



Estimated of Structural, Morphology and Antibacterial properties: Plant-Mediated Synthesis of AgO, NiO, and NiO - AgO Nanoparticles Using *Allium cepa* extract

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Abstract

Allium cepa extract was used to prepare AgO NPs, NiO NPs, NiO-AgO NCs by plant-mediated synthesis, all characteristics of these nanoparticles and antibacterial properties have been studied. XRD analysis confirmed the crystalline nature of the synthesized nanoparticles. The average crystalline size was 14.75nm, 38nm and 36.4 nm for AgO NPs, NiO NPs and NiO-AgO NCs respectively. NiO NPs were hexagonal, while AgO NPs were monoclinic phase. The NiO-AgO NCs represents a hybrid structure composed of NiO NPs and AgO NPs phase. EDX analysis verified that all samples contained the elements that were present (O, Ni, and Ag). UV-Vis was used to calculate the AgO, NiO, and NiO-AgO energy gaps are 3.11 eV, 3.08 eV and 3.38 eV respectively. Additionally, From FTIR spectroscopy, the investigation found that the extract from *Allium cepa* included functional groups that serve as agents that reducing and capping, the spectrum verifies existence of AgO and NiO and combination of AgO and NiO with adsorbed surface groups such carbonates and water Furthermore, from zeta potential, AgO NPs, NiO NPs and NiO-AgO NCs showed great stability at -29.1 mV, -22.6 mV, and -21.3 mV respectively. The study revealed that the material demonstrates greater antibacterial activity against Gram negative bacteria compared to Gram-positive ones. The NiO-AgO NCs showed the maximum inhibition values against *E. coli* and *Staphylococcus aureus* at a concentration of 75%, measuring about 28 mm and 27 mm, respectively.

Keywords: *Allium cepa* extract, Biomedical application, AgO NPs, NiO NPs NiO-AgO NCs, Green synthesis.

1.Introduction

Nanoparticles are extremely small particles with dimensions ranging from 1-100 nm. They have physical and chemical properties that differ from those of larger materials, and may comprise fibers and tubes in this size range^{1,2}. The green synthesis approach for nanoparticles outperforms physical and chemical procedures because it is straightforward, non-toxic, environmentally friendly, low-cost, and generates no hazardous waste³⁻⁶. This method relies on natural sources such as plants, microbes, and enzymes to reduce environmental impact and energy consumption while preserving reaction efficiency⁷⁻⁹. In a safe, biochemical process, metal ions are reduced and nanoparticles are created using biomolecules like proteins, enzymes, and phenolic chemicals¹⁰. A variety of characteristics, such as antibacterial activity, antioxidant activity, biocompatibility, and stability, make bioengineered nanoparticles appropriate for a wide range of medical applications, including drug delivery, cancer treatment, and diagnostics, as well as industrial applications because of their catalytic activity¹¹. NiO is a Nano-semiconductor with a large energy gap (3.6–4.0 eV) and distinct optical, electrical, and magnetic characteristics. It is also inexpensive, non-toxic, and employed as an excellent photo catalyst for eliminating organic contaminant^{12,13}. Numerous studies have proved its antibacterial efficacy when compounded

with various plant extracts, including aloe Vera and *Allium cepa*¹⁴⁻¹⁶. Ag NPs are among the most commonly employed nanomaterial's in medical applications due to their distinct biological features, which include antibacterial, antifungal, and antiviral activity, as well as their usage in diagnostics, drug transport, and therapy¹⁷⁻²⁰. Additionally, by boosting the generation of reactive oxygen species (ROS) and decreasing the energy gap, combining silver with NiO-Ag improves antibacterial activity and creates a synergistic effect between the two materials²¹⁻²⁴. Research has demonstrated that these Nano composites have more activity than pure NiO, with a drop in the minimum inhibitory concentration (MIC) and an increase in the inhibition zones^{23,24}. The aim of this research is to synthesize AgO NPs, NiO NPs, and NiO-AgO NCs using a green method that uses *Allium cepa* extract as a reducing and stabilizing agent, then characterize their structural and optical properties and evaluate their antibacterial activity against various bacterial strains. This work is significant because the combination of NiO and AgO is anticipated to increase antibacterial efficiency. In addition to the usage of plant extracts improves the nanoparticles' biocompatibility Applications like antimicrobial coatings, wound healing, and water purification systems. As a result, this study emphasizes the scientific and practical benefits of using green-synthesized nanomaterial's to address contemporary issues in environmental protection and healthcare.

2. Materials and Methods

2.1. Chemicals and reagents

Silver nitrate (AgNO_3) from AMICHEM LAB, India with purity reaches to 99.9%, Nickel sulfate ($\text{NiSO}_4 \cdot 6\text{H}_2\text{O}$) from THOMAS BAKER, India with purity 95% to 99% or more, NaOH, Distilled Water, and ethanol.

2.2. Preparation of *Allium cepa* extract

The fresh Onion (*Allium cepa*) were taken from the local market initially. They were properly cleaned numerous times with distilled water. The washed fruit was then dried under a parasol to completely remove moisture. The fresh Onion (*Allium cepa*) was powdered with a mechanical grinder before being stored in an airtight container. To produce the *Allium cepa* powder solution, place 100 ml of distilled water in a beaker and add 10 g of powdered *Allium cepa* plant. They are heated to 45°C for 30 minutes and constantly stirred with a magnetic stirrer. It was then cooled to room temperature. The resulting extract was initially filtered through standard filter paper Whatman No. 1 to remove any leafy debris. This *Allium cepa* extract was utilized as a reducing agent in the production of AgO NPs, NiO NPs, and NiO-AgO NCs. The surplus extract can be stored at 4 °C for future use as in **Figure 1**.

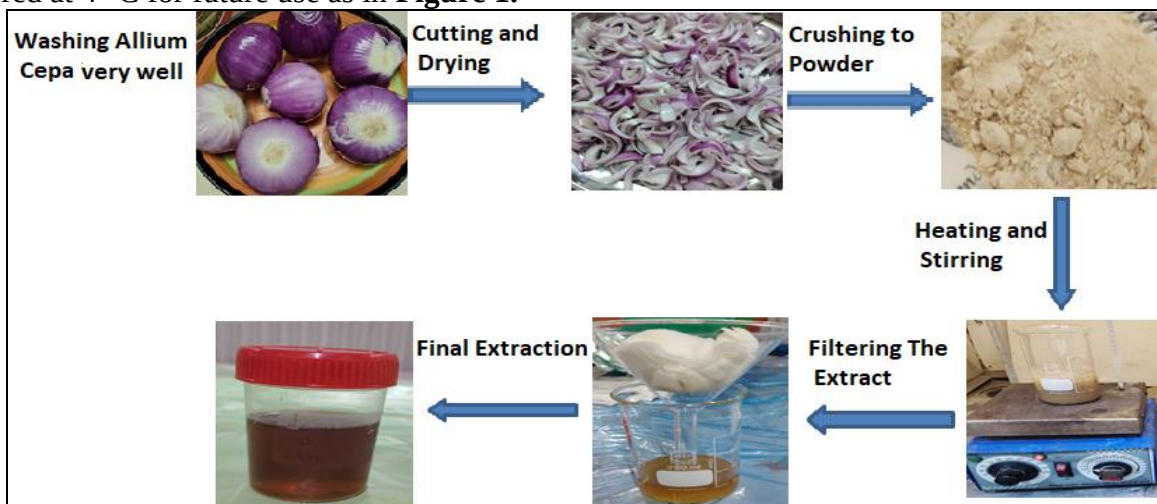


Figure 1. Schematic representation of Preparation of *Allium cepa* extract.

2.3. The preparation of the AgO and NiO NPs

Green synthesis of AgO and NiO NPs Was carried out as reported by³⁻⁵ with minor changes as in **Figure 2**. In Two Beakers of 500 mL, combine 100 mL of distilled water with 0.1 M of $\text{NiSO}_4 \cdot 6\text{H}_2\text{O}$, and 100 mL of distilled water with 0.1 M of AgNO_3 and heated them using a magnetic stirrer at 35°C for 15 minutes each separately. After that, 20 mL of *Allium cepa* plant extract was distilled using a dropper on each beaker. To adjust the pH to 12, 1 M NaOH solution was added for each beaker, and then stirred at 45°C for 30 minutes. The solution changed color to a light green and black precipitate indicating the evidence of formation NiO, AgO NPs. The solutions were stored overnight at room temperature. The NiO, AgO NPs was centrifuged and washed five times with distilled water and ethanol. Nanoparticles will be collected and dried for 1 hour at 80°C inside an oven with heated air. The precipitate was collected in two ceramic vessel and calcined in an air-heated furnace at 550°C for 1.5 hours to get NiO, AgO NPs. The Black powder of NiO NPs, and Gray powder of AgO NPs samples were used later.

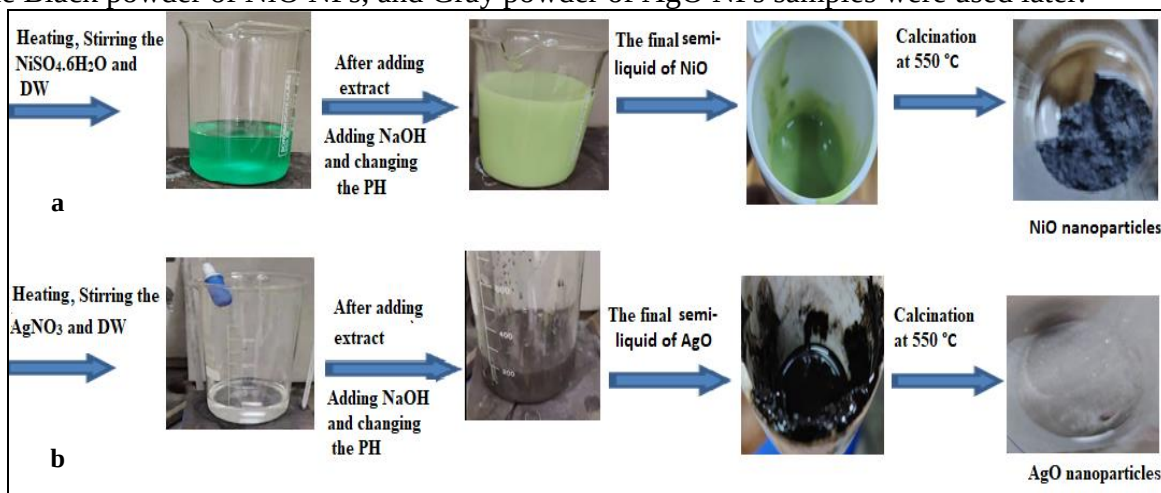


Figure 2. Schematic diagram for green synthesis of a) NiO NPs, b) AgO NPs.

2.4. Preparation of NiO-AgO NCs

Silver nitrate (1.6 g) and Nickel sulphate (2.6286 g) were separately dissolved in 100 mL of DI for each material, and were stirred for 30 min at a temperature of 45°C with a stirring speed of 1400 rpm. Then, the two solutions were mixed together. The *Allium cepa* leaf extract (10 ml) was added after 10 min in the form of drops, and the solution became pale green in color. Sodium hydroxide was added after 30 min in drops until the pH reached 11.5, and the color of the solution turned dark brown. The solution was overnight and then centrifuged to collect the precipitate. The precipitate was washed five times with (DI) and ethanol, then dried in an oven at 85°C for two hours. Finally, the dried product was calcined at 550°C for 1.5 hour as in **Figure 3**.

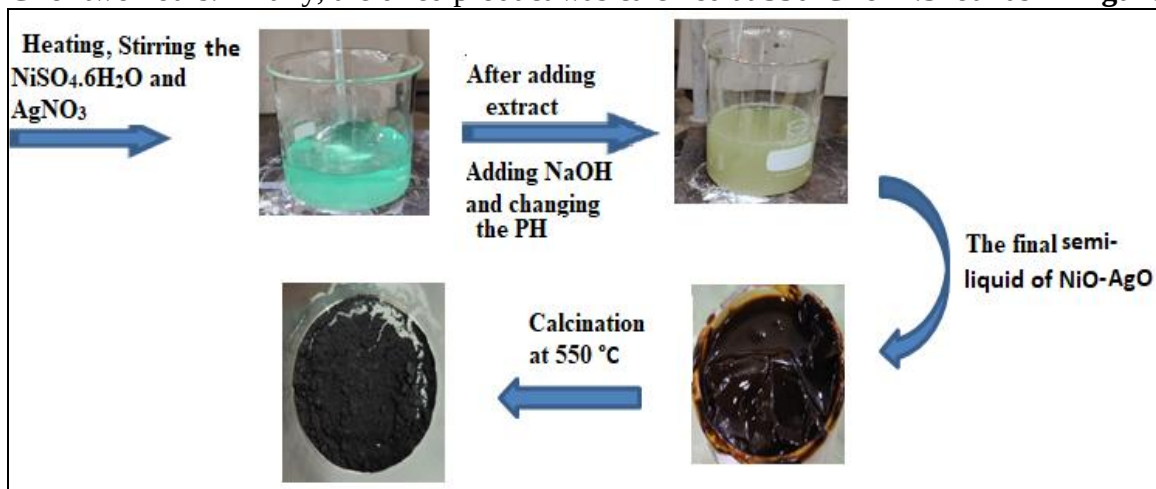


Figure 3. Schematic diagram for The green synthesis For NiO-AgO NCs.

3.Results

3.1.X-ray diffraction (XRD) analysis

X-ray diffraction (XRD) analysis is employed to determine the crystalline structure of nanoparticles, providing information about their crystallographic orientation and phase purity with (Cu K α , $\lambda = 1.5406 \text{ \AA}$). **Figure 4**, shows the XRD pattern of AgO NPs, with strong peaks at $2\theta = 38.58^\circ$ (111), 44.28° (200), 64.32° (220), and 77.40° (311). As demonstrated in **Table 1**, a face-centered cubic (FCC) structure is confirmed in accordance with JCPDS No. 00-014-0646.

Table 1. Determination of the crystalline size and structural parameters of AgO NPs, NiO NPs, NiO-AgO NCs

Phase	Miller indices (hkl)	2θ (degree)	FWHM (degree)	Crystallite size D (nm)	d-spacing [Å]
AgO	(111)	38.58	0.4428	19.0	2.333
AgO	(200)	44.28	0.7872	10.9	2.045
AgO	(220)	64.32	0.7872	11.9	1.448
AgO	(311)	77.40	0.5904	17.2	1.232
NiO	(003)	37.57	0.2952	28.4	2.394
NiO	(012)	43.54	0.2460	34.8	2.078
NiO	(104)	62.64	0.2460	37.8	1.483
NiO	(015)	75.39	0.1968	51.0	1.260
NiO-AgO	(015)	43.09	0.1476	57.9	2.098
NiO-AgO	(1010)	62.92	0.5904	15.8	1.477
NiO-AgO	(202)	75.52	0.3444	29.2	1.258

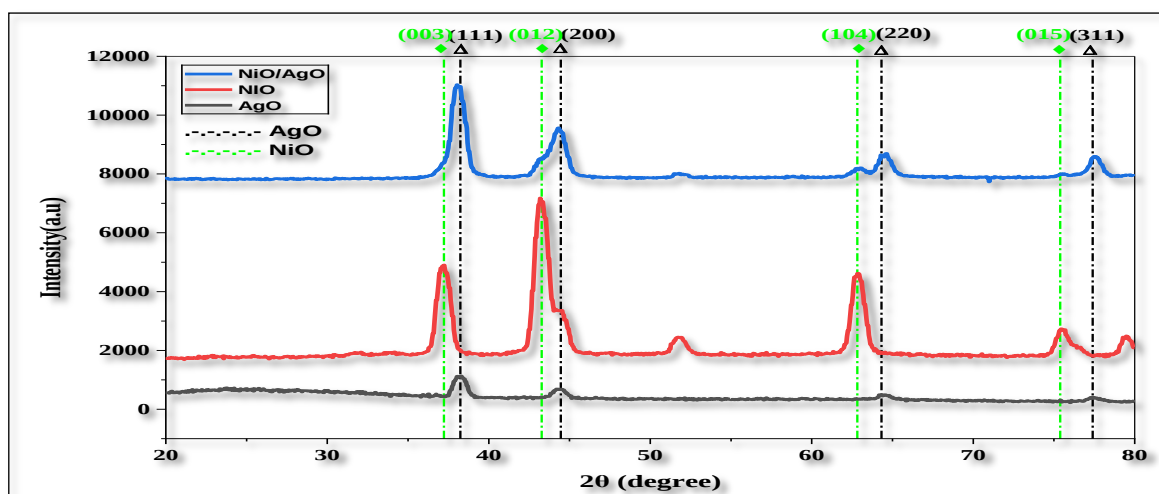


Figure 4. XRD patterns of AgO NPs, NiO NPs and NiO-AgO NCs

The Average crystallite size of AgO NPs was 14.75 nm which calculated using Scherer Equation1:

$$D = K \lambda / \beta \cos \theta \quad (1)$$

where D = crystal size (nm or Å), $K \approx 0.9$ (form factor), θ = the Bragg diffraction angle, and β = the full width at half maximum of the diffraction peaks (FWHM) in radians. Also, **Figure 4** shows an XRD diagram of The NiO NPs, This demonstrates a variety of lattice planes at 2θ values, such as 37.57° (003), 43.54° (012), 62.64° (104), and 75.39° (015).

As demonstrated in Table 1. There is a weak peak for NiO between 50° - 60° , with a value of roughly 52.1° (202), which is caused by crystal tension, small particle size, flaws, or superposition with another phase; thus, this peak is not regarded a typical main peak. All measured peaks were consistent with the Data Card, (JCPDS) No. 00-022-1189. The Scherrer equation was used to calculate the average crystallite size of NiO NPs, which was around 38 nm. Besides, in **Figure 4**, NiO-AgO NCs showed sharp peaks at $2\theta = 43.09^\circ$ (015), 62.92° (1010),

and 75.52° (202) As seen in **Table 1**, which are in line with JCPDS No. 01-082-0007. Due to AgO inclusion into the NiO lattice, which creates phase barriers and lattice strain and limits crystal development, the average crystallite size dropped to 36.4 nm. According to the Scherrer equation, an increase in the FWHM mathematically proves a decrease in crystallite size. This interfacial strain resulting from the variations in ionic radii and lattice constants between Ag and Ni is reflected as peak broadening in the XRD patterns, verifying smaller crystallite domains.

3.2. Energy Dispersive X-ray (EDX) Analysis

The samples' elemental composition was determined using energy dispersive X-ray spectroscopy (EDX). **Figure 5a** shows that AgO NPs contain a high concentration of oxygen and silver, as well as minimal amounts of nickel and zinc, indicating minor impurities. **Figure 5b** verifies NiO NPs, primarily consisting of nickel and oxygen, with minor quantities of zinc and silver, most likely from preparation or doping. These extra elements may improve optical, electrical, or catalytic properties while maintaining the material's essential makeup. In NiO-AgO NCs, the **Figure 5c**, EDX indicates oxygen, nickel, and silver, confirming the creation of a double oxide system with AgO as the dominating phase. These findings show that a molecule with a significant oxide character was successfully prepared, potentially improving the sample's physicochemical characteristics.

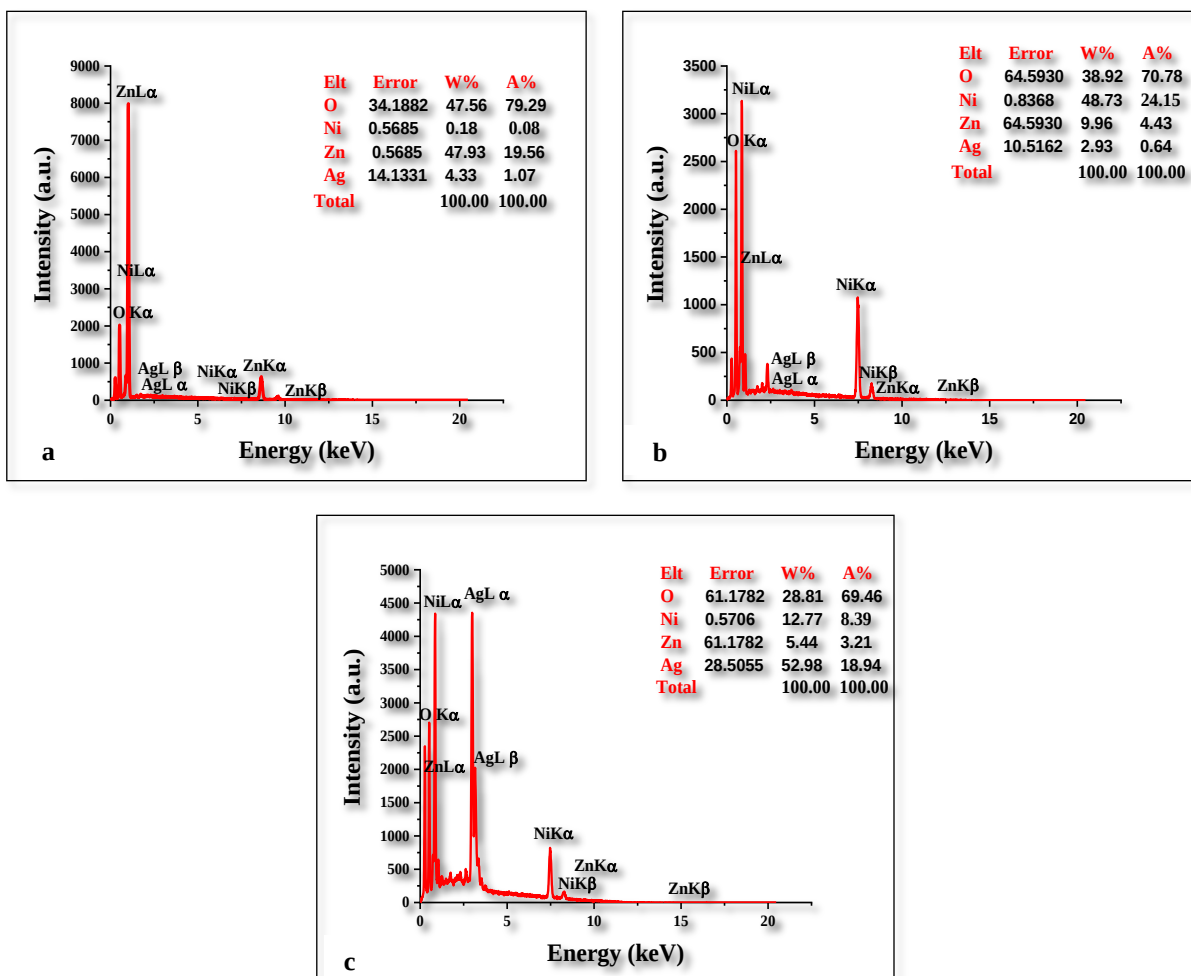


Figure 5. EDX Spectroscopy of **a-** AgO NPs, **b-** NiO NPs, **c-** NiO-AgO NCs .

3.3. Ultraviolet-visible (UV-Vis) analysis

The optical characteristics of AgO NPs, NiO NPs, and NiO-AgO NCs in the 300–800 nm range were investigated using ultraviolet-visible (UV-Vis) spectroscopy, as seen in **Figure 6**. Due to charge-transfer transitions between O_2 and Ag_2 ions, AgO NPs exhibit a significant absorption peak in the deep UV range (180–220 nm), with little absorption in the visible and near-infrared

areas, suggesting a wide band gap. In line with a broad-band gap semiconductor, NiO NPs show two UV peaks (180–220 nm and 300–360 nm) from d–d transitions and $\text{Ni}^{2+}\text{--O}^{2-}$ charge-transfer, with little visible absorption. According to this behavior, NiO is a broad-band gap semiconductor with low absorption in the visible light region and high absorption only in the UV. According to XRD and FE-SEM data, NiO-AgO NCs exhibit a UV peak at 180–220 nm, stable low absorption in 350–700 nm, and a gradual increase in the NIR region (750–1080 nm), which reflects electronic coupling between NiO and AgO, the creation of new energy levels, an increased band gap, and a decreased crystallite size. The relationship-based Tauc Plot approach was used to calculate the optical band gap as in **Figure 7a**:

$$\alpha h\nu = A(h\nu - E_g)^n \quad (2)$$

In this equation, α represents the absorption coefficient, $h\nu$ represents photon energy, and A is a material-specific constant. This study employed the exponent $n = 2$ to indicate that the electron transition in the sample is an indirect permitted transition.

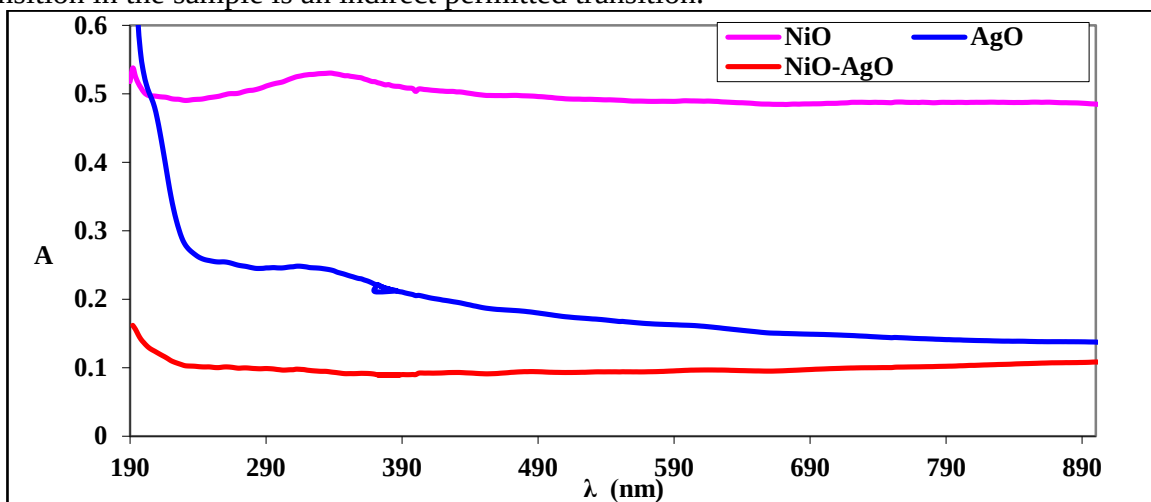


Figure 6. Absorption spectrum of AgO NPs, NiO NPs, NiO-AgO NCs.

The optical energy gap of AgO NPs was 3.11 eV as shown in **Figure 7a**, which is larger than the standard value. This increase is due to the nanoparticles' plasmonic activity, which enhances electronic transitions at higher energies and increases the apparent band gap. This suggests that the sample has optical properties that are appropriate for photonic applications such as optical sensing, solar cell absorption enhancement, and photo catalytic antibacterial activity. The Tauc relation was used to calculate the energy gap for NiO NPs from the UV–Vis spectra, and the result was roughly 3.08 eV as in **Figure 7b**.

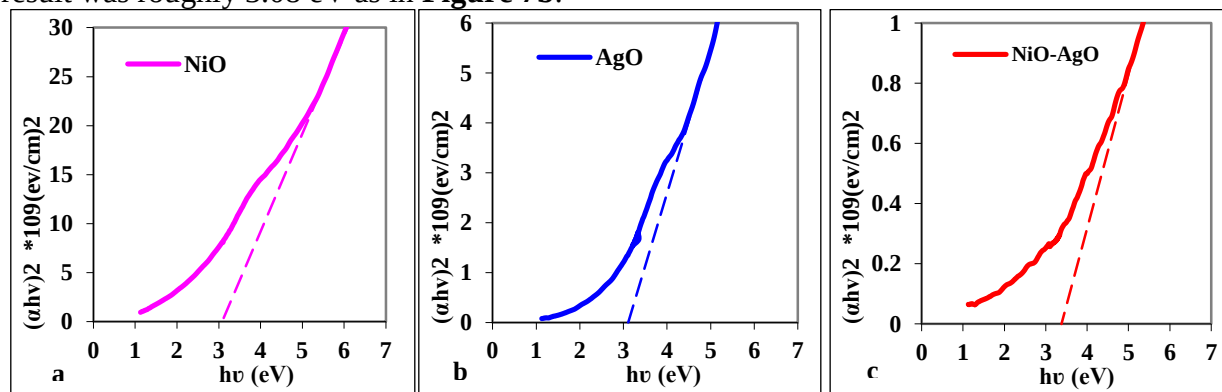


Figure 7. Energy gap of a. NiO NPs, b. AgO NPs, c. NiO-AgO NCs.

This number highlights the material's wide-band gap features and indicates the beginning of optical electronic transitions, which makes it useful for optical and electronic applications that need stable optical qualities. After synthesizing AgO-NiO NCs, the energy gap was around 3.38

eV as seen in **Figure 7c**, showing that optical electronic transitions began in the composite after mixing AgO and NiO NPs. This also represents the effect of mixing on the sample's electronic structure, which may improve its optical and electrical properties. These results demonstrate that adding AgO NPs improves NiO's optical characteristics as well as electrical transitions, making the composite appropriate for wide-band gap optoelectronic applications.

3.4. Infrared Spectroscopy FTIR Analysis

Fourier transform infrared spectroscopy was used for the identification of the functional groups present on the synthesized AgO NPs, as shown in **Figure 8a** and **Table 2**. In **Figure 8a**, AgO NPs exhibit a broad band at $3400\text{--}3500\text{ cm}^{-1}$, indicating surface hydroxyl groups or adsorbed water according to **Table 2**. Water's H-O-H bending vibrations are responsible for the peak at $1630\text{--}1650\text{ cm}^{-1}$, whereas C-N vibrations cause the bands at $1450\text{--}1380\text{ cm}^{-1}$. Weak peaks at $2920\text{--}2850\text{ cm}^{-1}$ indicate aliphatic C-H stretching, while peaks at $1100\text{--}1000\text{ cm}^{-1}$ relate to C-O or C-O-C vibrations, indicating reducing residues. Strong peaks between $400\text{--}600\text{ cm}^{-1}$ confirm Ag-O bond vibrations and validate the production of AgO. While in **Figure 8b**, the Fourier Transform Infrared (FT-IR) spectrum of the NiO specimen shows O-H stretching at $3400\text{--}3500\text{ cm}^{-1}$ indicates surface hydroxyl groups or adsorbed water, while H-O-H bending at $1630\text{--}1650\text{ cm}^{-1}$ as shown in **Table 2**. Weak C-H stretching at $2920\text{--}2850\text{ cm}^{-1}$ indicates trace organic residues, while C-O stretching occurs at $1100\text{--}1000\text{ cm}^{-1}$. Peaks between $400\text{--}600\text{ cm}^{-1}$ correspond to Ni-O and Ag-O bond vibrations, demonstrating binary compound production and oxide lattice interaction. However, **Figure 8c** illustrates the FT-IR spectrum of NiO-AgO NCs, which reveals a broad band at $3400\text{--}3500\text{ cm}^{-1}$ due to O-H stretching vibrations of adsorbed water or surface hydroxyl groups. A band at $1600\text{--}1650\text{ cm}^{-1}$ indicates H-O-H bending in water molecules. Surface impurities, including carbonates, C-O, and N-O groups, cause peaks at $1400\text{--}1500\text{ cm}^{-1}$ and $1000\text{--}1200\text{ cm}^{-1}$, respectively as seen in **Table 2**. The composite contains both Ni-O and Ag-O bond vibrations, as seen by strong peaks at $450\text{--}550\text{ cm}^{-1}$ and $500\text{--}650\text{ cm}^{-1}$. As a result, the spectrum verifies the existence of a combination of AgO NPs and NiO NPs with adsorbed surface groups such carbonates and water.

Table 2. FTIR measurements for AgO NPs, NiO NPs, and NiO-AgO NCs.

Band type NPs	AgO NPs (cm^{-1})	NiO NPs (cm^{-1})	NiO-AgO NCs (cm^{-1})
O-H	~ 3400	~ 3430	$3400\text{--}3500$
C-H	$\sim 2850\text{--}2900$	$\sim 2850\text{--}2920$	$1600\text{--}1650$
C=O /H-O-H bending	$\sim 1650\text{--}1620$	$\sim 1650\text{--}1630$	$1400\text{--}1500$
C-N/N-H aromatic	$\sim 1300\text{--}1400$	$\sim 1300\text{--}1380$	$1000\text{--}1200$
C-O/C-O-C	$\sim 1000\text{--}1130$	$\sim 1020\text{--}1100$	$500\text{--}600$
Metal-O (Ag-O, Ni-O, Ag-O-Ni-O)	(Ag-O) $\sim 430\text{--}500$	(Ni-O) $\sim 480\text{--}520$	$450\text{--}550$

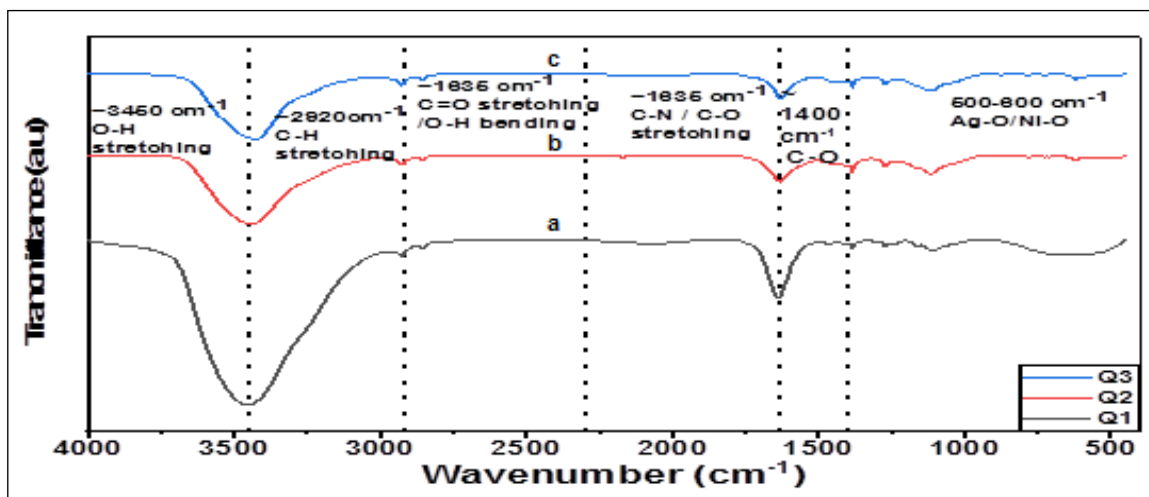


Figure 8. FTIR spectrum of: a. AgO NPs, b. NiO NPs, c. NiO-AgO NCs.

3.5.Zeta potential

Zeta potential analysis was used to determine the surface charge and stability of nanoparticles produced from *Allium cepa* leaf extract. The average zeta potentials of AgO NPs were -29.1 mV (moderate to good stability), -22.6 mV for NiO NPs, and -21.3 mV for NiO-AgO NCs. Compared to AgO, NiO and the composite had lower negative values, indicating lesser electrostatic stability and higher aggregation potential. As seen in **Figure 9**, the small drop in negative charge during composite creation indicates that silver alters surface charge locations, lowering electrostatic repulsion while maintaining high particle stability.

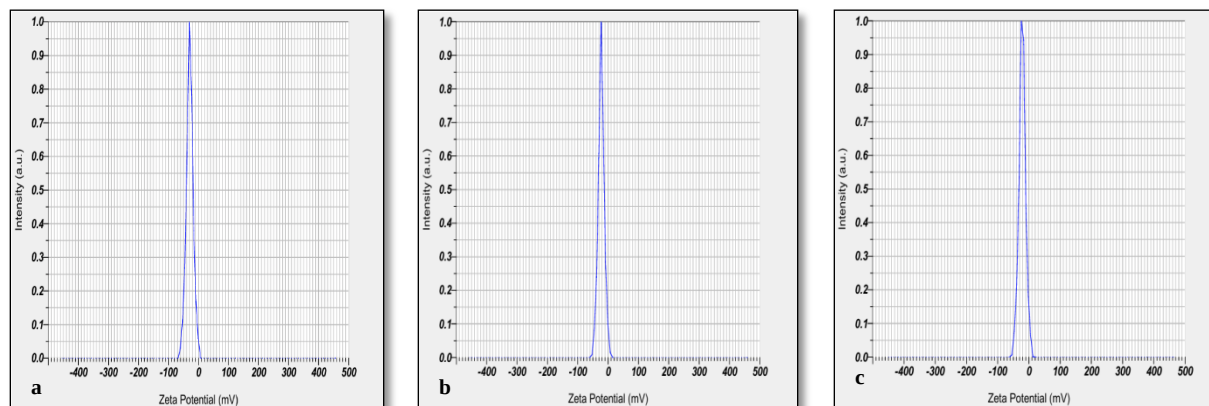


Figure 9. Zeta potential for **a)** AgO NPs, **b)** NiO NPs, **c)** NiO-AgO NCs.

3.6.FE-SEM

Field Emission Scanning Electron Microscopy FE-SEM was used to carefully investigate the shape, surface morphology and crystallinity of the obtained NiO, AgO and NiO-AgO nanoparticles. **Figure 10** shows that the FE-SEM images for, AgO NPs, and NiO-AgO NCs contained small spherical particles with uniform distribution with an average size of 75.56nm and 51.57nm and stander deviation of 27.06 and 14 .68 respectively.

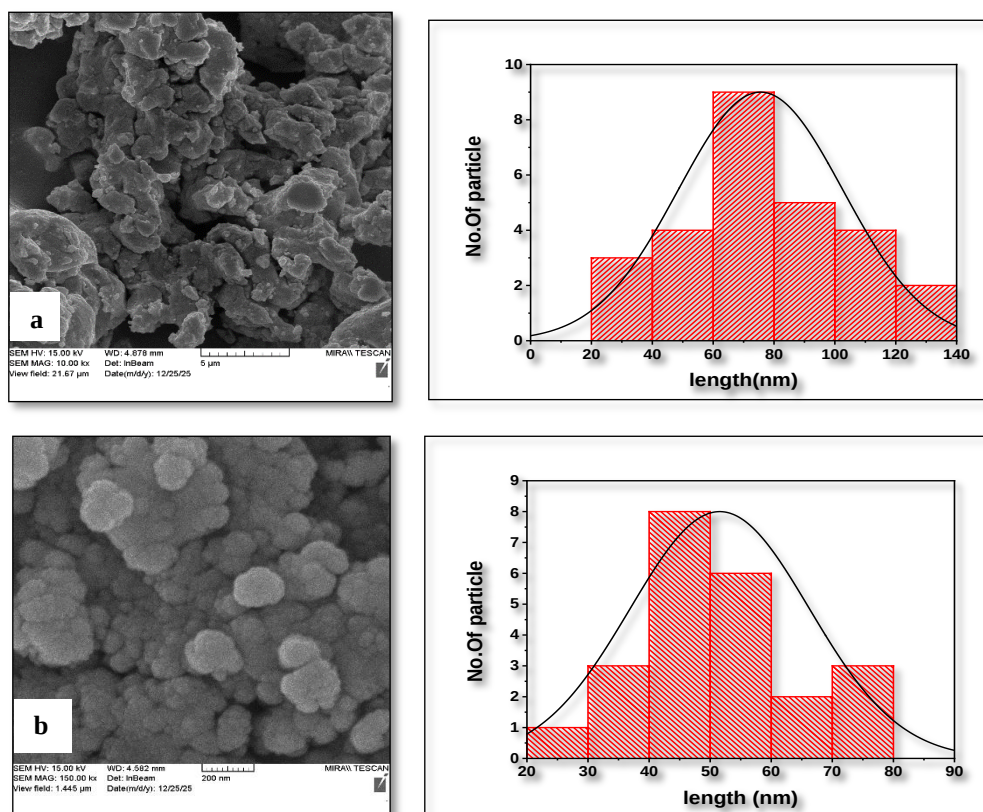


Figure 10. FESEM of **a-** AgO NPs, **b-** NiO-AgO NCs.

Crystals have greater ability to grow in a single-oxide system, but in a composite system, the two phases serve as barriers. NiO crystals rapidly come into contact with AgO grains as they develop, which restricts lattice growth and results in smaller, more polished crystallites. When both Ag^+ and Ni^{2+} ions are present, the onion extract's phytochemicals—such as quercetin and phenolic—act as reducing and capping agents, boosting nucleation sites. Smaller sizes arise from each crystal having less material to grow when there are more nuclei. The extract's biomolecules attach to the surfaces of the particles, and in the composite, the interaction of two oxides intensifies this "pinning" effect, preventing coalescence and producing distinct, smaller particles shown in FESEM.

3.7. Antibacterial activity

The antibacterial activity of green-synthesized AgO NPs, NiO NPs, and NiO-AgO NCs was tested against Gram-positive and Gram-negative microorganisms. Each sample's suspension was made at 100 mg/mL and diluted to 50, 75, and 100 mg/mL using the equation ($C_1 \times V_1 = C_2 \times V_2$). As demonstrated in **Figure 11**, all samples had antibacterial activity, which varied with concentration and composition. Because there were fewer surface contact sites, AgO NPs exhibited limited action at 100% concentration, with inhibition zones of about 10 mm for both *S. aureus* and *E. coli*. Due to increased surface activity and the production of reactive oxygen species (ROS), NiO NPs showed greater activity, with inhibition zones of 16 mm against *E. coli* and 12 mm against *S. aureus*.

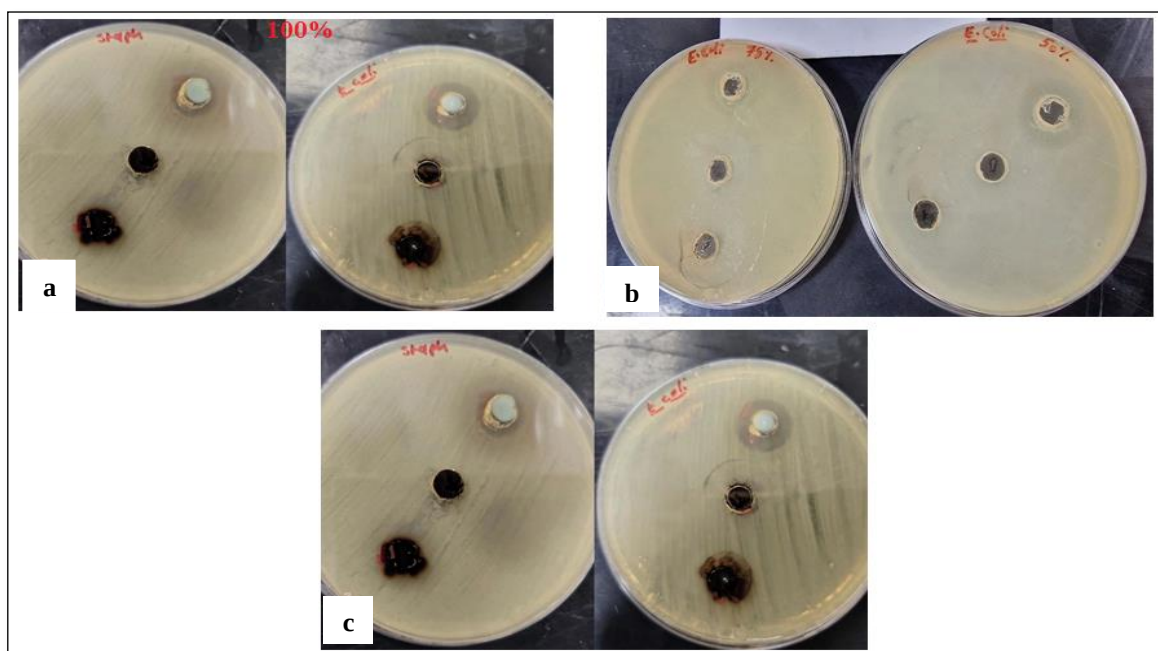


Figure 11. Antibacterial activity of AgO NPs, NiO NPs, NiO-AgO NCs.

Because of the synergistic action of AgO (increased contact and charge transfer) and NiO (greater surface activity and ROS production), NiO-AgO NCs showed the strongest antibacterial efficacy at 100% concentration, with inhibition zones of 21 mm for *E. coli* and 15 mm for *S. aureus*. *E. coli* was more sensitive than *S. aureus*, most likely due to Gram-negative bacteria's weaker peptidoglycan coating, which allows for higher nanoparticle penetration. Concentrations of 50% to 75% resulted in greater inhibition zones, with NiO-AgO NCs reaching maximum zones of ~28 mm (*E. coli*) and 27 mm (*S. aureus*). Higher concentrations boost the number of active nanoparticles, accessible surface area, ROS production, and ion release. The inhibition values are shown in **Table 3**.

Table 3. Antibacterial activity of the green synthesized **A)** AgO NPs, **B)** NiO NPs and **C)** NiO-AgO NCs against Gram negative bacteria (*S.aureus*, *E.coli*).

Samples	Conc. (in mg/mL)	<i>E. coli</i> (mm)	<i>S.aureus</i> (mm)
[A] AgO NPs	100%	10	10
	75%	12	12
	50%	13	10
[B] NiO NPs	100%	16	12
	75%	12	13
	50%	10	17
[C] NiO-AgO NCs	100%	21	15
	75%	20	26
	50%	28	27

4.Disscusion

In this study, AgO NPs, NiO NPs, and NiO-AgO NCs were successfully synthesized utilizing onion extract as a reducing and stabilizing agent. The characterization results indicated the synthesis of crystalline nanoparticles with increased characteristics¹⁻²⁴. XRD research demonstrated that all samples had strong crystallinity; AgO had crisp diffraction peaks suggesting great phase purity, whereas NiO showed its characteristic peaks as well as a weak extra peak owing to lattice strain or crystal defects. The NiO-AgO NCs showed diffraction peaks for both oxides, indicating that the composite was successfully formed. EDX analysis confirmed the elemental composition of the samples, with AgO consisting primarily of Ag and O, NiO of Ni and O, and the composite of Ni, Ag, and O, with minor trace elements attributed to the green synthesis method without changing the structure. UV-Vis spectra revealed strong ultraviolet absorption, with calculated band gap values of 3.11 eV for AgO, 3.08 eV for NiO, and 3.38 eV for the NiO-AgO NCs, indicating wide band gap semiconductor behavior. The composite's increased band gap is attributed to reduced particle size and electronic interaction between the two oxides. FTIR analysis confirmed the presence of distinctive Ag-O and Ni-O bonds, indicating that oxide production was successful. Broad O-H bands were also found, which corresponded to adsorbed water and hydroxyl groups. The presence of C-H and C-O functional groups comes from the onion extract employed in green synthesis, indicating the importance of biomolecules as reducing and capping agents that stabilize nanoparticles and prevent aggregation. Zeta potential values for AgO NPs, NiO NPs, and NiO-AgO NCs were -29.1 mV, -22.6 mV, and -21.3 mV, respectively. NiO and the composite showed lower negative values than AgO, suggesting a small decrease in electrostatic stability and an increased propensity for aggregation. The minor drop in negative charge that occurs during the production of the composite indicates that the addition of silver modifies the distribution of surface charges, so reducing electrostatic repulsion while preserving high overall particle stability. FE-SEM images indicated nanoparticles that were primarily spherical and uniformly dispersed, with the composite having lower particle sizes than pure NiO due to enhanced nucleation sites and crystal development inhibition by biomolecules serving as capping agents. The antibacterial results showed that the NiO-AgO NCs had much better activity against *E. coli* and *S. aureus* than individual AgO and NiO NPs, with a stronger effect against *E. coli* due to its thinner cell wall structure. The synergistic combination between AgO, which increases membrane permeability and ion release, and NiO, which encourages the production of reactive oxygen species (ROS), is responsible for this improved antibacterial activity. The remarkable potential of the NiO-AgO NCs for biomedical applications was further demonstrated by the fact that increasing nanoparticle concentration led to a considerable improvement in antibacterial activity for all samples due to increased surface area, ion release, and ROS formation.

5. Conclusion

By the present study, that we investigate an environmentally friendly, economical, and energy-efficient production of The AgO NPs, NiO NPs and bimetallic AgO-NiO Nano composite using *Allium cepa* The Leaf Extraction. This environmentally friendly method is made easier by the plant extract's bioactive components, including phenols and flavonoids. In addition to confirming the successful synthesis of AgO NPs, NiO NPs, and AgO-NiO NCs, Techniques for structural and optical characterization revealed details about their size and morphology. The FTIR, UV-Vis, and XRD analyses revealed the production of crystalline nanostructures with distinctive morphologies and optical characteristics. NiO-AgO NCs demonstrated the highest antibacterial activity among the produced materials, notably against Gram-negative *Escherichia coli*, which could be due to their simpler cell wall construction. Importantly, the usage of *Allium cepa* leaf extract was found to be not only ecologically benign but also more successful than other plant-based extracts reported in literature, such as neem and aloe vera, emphasizing its originality and promise as a green synthesis agent. These findings have implications for the use of such nanomaterial's in biomedical disciplines, particularly in the production of antibacterial drugs or coatings. Future research should focus on in vivo evaluations, long-term stability, and antibacterial activity mechanisms in order to promote therapeutic applications.

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Conflict of Interest

The authors declare that they have no conflicts of interest.

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Ethical Clearance

This study does not involve human or animal subjects, therefore ethical approval is not required.

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