



Green Synthesis of (AgO, ZnO, CuO) Nanoparticles Using *Moringa oleifera* Leaves Extract and Their Composite Characterization.

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ABSTRACT

Nanotechnology offers sustainable alternatives to conventional chemical practices for crop protection and food preservation. Silver oxide (AgO), zinc oxide (ZnO), and copper oxide (CuO) nanoparticles were synthesized using *Moringa oleifera* leaf extract as a natural reducing and stabilizing agent. Phytochemical analysis carried out confirmed the presence of bioactive compounds (phenols, alkaloids, flavonoids, terpenoids, and saponins) that facilitated efficient nanoparticle formation. The synthesized nanoparticles were combined into ternary nanocomposites, which exhibited improved crystallinity, stability, and antimicrobial potential. The synthesis process, conducted using analytical-grade reagents in Abuja, Nigeria, was characterized by advanced techniques, including UV-visible spectroscopy (UV), High-Resolution Scanning Electron Microscopy (HRSEM), X-ray Diffraction (XRD), Fourier transform infrared spectroscopy (FTIR), and Dynamic light scattering (DLS). This plant-mediated synthesis proved to be a cost-effective, non-toxic, and sustainable approach, which can provide evidence for the application of green nanotechnology in enhancing crop protection and prolonging food shelf life.

Keywords: Nanocomposites, *Moringa oleifera*, green synthesis, characterization.

INTRODUCTION

Nanotechnology manipulates matter at the atomic scale (1-100 nm) to revolutionize sectors like agriculture by reducing reliance on synthetic fertilizers and pesticides. While conventional synthesis is often costly and hazardous, "green nanotechnology" offers a sustainable alternative by utilizing biological sources instead of toxic chemicals (Alhalili, 2022). Plant materials, such as *Moringa oleifera*, are particularly effective due to bioactive phytochemicals that serve as natural reducing and stabilizing agents. Research has successfully utilized these extracts to synthesize silver, zinc, and copper oxide nanoparticles (Toyosi *et al.*, 2021). These eco-friendly nanomaterials provide a cost-effective, non-toxic solution for enhancing food shelf life and improving mechanical and barrier properties in stored products (De Sousa *et al.*, 2023).

MATERIALS AND METHODS

Materials: All the chemicals and reagents used in this study are of analytical grade with percentage purity in the range of 97-99 %.

Sample collection for moringa leaves: The moringa leaves were collected from the National Biotechnology Research and Development Agency (NBRDA) complex in Abuja.

Preparation of Samples of Moringa Leaves and Extraction from *Moringa oleifera* leaves: The leaves were screened to remove bad ones and were dried at room temperature. Thus, they were ground with distilled water using a mixer grinder and filtered to get aqueous leaf extract (Amaglo, 2020). The aqueous leaf extract was allowed to dry and stored in a clean airtight

container.

Phytochemical Screening of the *Moringa oleifera* extract: This includes (Qualitative and Quantitative) tests carried out on the aqueous leaf extract sample using standard procedures described by Toyosi *et al.* (2021). This test was used to confirm the quality and the presence or absence of phenols, alkaloids, terpenoids, flavonoids, and saponins in the leaf extract of *Moringa oleifera*.

Synthesis of AgO, CuO, and ZnO Nanoparticles

Green synthesis of silver Nanoparticles: AgO were synthesized by adding *Moringa oleifera* extract to AgNO₃ (4.0 mM), adjusting pH to 10, and annealing at 450 °C. DOE investigated the effects of stirring time (30-120 min) on synthesis. Moringa-mediated Ag NP synthesis involved pH adjustment and annealing; DOE optimized stirring time (30-120 min).

Green Synthesis of Zinc Oxide Nanoparticles: ZnO nanoparticles were synthesized by reacting *Moringa oleifera* extract with zinc acetate dihydrate (pH 10), followed by calcination at 450 °C (Muthusamy et al., 2025). DOE optimized stirring time, precursor concentration, and extract volume. Hence, Moringa-mediated ZnO nanoparticles were synthesized via a green method, optimized by DOE

Green synthesis of copper oxide Nanoparticles: CuO nanoparticles were synthesized by adding *Moringa oleifera* extract to CuSO₄, adjusting pH (6-10), and calcining at 450 °C (Alhalili, 2022). DOE optimized stirring time, pH, and CuSO₄ concentration. Moringa-mediated CuO nanoparticles synthesized via a green method were optimized by DOE.

Development of a nanocomposite with AgO, CuO, and ZnO Nanoparticles: Synthesis of ternary nanocomposites of AgO, CuO, and ZnO nanoparticles (1:1:1, 1:2:1, 1:1:2, 2:1:1 mass ratios) was dispersed in water, ultrasonicated, aged, and calcined at 450 °C to form ternary nanocomposites (Jamwal *et al.*, 2025).

Characterization of the Nanoparticles and their composites: Characterization of the nanocomposites and their nanoparticles was achieved using standard procedures for various characterization techniques such as UV, FTIR, HRSEM, and DLS.

Data Analysis: All data that were generated were subjected to analysis of variance (ANOVA) using the statistical software SPSS version 20 (George & Mallery, 2019).

RESULTS

Extraction from *Moringa oleifera* leaves: Aqueous *Moringa oleifera* leaf extract was obtained from the extraction carried out on *Moringa oleifera* leaves



Plate I: Aqueous *Moringa oleifera* leaf extract

Phytochemical composition Results of Aqueous Moringa Extract: *Moringa oleifera* extract possesses a potent biochemical profile. These bioactive reductants, alongside flavonoids and tannins, facilitate controlled nucleation and stabilization of AgO, ZnO, and CuO nanoparticles.

Table 1: Phytochemical composition results of Aqueous Moringa Extract

Constituents	Quantitative Observation (mg/g)	Qualitative Observation
Phenols	21.35 ± 0.05	+
Tannins	6.54 ± 0.25	+
Alkaloids	20.70 ± 0.18	+
Flavonoids	14.20 ± 0.02	+
Terpenoids	21.46 ± 0.07	+
Saponins	21.85 ± 0.16	+
Glycosides	0.00 ± 0.00	-
Cardiac Glycosides	6.91 ± 0.01	+
Anthraquomones	6.81 ± 0.10	+
Steroids	0.00 ± 0.00	-

+ Present - Absent

Synthesis results of AgO, ZnO and CuO nanoparticles



AgO nanoparticles



CuO nanoparticles



ZnO nanoparticles

Plate II: Green Synthesis of AgO, ZnO and CuO nanoparticles

Green-synthesized silver Nanoparticles: Silver nanoparticles (AgO) that were prepared showed a visible color change from light brown to black, indicating the formation of silver nanoparticles.

Green Synthesized Zinc oxide (ZnO) Nanoparticles: Zinc oxide nanoparticles (ZnO) synthesized showed a distinct color transition from light brown to white, signifying nanoparticle formation.

Green-synthesized copper oxide (CuO) nanoparticles: Copper oxide nanoparticles (CuO) that were produced had a color change from pale blue to reddish-brown, indicating the precipitation of CuO nanoparticles.

Development of nanocomposite with AgO, CuO, and ZnO nanoparticles: Ternary AgO-CuO-ZnO nanocomposites were synthesized via ultrasonication and calcination, varying mass ratios to form stable ternary nanocomposites.

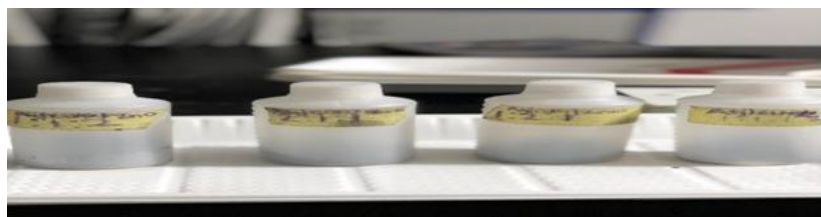


Plate III: showing the composites in ratios of 1:1:2, 2:1:1, 1:2:1, and 1:1:1.

Characterisation of synthesised AgO, ZnO and CuO nanoparticles

UV-visible spectrum and Tauc plot (inset) of ZnO, AgO and CuO nanoparticles

UV-Vis spectrum confirms Moringa-mediated ZnO nanoparticles with defined optical features and stability. ZnO nanoparticles show an absorption peak at 360.40 nm, mediated by Moringa flavonoids and phenolics.

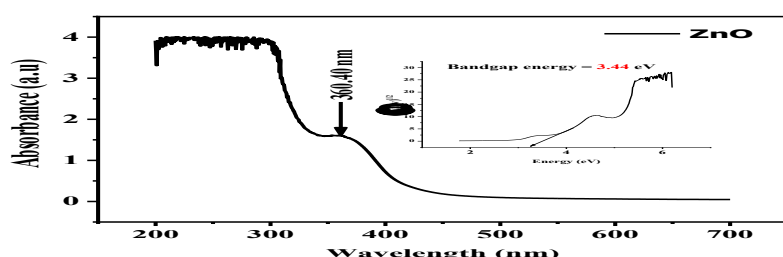


Figure 1: UV-visible Spectrum and Tauc Plot (inset) of ZnO Nanoparticles

UV-Vis and Tauc plot confirm Moringa-mediated AgO nanoparticles with quantum confinement and stability. AgO nanoparticles show an SPR peak at 390.89 nm and a band gap of 3.11 eV, mediated by Moringa *oleifera* phytochemicals.

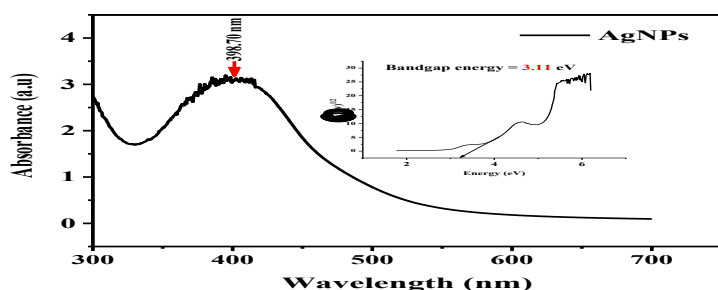


Figure 2: UV-visible Spectrum and Tauc Plot (inset) of AgO Nanoparticles

UV-Vis and Tauc plot confirm Moringa-mediated CuO nanoparticles with quantum confinement and stability. CuO nanoparticles show absorption at 269.65 nm and a band gap of 3.63 eV, mediated by Moringa *oleifera* phytochemicals.

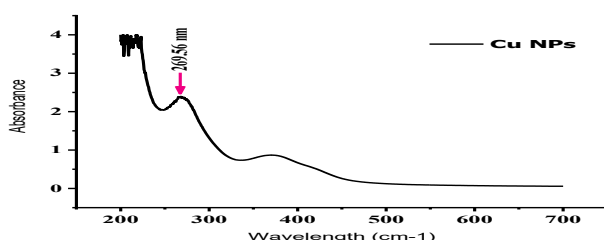


Figure 3: UV-visible Spectrum and Tauc Plot (inset) of CuO Nanoparticles

Dynamic light scattering (DLS) analysis of ZnO, AgO and CuO nanoparticles

The particle size distribution of the synthesised nanoparticles using moringa plant extract was determined through dynamic light scattering (DLS) analysis, as presented below:

DLS for ZnO Nanoparticle: DLS analysis confirms Moringa-mediated ZnO nanoparticles with narrow size distribution and stability. ZnO nanoparticles (~64 nm, PDI: 0.254) show a monodisperse distribution, stabilized by *Moringa oleifera* phytochemicals.

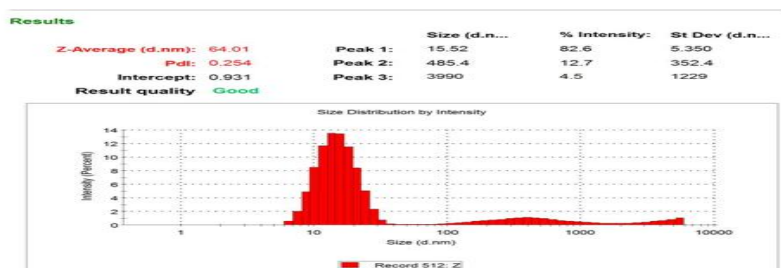


Figure 4: Dynamic Light Scattering (DLS) results of ZnO Nanoparticles

DLS for AgO Nanoparticle: DLS analysis confirms Moringa-mediated silver nanoparticles with narrow size distribution and high stability. Silver nanoparticles (~66 nm, PDI: 0.292) show a monodisperse size distribution, stabilized by Moringa phytochemicals, suitable for nanocomposite preservation of fruits.

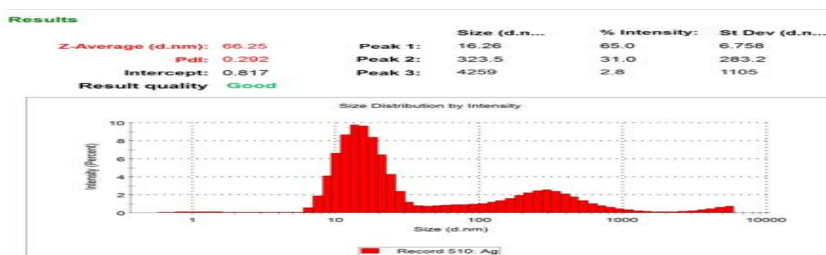


Figure 5 : Dynamic Light Scattering (DLS) result of AgO Nanoparticles

DLS for CuO Nanoparticle: DLS analysis confirms Moringa-mediated copper nanoparticles with good dispersion and stability via surface functionalization. Copper nanoparticles (~57 nm, PDI: 0.235) show a well-dispersed population, stabilized by *Moringa oleifera* phytochemicals.

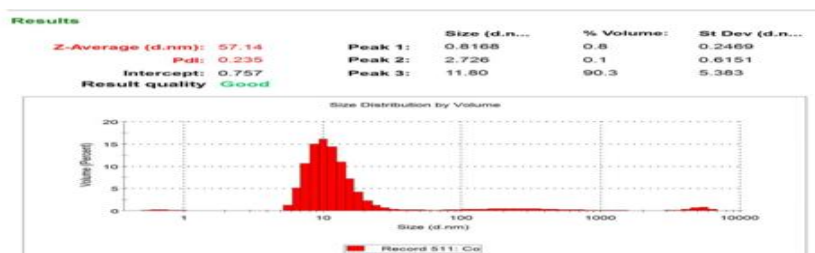


Figure 6: Dynamic Light Scattering (DLS) result of CuO Nanoparticles

DLS analysis of formulated ZnO, AgO, CuO nanocomposite

CP2:1:1

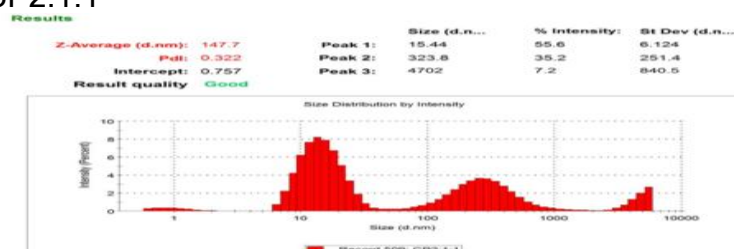


Figure 7: Dynamic Light Scattering (DLS) result of nanocomposite ratio 2:1:1

CP1:1:1

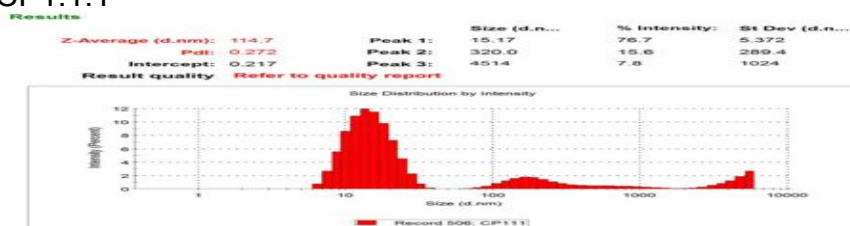


Figure 8: Dynamic Light Scattering (DLS) result of nanocomposite ratio 1:1:1

CP1:1:2

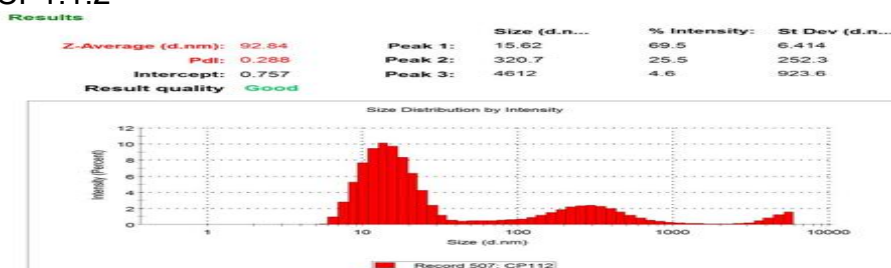


Figure 9 : Dynamic Light Scattering (DLS) result of nanocomposite ratio 1:1:2

CP 1:2:1

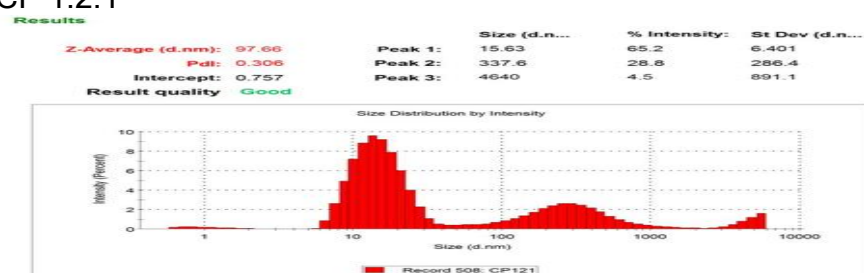


Figure 10: Dynamic Light Scattering (DLS) result of nanocomposite ratio 1:2:1

DLS analysis confirms Moringa-mediated nanocomposites with size/stability influenced by precursor ratios; sub-20 nm populations persist across samples. Nanocomposite size and stability vary with precursor ratios; CuO-rich (1:1:2) shows the smallest size (92.84 nm) and highest stability

X-ray Diffraction (XRD) Analysis of ZnO, AgO, and CuO nanoparticles

XRD confirms phase purity and crystallinity of ZnO, AgO, and CuO nanoparticles mediated by *Moringa oleifera*. Moringa-mediated green synthesis yields crystalline nanoparticles suitable for fruit shelf-life extension.

XRD for ZnO Nanoparticle

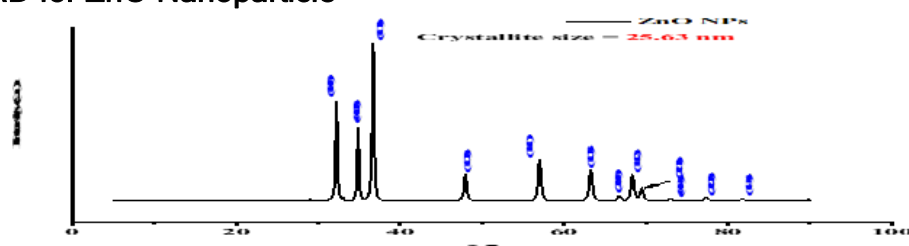


Figure 11 : X-ray Diffraction (XRD) Analysis of ZnO Nanoparticles

XRD confirms ZnO nanoparticles with characteristic peaks and a hexagonal structure. ZnO nanoparticles show a hexagonal wurtzite structure (JCPDS 00-036-1261) & crystallite size of 25.63 nm.

XRD for CuO Nanoparticle

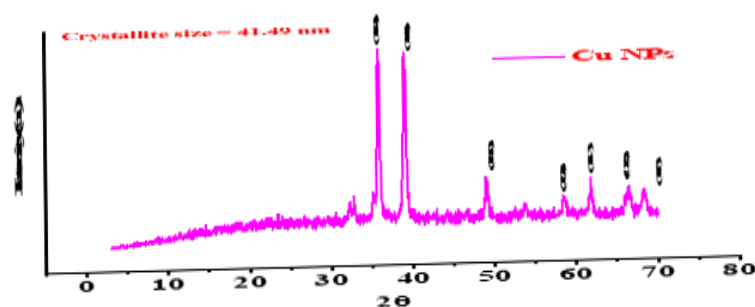


Figure 12: X-ray Diffraction (XRD) Analysis of CuO Nanoparticles

XRD confirms CuO nanoparticles with high crystalline perfection and low defect density. CuO nanoparticles show tenorite structure (JCPDS 04-005-4872), crystallite size: 41.49 nm.

XRD for AgO Nanoparticle

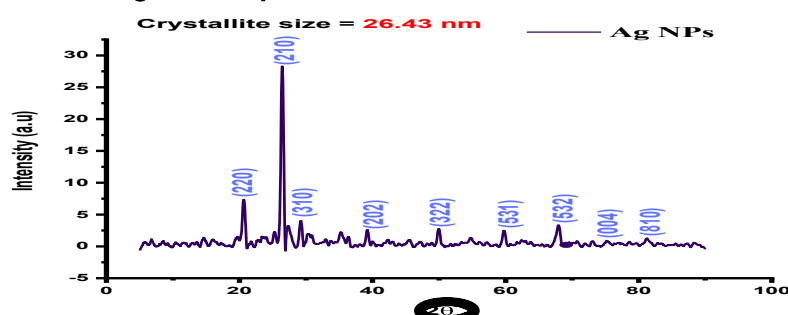


Figure 13: X-ray Diffraction (XRD) Analysis of AgO Nanoparticle

XRD confirms AgO nanoparticles with high structural integrity and stability. AgO nanoparticles show an fcc structure (JCPDS 04-0783) and a crystallite size of 26.43 nm.

XRD for NCP (Nanocomposites)

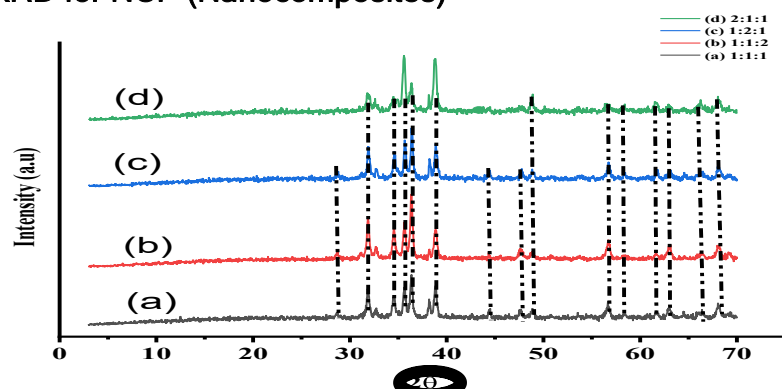


Figure 14: XRD analysis of ZnO, AgO, CuO nanocomposite

XRD confirms successful integration of oxide phases; CuO inhibits grain growth, and ZnO promotes lattice organization. ZnO/AgO/CuO nanocomposites show varied structural properties with precursor ratios; the 1:1:2 ratio is optimal for minimal size (30.39 nm) and integrity.

FTIR spectrum of the synthesized ZnO, AgO, and CuO nanoparticles

FTIR confirms that *Moringa oleifera* phytochemicals (saponins, tannins, alkaloids, proteins) cap and stabilize ZnO, AgO, CuO nanoparticles. Moringa-mediated synthesis involves biomolecular surface functionalization of nanoparticles.

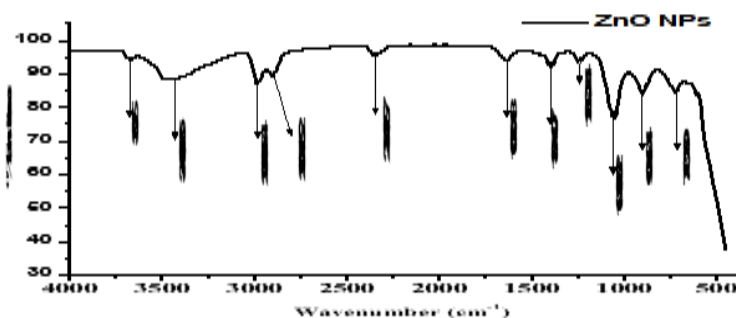


Figure 15: FTIR Spectrum of the Synthesized ZnO Nanoparticles

FTIR confirms that *Moringa oleifera* phytochemicals (polyphenols, flavonoids, terpenoids, proteins) cap and reduce ZnO nanoparticles. Moringa-mediated ZnO synthesis involves cooperative biomolecular capping and Zn-O bond formation.

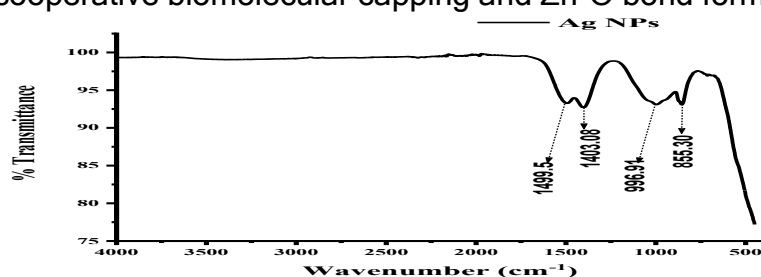


Figure 16: FTIR Spectrum of the Synthesized AgO Nanoparticles

FTIR confirms that *Moringa oleifera* phytochemicals (polyphenols, flavonoids, tannins, proteins) stabilize AgO nanoparticles. Moringa-mediated AgO synthesis involves biomolecular capping and Ag-O bond formation.

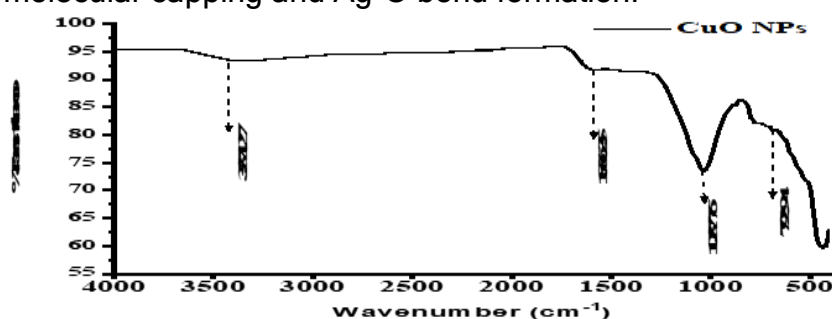


Figure 17: FTIR Spectrum of the Synthesized CuO Nanoparticles

FTIR confirms that *Moringa oleifera* phytochemicals (phenolics, saponins, proteins, flavonoids) mediate CuO nanoparticle synthesis. Moringa-mediated CuO synthesis involves biomolecular capping and Cu-O bond formation.

FTIR for NCP (Nanocomposites)

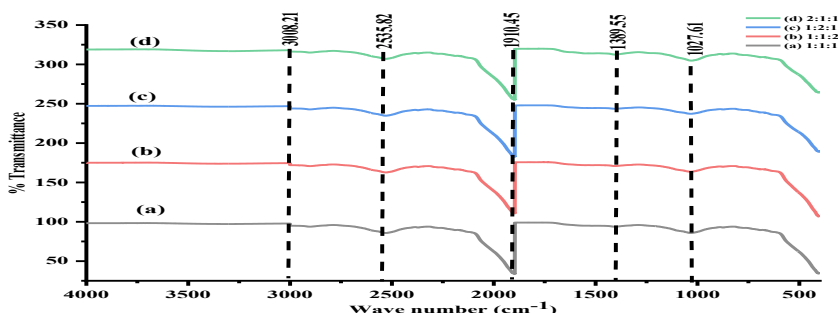


Figure 18: FTIR analysis of ZnO, AgO, CuO nanocomposites:

FTIR spectra confirm that *Moringa oleifera* phytochemicals stabilize ZnO/AgO/CuO nanocomposites, enhancing antimicrobial and antioxidant activity for agricultural use. Moringa phytochemicals bind to nanocomposites, boosting eco-friendly agricultural potential.

HRSEM/EDX analysis of ZnO, AgO, and CuO nanoparticles:

HRSEM and EDS confirm high-purity AgO nanoparticles for agricultural applications. Moringa-mediated AgO nanoparticles (~43 nm, spherical, Ag: 92.51%, O: 7.49%) suit antimicrobial fruit preservation.

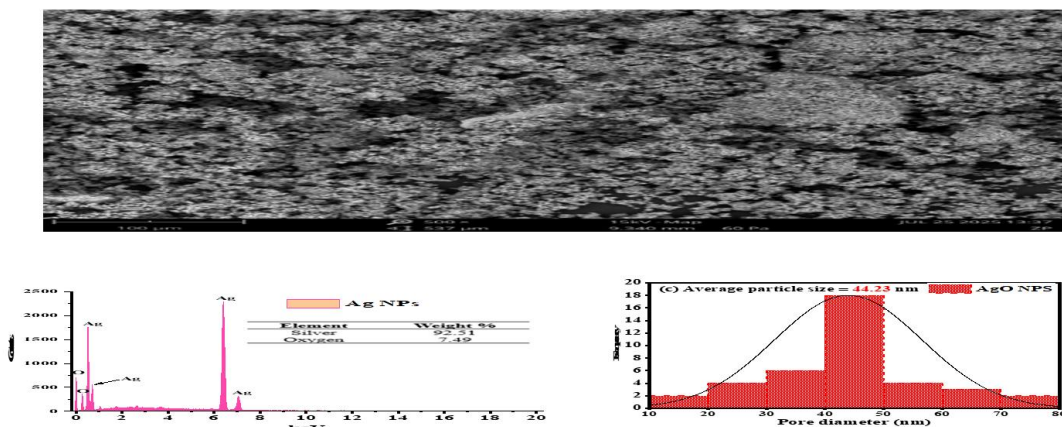


Figure 19: (a) HRSEM of AgO nanoparticles; (b) HRSEM EDX spectrum of AgO nanoparticles; (c) Average particle size calculated from

HRSEM for Zinc oxide (ZnO) Nanoparticles: Moringa-mediated ZnO nanoparticles (~19 nm, irregular spherical-hexagonal, Zn: 57.06%, O: 42.94%) suit food preservation. HRSEM and EDS confirm high-purity ZnO nanoparticles with minimal agglomeration.

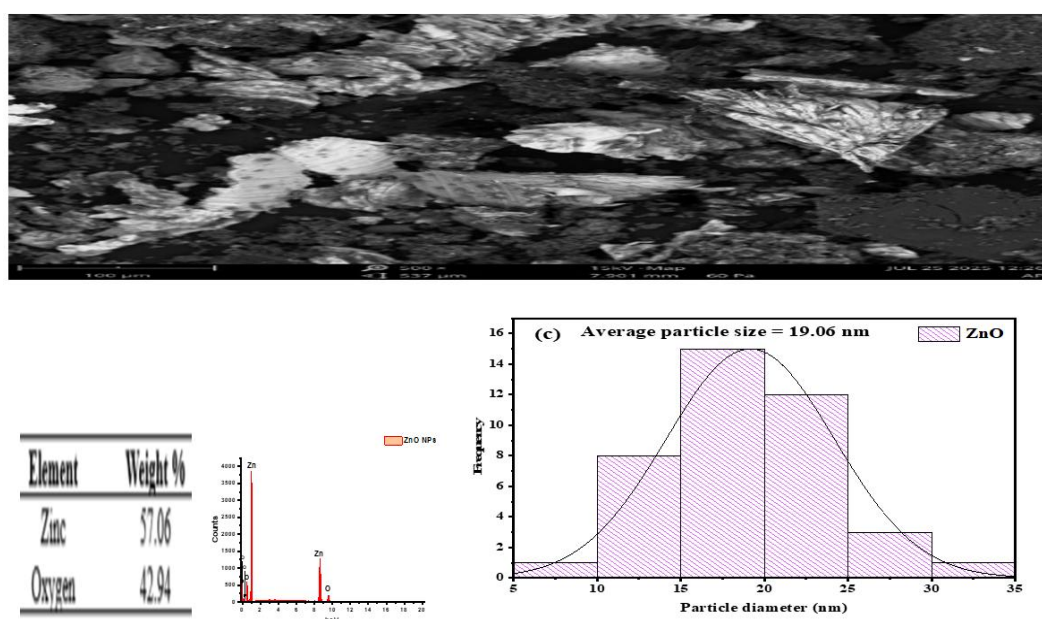


Figure 20: (a) HRSEM of ZnO nanoparticles, (b) HRSEM EDX spectrum of ZnO nanoparticles, (c) Average particle size calculated from

HRSEM for Copper oxide (CuO) Nanoparticles: Moringa-mediated CuO nanoparticles (~30 nm, irregular spherical-elongated, Cu: 60.01%, O: 39.99%) suit fruit preservation. HRSEM and EDS confirm high-purity CuO nanoparticles.

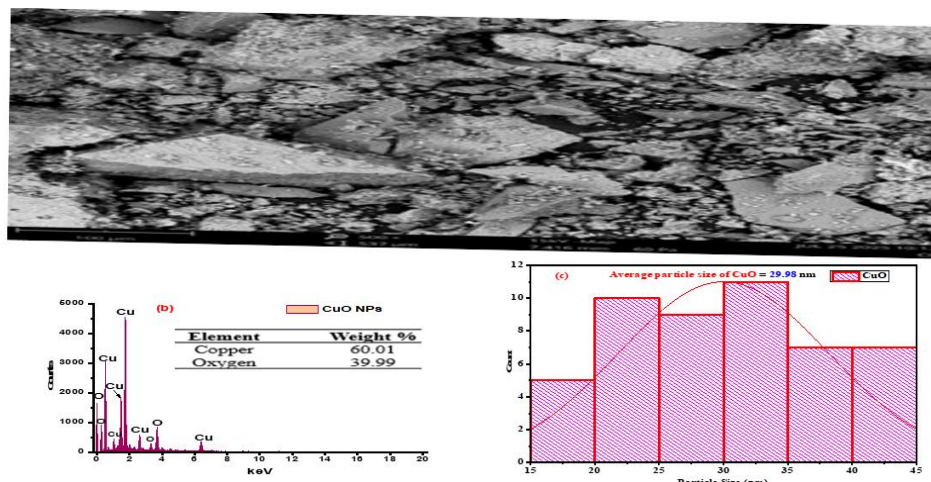


Figure 21: (a) HRSEM of CuO nanoparticles; (b) HRSEM EDX spectrum of CuO nanoparticles; (c) Average particle size calculated from

HRSEM analysis of AgO, ZnO, CuO nanocomposite: Moringa-mediated ZnO/AgO/CuO nanocomposites (16.62–29.27 nm) show compact, heterogeneous morphology, promising for antimicrobial fruit preservation. HRSEM and EDS confirm phytochemical-controlled nanocomposites with high surface area.

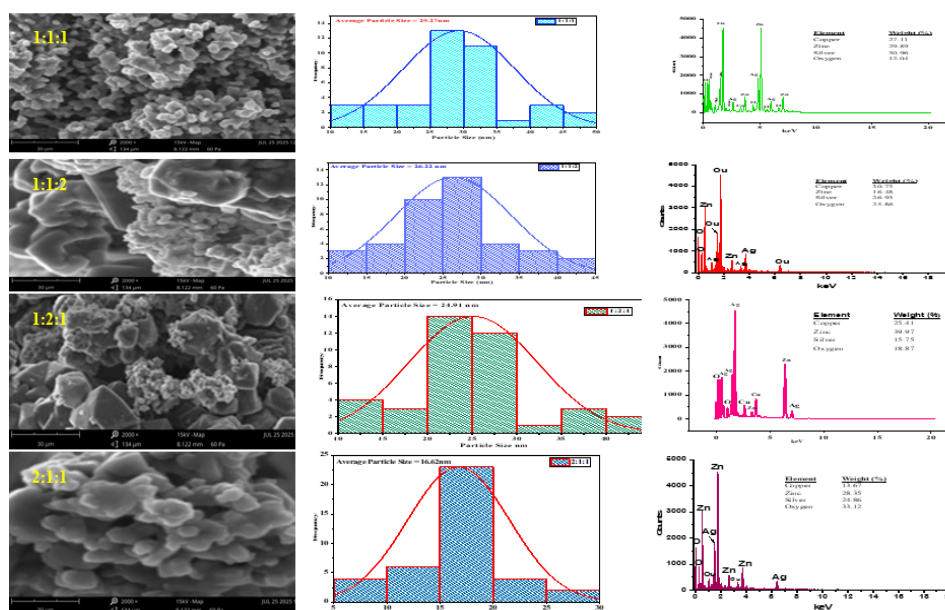


Figure 22 : (a) HRSEM of nanocomposites (b) HRSEM EDX spectrum of nanocomposites (c) Average particle size calculated from

DISCUSSION

Phytochemical Analysis of Aqueous *Moringa oleifera* leaf extract: *Moringa oleifera* extract synthesizes nanoparticles with antioxidant and antimicrobial properties, extending fruit shelf life cost-effectively. Rich in flavonoids, phenols, and terpenoids, Moringa extract enables eco-friendly nanoparticle synthesis (Amglo 2020).

Nanoparticle Synthesis: The successful green synthesis of AgO, ZnO, and CuO nanoparticles was visually confirmed by distinct color transitions, marking the successful reduction and stabilization of metal ions by the Moringa extract (Zhou *et al.*, 2023).

Silver oxide (AgO) nanoparticle: AgO nanoparticle synthesis was confirmed by colour change

(light brown to dark brown) and UV-Vis spectra, via Moringa-mediated reduction.

Zinc oxide (ZnO) nanoparticle: ZnO nanoparticle synthesis was confirmed by color change (light brown to white) and UV activation with spectral selectivity.

Cooper oxide (CuO) Nanoparticle: Refluxing Moringa leaf extract with copper solution yielded a distinct color transition from light brown to reddish-brown, confirming the formation of CuO nanoparticles (Zhang *et al.*, 2025).

Nanocomposites: Nanocomposites with various nanoparticle ratios were successfully developed, exhibiting enhanced stability and antimicrobial activity for potential agricultural applications (Malik *et al.*, 2025).

Characterization of Nanoparticles and Nanocomposites: Characterization (SEM, UV-Vis, DLS, FTIR, XRD) confirms Moringa-mediated nanocomposites with high crystallinity and stability for agricultural use (Rahimi, 2025).

UV-visible spectrum and Tauc plot (inset) of ZnO, AgO, and CuO nanoparticles : UV-Vis and Tauc plot analyses confirm green synthesis of ZnO, AgO, and CuO nanoparticles, suitable for eco-friendly preservative formulations. Moringa *oleifera*-mediated ZnO, AgO, and CuO nanoparticles were synthesized, showing optical activity.

Dynamic Light Scattering of ZnO, AgO, and CuO nanoparticles and nanocomposites: DLS and zeta potential confirm stable nanoparticles, enhancing shelf-life extension of produce. Moringa-mediated ZnO, AgO, and CuO nanoparticles show narrow size distributions (PDI < 0.3, 50-70 nm) and high colloidal stability.

XRD of ZnO, AgO, and CuO nanoparticles and nanocomposites: XRD confirms Moringa-mediated ZnO, AgO, and CuO nanoparticles with high crystallinity, suitable for applications in Agricultural food preservation.

FTIR spectrum of the synthesized ZnO, AgO, and CuO nanoparticles and nanocomposites: FTIR confirms Moringa phytochemicals functionalize ZnO, AgO, and CuO surfaces, enhancing biocompatibility and antimicrobial effects. (Pasieczna-patkowska, 2025).

HRSEM/EDX of ZnO, AgO, and CuO nanoparticles and nanocomposites: Moringa-mediated ZnO, AgO, and CuO nanoparticles (~19 nm) show tailored UV-protection and antimicrobial properties for eco-friendly packaging. Precursor ratios influence morphology, boosting antioxidant and barrier properties for sustainable food packaging.

CONCLUSION

Moringa oleifera-mediated synthesis yields eco-friendly AgO, CuO, ZnO nanoparticles with strong antimicrobial properties for food and agriculture applications. Green synthesis offers a sustainable alternative to chemical-based methods for food preservation and crop protection.

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