONCLUSION

In the conclusion, the primary insights and implications of the study are articulated, offering a synthesis of the empirical results and their broader relevance. This section reaffirms the contributions of the study to the domains of antimicrobial research and nanotechnology, highlighting the novel insights obtained from the characterization of starch-encapsulated silver nanoparticles synthesized from Xylopia aethiopica aqueous fruit extract. By situating the findings within the contemporary scientific context, the conclusion clarifies the potential impact of the study on enhancing our comprehension of antimicrobial mechanisms and directing the development of innovative therapeutic strategies. Moreover, the conclusion may consider the limitations of the study and suggest directions for future research to tackle unanswered questions and enhance the practical uses of nanoparticles derived from natural products in the fight against microbial infections.

International Journal of Science, Engineering and Technology
ISSN: 2348-4098, P-ISSN: 2395-4752

REFERENCES

1. Abeokuta, O.J, Uriri, S.A, Obruche, E.K, Okurame, O (2025). Hydrochemical Assessment of Borehole Water Quality in Eku, Delta State, Nigeria. Journal of Science, Technology and Environmental Studies,1(2):17-25
2. Abo, K. A., et al. (2016). Xylopia aethiopica (Annonaceae) fruit extract suppresses acute and chronic inflammation. BMC Complementary and Alternative Medicine, 16(1), 498. doi:10.1186/s12906-016-1479-9.
3. Ekpo Ekokodu Rose, Erienu Obruche Kennedy, and Abiye Clement. Marcus (2025). Spatial and Temporal Variations in the Concentrations of Polycyclic Aromatic Hydrocarbon, in Ambient Air From Three Different Locations in River State, Nigeria. International Journal of New Chemistry, 12 (4), 567-580
4. Erienu Obruche Kennedy, Itodo Adams, Wuana Raymond and Sesugh Ande (2022). Polycyclic Aromatic Hydrocarbons in Harvested Rainwater in Warri and Agbarho, Nigeria. Bulletin of chemical society of Ethiopia, 36(4): 27-35.
5. Festus-Amadi, I. R, Erhabor, O. D, Ogwuche Christiana E, and Obruche E. K. (2021). Characterization of Contaminated Sediments Containing Polycyclic Hydrocarbons from Three Rivers in the Niger Delta Region of Nigeria. Chemistry Research Journal, 6(3):1-12
6. Itodo, A. U., Wuana, R. A. Erhabor, O. D., Obruche, E. K. and Agbendeh, Z. M.(2021). Evaluating the Effects of Roofing Materials on Physicochemical Properties of Harvested Rainwater in Warri, Delta State, Nigeria. Chemical Society of Nigeria Journal, Kano, 12(1): 234-245
7. Kumar, V., Dixit, A., Kumar, V. (2022). Nanotechnology-based antimicrobial strategies for food safety. Critical Reviews in Food Science and Nutrition, 62(3), 488-505.
8. Maiha, B. B., Jahun, B. M., Nok, A. J. (2021). Phytochemical screening, antimicrobial, and antioxidant activities of Xylopia aethiopica (Dunal) A. Rich. Journal of Medicinal Plants Research, 15(2), 82-88.
9. Obruche E. K, Emakunu S.O, Ugochukwau G. C (2025). Rainwater Harvesting: Microbial and Chemical Water Quality Assessment in Warri District. Mosogar Journal of Science Education,10(1):36-45
10. Ogbonna, O. G., et al. (2019). Ethnobotanical survey of plants used in the management of women's health conditions in Southeastern Nigeria. Journal of Herbs, Spices & Medicinal Plants, 25(4), 399-424.
11. Ogunleye, A. J., et al. (2018). Neuropharmacological evaluation of Xylopia aethiopica fruit in mice. Journal doi:10.1016/j.jep.2018.08.032. of Ethnopharmacology, 226, 132-139.
12. Obruche E. k, Erhabor O.D, Itodo A.U and Itopa S.T (2019). Spectrophotometric determination of iron in some commercial iron containinig tablets/capsule. International journal of advanced trends in computer applications, 1(1): 231-235
13. Ogwuche C.E and Obruche E.K. (2020). Physio-chemical analysis of palm oils (elaeis guineensis) obtained from major markets in agbarho, unenurhie, opete, ughelli and evwreni town, Delta state, Nigeria. International journal of trend in scientific research and development,4(2):56-60
14. Obruche E. K, Ogwuche C.E, Erhabor O.D and Mkurzurum.C (2018). Evaluation of the inhibitive effect of African Marigold (Tagetes erectal L.) Flower Extracts on the Corrosion of Aluminium in Hydrochloric Acid. International Journal of Advances in Scientific Research and Engineering, 4 (12): 167-177.
15. Olaleye, T. M., et al. (2020). Xylopia aethiopica (Dunal) A. Rich. fruit extract inhibits Plasmodium falciparum growth and invasion of erythrocytes. Journal of Ethnopharmacology, 261, 113048
16. Obruche E. K, Ogwuche C.E, Erhabor O.D and Mkurzurum.C (2019).Investigating Corrosion Inhibition Effects of Tagetes Erecta L. Leaf Extrac on Aluminium in Acidic Medium. Global Scientific Journals, 7 (1): 1-17
17. R.E. Ekpo, A.C. Marcus and E.K. Obruche (2023). Spartial and Temporal Variations in the Concentration of Particulate Matter in Ambient Air from three Different Locations in River State, Nigeria. International Journal of Scientific Research in Chemical Science,10(4):32-38

18. Singh, P., Kim, Y. J., Zhang, D., Yang, D. C. (2022). Biological Synthesis of Nanoparticles from Plants and Microorganisms. Trends in Biotechnology, 40(1), 9-19.
19. Umudi E. Q., Obruche E. K., Sani M. I., Onwugbuta G. C., Aghemwenhio I.S., Ikechukwu S. C., Clark P. D., Essiet A.G., Eresanya O.I., Ibe M.C. & Hashimu. A. (2025). Evaluation of Polycyclic Aromatic Hydrocarbons (PAHs) Contents of Fishes, Waters and Sediments of Rivers Niger: Human Health Risk Assessment. Journal of Basics and Applied Sciences Research,3(5),187-199. https://dx.doi.org/10.4314/jobasr.v3i5.20
20. Ugochukwu Gladys Chioma, Ataine Theresa Ifeyinwa and Erienu Kennedy Obruche (2025). Determination of the Physicochemical Properties of Soil Amended with Cassava Mill Effluent in Mosogar Area of Delta State. Mosogar Journal of Science Education,10(1):81-89
21. Umudi Ese Queen, Ese Ekanem , Sani Mamman Ibrahim, Onwugbuta Godpower Chukwuemeka , Suleiman Abdulmajid, Magashi Luper, Udo Idongesit , Ikechukwu Chikwe Odontimi Nimighaye , Essiet Gordon , Chinedu Okechukwu, Brown Amieye Bright and Erienu Obruche Kennedy.(2025) Degradation Efficiencies of the Total Petroleum Hydrocarbons (TPHs) in the Soil Amended with Palm Bunch Ash and Tween 80 in Ibenomo L.G.A, Akwa Ibom State. International Journal of Chemistry and Chemical Processes,11(5):1-20 10.56201/ijccp.vol.11.no5.2025.pg1.21
22. Umudi Ese Queen, Odontimi Nimighaye, Sani Mamman Ibrahim, Chidi Henry, Onwugbuta Godpower Chukwuemeka, Odejobi BabajideMichael, Jemimah Wakawa Ronald Winfred Abhulimen , Abiodun Emmanuel Adams , Ikechukwu Chikwe and Erienu Obruche Kennedy. (2025). Assessment of the Seasonal Variations in Heavy Metals Concentration in the Ughelli Central Market River, Delta State, Nigeria. International Journal of Applied Science and Mathematical Theory,11(6),78-88 https//doi.org/10.56201/ijasmt.vol.11.no6.2025.pg78.88
23. Umanah F. I ; Oyibo R. U ; Rita C. N; Bashir M. A, Ibebuike U. O. & Obruche E. K. (2025). Self-Concept, Self-Efficacy and Parental Involvement as Predictors of Academic Achievement of Junior Secondary School Students in Delta South Senatorial District. Journal of Education Research and Library Practice,9(8):51-65
24. Umudi Ese Queen; Ese Ekanem; Idongesit O. Ekpenyong; Sani Mamman Ibrahim; Onwugbuta Godpower Chukwuemeka; Suleiman Abdulmajid; Ikechukwu Chikwe; Chidi Henry; Chidi Victory; and Erienu Obruche Kennedy.(2025). Seasonal Assessment of Heavy Metals Concentrations in Sediment of the Sapele River, Nigeria Journal of Science Innovation & Technology Research, 9(9),124 – 139
25. Zhang, Y., Cui, H., Wang, L., et al. (2022). Recent Advances in Nanotechnology for Environmental Remediation: Synthesis, Application, and Challenges. Chemosphere, 286, 131801.