

Comparative Structural, Optical, Morphological and Elemental Characterisation of Jujube-Mediated Silver and Zinc Oxide Nanoparticles

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ABSTRACT

Plant extracts offer a practical route for nanoparticle synthesis because naturally occurring compounds can participate in particle formation and remain associated with the resulting material. In this study, jujube extract was used to prepare silver nanoparticles (AgNPs) and zinc oxide nanoparticles (ZnO NPs). Both products were examined using the same set of characterization techniques: X-ray diffraction (XRD), Fourier-transform infrared spectroscopy (FTIR), ultraviolet-visible (UV–Vis) spectroscopy, scanning electron microscopy (SEM), and energy-dispersive X-ray spectroscopy (EDX). The XRD results clearly differentiated the two materials. The Ag sample showed peaks at approximately 38.27°, 44.45°, 64.55°, and 77.57°, characteristic of face-centered-cubic Ag, while the ZnO sample displayed reflections at 31.91°, 34.55°, 36.38°, 47.60°, 56.78°, and 63.02°, consistent with hexagonal wurtzite ZnO. FTIR spectra from both samples contained bands associated with plant-derived functional groups, along with low-wavenumber features related to their respective inorganic phases. Their optical responses were also distinct. Ag showed the characteristic response of metallic nanoparticles, whereas ZnO exhibited an optical edge at about 392.5 nm, corresponding to approximately 3.16 eV. This value was calculated from the optical-edge wavelength and is not presented as a formal Tauc band gap. SEM images showed rough, uneven, and strongly aggregated surfaces in both samples. EDX further showed strong Ag signals in the silver sample and Zn and O as the main detected elements in the ZnO sample. Overall, the study compares two different nanomaterials produced using the same jujube-based approach and shows how their structural, optical, morphological, and elemental characteristics differ.

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INTRODUCTION

The metabolites naturally available in plant extracts can be involved in the metal-ion reduction, nucleation, growth control, and surface stabilization processes, which are now a source of study for the synthesis of inorganic nanomaterials. It has recently been shown that plant-mediated pathways produce crystalline Ag and ZnO and that there are measurable quantities of organic species on the particle surfaces (Islam et al., 2024; Peta & Singh, 2025; Aliannezhadi et al., 2024; Abdelbaky et al., 2023; Mushtaq et al., 2023; Al-Askar et al., 2023). The growing body of literature also demonstrates that the crystallinity, morphology, and optical behavior of the final material are not solely dependent upon the botanical name but rather on the composition of the extract, the precursor chemistry, pH, temperature, reaction time, and post-synthesis treatment (Zulfiqar et al., 2024; Akhter et al., 2024; Thomas et al., 2024; Dos Santos et al., 2026; Jadoun et al., 2024; Kharde et al., 2024).

The comparison of silver and ZnO is very useful because they are in different electronic and structural regimes. The optical properties of ZnO are typically described in terms of its near-ultraviolet absorption edge (Dhir et al., 2024; Alharbi et al., 2023; Alotaibi et al., 2024; Mehrotra et al., 2024; Sundar et al., 2024; Konappa et al., 2025), while the collective electronic behavior of metallic Ag at the nanoscale is the one that governs. Thus, a characterization process is not necessarily identical for both materials, even if the process itself is the same. In recent Ag studies, the UV–Vis along with XRD, FTIR, SEM, and EDX are often combined, and in

studies of ZnO, similarly, the UV–Vis is often coupled with surface or thermal analysis. In recent Ag studies, the UV–Vis is often coupled with XRD, FTIR, SEM, and EDX, and in studies of ZnO, the UV–Vis is often coupled with additional surface or thermal analyses (Thomas et al., 2024; Dos Santos et al., 2026; Jadoun et al., 2024; Kharde et al., 2024; Dhir et al., 2024; Alharbi et al., 2023; Alotaibi et al., 2024; Mehrotra et al., 2024; Sundar et al., 2024; Konappa et al., 2025; Vidyasagar et al., 2024; Ibrahim et al., 2024; Al-darwesh et al., 2024; Mohsen Ali et al., 2026; Fatima et al., 2026; Bhattacharjee et al., 2026; Palanivel et al., 2026).

Recent reports (2023–2026) have documented plant-mediated silver (Ag) prepared from *Salvia officinalis* (Takcı et al., 2023; Karan et al., 2023; Veera et al., 2023; Mishra et al., 2024; Islam et al., 2024; Mousa et al., 2024; Adhavan et al., 2024; Tiwari et al., 2024; Bekele et al., 2024; Singh et al., 2024; Pugazhenthiran et al., 2024; Dafalla et al., 2025; Khattak et al., 2024), *Sambucus ebulus* [29–31], *Corallocarpus epigaeus*, and *Ocimum sanctum*, as well as zinc oxide (ZnO) obtained from onion peel and ginger. These studies define the scope of the field but also show a common weakness: Ag and ZnO are commonly studied as two separate classes of materials, and when both materials are grown in the same plant, the comparison is often made in terms of biological performance and not a common structure–surface–optical–morphological–elemental analysis (Sharma et al., 2025; Barretto et al., 2025; Sivakumar et al., 2025; Rathi et al., 2025).

The main objective of the present research is to fill this gap with a design approach that deliberately compares. Jujube is regarded as a common botanical platform, and Ag and ZnO are considered two different material systems. The goal of this work is not to compare the two materials but rather to characterize the differences in their experimentally observed phase, surface chemistry, optical response, morphology, and elemental composition when applying a common green-synthesis concept.

This distinction is important because a plant-mediated route should not be interpreted as producing a generic class of 'green nanoparticles'; it produces a material whose behaviour remains controlled by its intrinsic composition and structure (Nayel et al., 2025; Shinde et al., 2025; Elias et al., 2025; Dagher et al., 2025).

Aim of the study. The aim of this study is to compare jujube-mediated Ag and ZnO nanoparticles using XRD, FTIR, UV-Vis spectroscopy, SEM and EDX, and to relate the observed differences in crystal structure, surface-associated chemistry, optical response, morphology and elemental composition within the same botanical framework. The resulting contribution is therefore a five-level comparison rather than a routine synthesis report. Recent literature has already demonstrated that both Ag and ZnO can be obtained by plant-mediated routes, and some studies have produced both from a single botanical source (Shrestha et al., 2025; Gökderer et al., 2025; Bimal et al., 2026; Umar et al., 2026). The present work moves beyond that precedent by placing the two products on matched analytical scales and by interpreting each measurement according to the physics and chemistry of the corresponding material.

Research Gap and Novelty

The central gap is comparative rather than synthetic. The literature contains many individual green-synthesis reports, but fewer studies are designed around a common botanical platform in which a metallic nanophase and a semiconductor nanophase are evaluated through the same five complementary measurements. A direct comparison is especially valuable when SEM and EDX are considered alongside XRD, FTIR and UV-Vis, because morphology and

elemental composition provide constraints on interpretations that cannot be obtained from spectroscopy alone.

The present study is novel in three respects. The botanical reference is firstly the same concept of jujube-derived synthesis. The inorganic products are chemically different. Second, the comparison is constructed over five levels of characterization and not a single property. Third, the SEM comparison is performed at matched magnification and scale-bar ranges, 1.00 kX/50 μm , 5.00 kX/10 μm and 15.0 kX/3 μm , to prevent confusing differences in aggregation and surface organization with differences in imaging scale. The novelty must therefore be interpreted as a structured comparison of two nanoworlds built from one botanical platform. The plant-mediated Ag or ZnO synthesis itself is not claimed to be new. The contribution is scientifically defensible. The comparative framework is the central message.

MATERIALS AND METHODS

The experimental characterization records supplied for this study were used as the basis for reporting the results. Published data were not used to replace experimental measurements or to obtain numerical values. Only published literature was consulted to provide background and to compare the current observations with previously published literature.

Characterization Workflow

The order of the analysis was arranged in a way that each technique was focused on a part of the nanoparticles. The crystalline phases were identified using XRD, and the functional groups on the nanoparticle surfaces were characterized by FTIR. The optical response was studied by UV-Vis spectroscopy, and the morphology and degree of aggregation at the length scales examined were studied by SEM. The elements present in the studied regions were determined by EDX. Such division of roles helps to guarantee that the conclusions are drawn from the most appropriate technique for the corresponding property. The comparative analysis procedure is based on five characterization techniques and is shown step-by-step in Figure 1.

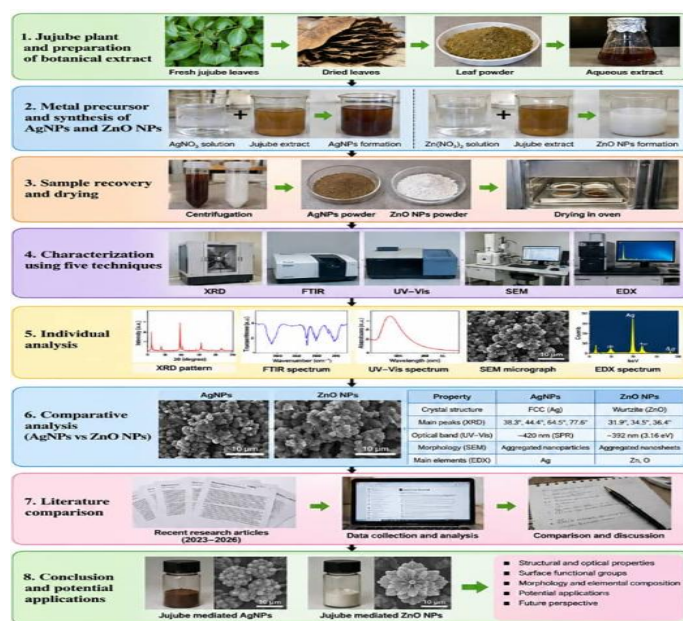


Figure 1: Methodology Flowchart for the Comparative Five-technique Analysis

XRD Analysis

The provided diffraction highest were assigned by comparison with the characteristic reflections of fcc Ag and hexagonal wurtzite ZnO. Apparent coherent-domain dimensions were estimated with the Scherrer relation using Cu K α radiation ($\lambda = 1.5406 \text{ \AA}$) and $K = 0.9$. Because independent instrumental broadening was not available, these values are treated as apparent coherent-domain estimates rather than direct particle diameters, consistent with current characterization practice (Al-darwesh et al., 2024), (Mousa et al., 2024).

FTIR and UV–Vis Analysis

FTIR spectra were examined for broad O–H/N–H contributions, carbonyl or other oxygenated organic groups, fingerprint-region bands and low-wavenumber metal/metal–oxygen features. UV–Vis spectra were interpreted according to the material class. The ZnO optical edge was estimated

from the supplied spectrum at approximately 392.5 nm and converted using $E = 1240/\lambda$, giving approximately 3.16 eV. This is described as an optical edge rather than a formal Tauc band gap because the supplied data did not independently establish an absorption quantity and path length.

SEM and EDX

The images obtained were not sufficient to resolve individual particles sufficiently enough to allow a defensible particle-size distribution to be obtained. Thus, only morphology, surface texture, and aggregation could be examined with SEM. The Ag and ZnO were compared at the same three magnification/scale bar levels. The results of EDX were reported from the instrument output. The elemental percentages are normalized values and should not be interpreted as a stoichiometric proof or as a proof for lattice incorporation, oxidation state, or doping.

RESULTS AND DISCUSSION

XRD Reveals Two Distinct Crystalline Materials

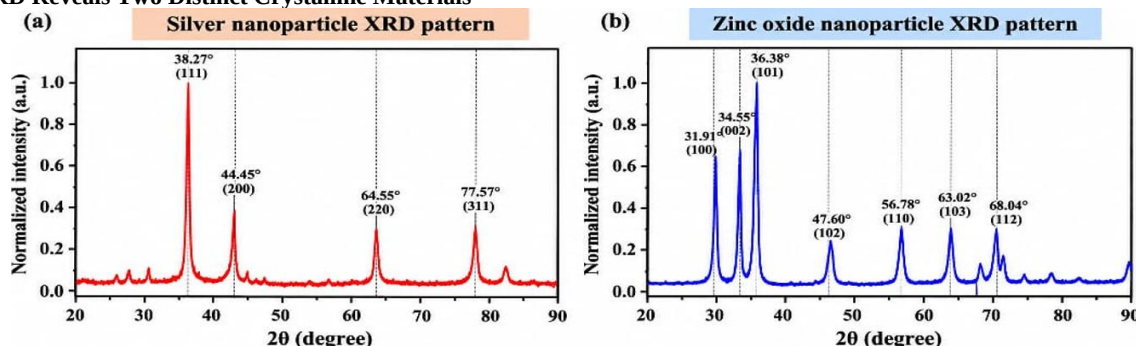


Figure 2: Comparative XRD Patterns of (a) Jujube-mediated AgNPs and (b) Jujube-mediated ZnO NPs

The crystalline nature, phase identification and structural properties of the jujube mediated Ag and ZnO nanoparticles were established by X-ray diffraction. This analysis is important for the present comparative study because the formation of essentially different crystalline phases is expected for both Ag and ZnO, which are synthesized from the same botanical source. The diffraction profiles thus allow a direct comparison of the metallic Ag phase and the oxide ZnO phase and a study of the characteristic reflections of the phases. In the case of Ag, the principal reflections associated with the face-centered cubic (fcc) structure are highlighted while the ZnO pattern is examined in the context of the characteristic reflections of the hexagonal wurtzite ZnO structure. The location and intensity of the reflections are also taken into account as a possibility of the crystalline nature of the synthesized materials. The XRD patterns of the jujube-mediated Ag and ZnO nanostructures are shown in Figure 2, which permits the structural differences of them to be compared on a common basis.

The silver Nanoparticles (AgNPs) pattern comprises principal reflections near 38.27°, 44.45°, 64.55° and 77.57°, corresponding to the fcc Ag (111), (200), (220) and (311) planes. The ZnO pattern is structurally different, with reflections near 31.91°, 34.55°, 36.38°, 47.60°, 56.78° and 63.02°, consistent with hexagonal wurtzite ZnO. The contrast is important because the two products are not variants of the same crystal system; they represent an elemental metal and a metal oxide with different bonding and electronic structures. Considering of figure 2, the dominant Ag (111) reflection and the characteristic sequence of higher-angle Ag peaks establish a crystalline metallic Ag phase in the supplied sample. The ZnO pattern, in contrast, contains the expected low-angle

wurtzite sequence, with the prominent feature near 36.38° associated with the (101) plane. The absence of an obvious Ag reflection in the ZnO pattern and the absence of a ZnO sequence in the Ag pattern support treating the two products as separate phases rather than as an Ag-doped ZnO composite. This interpretation is consistent with recent green-synthesis reports in which fcc Ag and wurtzite ZnO are independently identified by XRD (Takcı et al., 2023), (Karan et al., 2023), (Adhavan et al., 2024), (Bekele et al., 2024).

The apparent coherent-domain values calculated from the supplied ZnO peaks fall roughly in the 168–214 nm range. These values should not be called particle sizes. The SEM images later in this paper show agglomerated structures at the micrometre observation scale, demonstrating why diffraction-domain estimates and morphological particle dimensions must be kept conceptually separate.

FTIR Separates Shared Botanical Surface Chemistry from Phase-specific Vibrations

FTIR spectroscopy was employed to examine the surface-associated functional groups retained on the synthesized nanoparticles and to assess the possible involvement of phytochemical constituents from the jujube extract during nanoparticle formation. In plant-mediated synthesis, biomolecules present in the extract may participate in the reduction, complexation, nucleation, and stabilization processes, and some of their characteristic vibrational features can remain associated with the resulting nanoparticle surface. A comparison of the Ag and ZnO spectra is therefore useful for determining whether similar or different functional-group signatures are present after formation of the two nanomaterials. The FTIR profiles are interpreted from the

observed absorption features rather than being used to assign specific phytochemicals without complementary chemical analysis. Particular attention is given to the broad hydroxyl-related region, carbonyl- or other oxygen-containing functional-group regions, and the lower-wavenumber

vibrations associated with the inorganic components. Figure 2 compares the FTIR spectra of the jujube-mediated Ag and ZnO nanoparticles and provides the basis for discussing their surface-associated chemical signatures and differences.

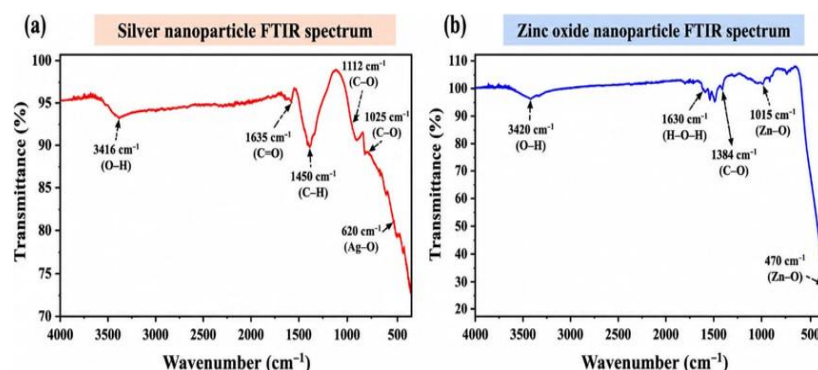


Figure 3: Comparative FTIR Spectra of (a) Jujube-mediated Ag Nanoparticles and (b) Jujube-mediated ZnO Nanoparticles

The Ag and ZnO spectra both retain broad high-wavenumber and fingerprint-region contributions associated with organic surface species from the botanical synthesis environment. The ZnO spectrum also shows a pronounced low-wavenumber response extending into the Zn–O vibrational region, whereas the Ag spectrum does not provide an equivalent oxide-lattice signature.

The most useful interpretation is comparative rather than assigning every band to a single phytochemical. The spectra support the persistence of plant-derived surface-associated chemistry after synthesis, while the lower-wavenumber behaviour differs because ZnO contains an oxide lattice and Ag is an elemental metal. Similar combinations of phytochemical-associated FTIR bands and metal or metal–oxygen vibrations have been reported for recent plant-mediated Ag and ZnO systems (Vidyasagar et al., 2024), (Ibrahim et al., 2024), (Veera et al., 2023), (Tiwari et al., 2024), (Pugazhenthiran et al., 2024). FTIR alone, however, cannot identify the exact molecule responsible for each band or prove the oxidation state of the metal.

UV–Vis Exposes the Electronic Difference between Ag and ZnO

UV–Vis spectroscopy was used to examine the optical response of the two jujube-mediated nanomaterials and to identify the characteristic spectral features associated with metallic Ag and semiconducting ZnO. Because the two materials possess fundamentally different electronic structures, their optical spectra provide an important point of comparison within the present study. The Ag spectrum is considered primarily in terms of its characteristic nanoparticle optical response, including the observed broad absorption feature associated with the collective response of conduction electrons. In contrast, the ZnO spectrum is examined through its pronounced absorption edge in the near-ultraviolet region. From the supplied ZnO spectrum, an optical edge of approximately 392.5 nm, corresponding to about 3.16 eV, is observed. This value should be viewed as an optical-edge estimate rather than a formal Tauc band-gap determination because the provided data set does not contain the absorption-coefficient data necessary for a rigorous Tauc analysis. The UV–Vis spectra of Ag and ZnO nanoparticles are presented in Figure 4 and show the different optical behavior due to the different material structure.

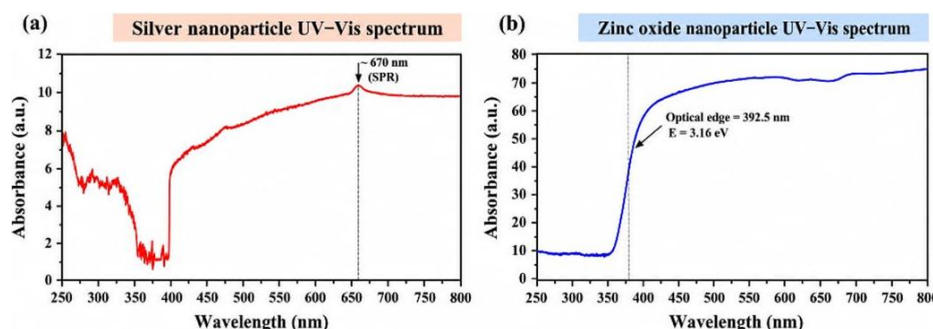


Figure 4: Comparative UV–Vis Responses of (a) Jujube-mediated Ag Nanoparticles and (b) Jujube-mediated ZnO Nanoparticles

The Ag spectrum shows a broad metallic nanoparticle response with no justified semiconductor-type absorption edge. The ZnO spectrum, by contrast, develops a steep near-ultraviolet absorption transition. The supplied derivative-

based estimate places the ZnO optical edge at approximately 392.5 nm, equivalent to about 3.16 eV.

This is one of the clearest demonstrations of why the two materials should not be evaluated using one optical criterion. Ag nanoparticles display optical behaviour associated with

their metallic electronic structure and nanoparticle surface response, whereas ZnO retains a characteristic semiconductor absorption edge. Recent Ag studies commonly report visible-region plasmonic responses whose position depends on particle morphology, aggregation and surface environment (Takci et al., 2023), (Mishra et al., 2024), (Singh et al., 2024). Recent ZnO studies report optical features spanning the near-UV region, with the measured position shifting with plant source and processing conditions (Islam et al., 2024), (Dafalla et al., 2025), (Khattak et al., 2024). The present value of ~3.16 eV is therefore interpreted as an optical edge consistent with ZnO rather than as a universal 'green-synthesis band gap.'

SEM shows Aggregation as a Shared Morphological Feature

Scanning electron microscopy was used to examine the surface morphology, particle aggregation, and overall microstructural appearance of the jujube-mediated Ag and ZnO nanoparticles. Morphological comparison is important

because the crystal structure and surface chemistry identified by XRD and FTIR do not directly describe how the synthesized materials are distributed at the microscale. The SEM observations therefore provide complementary information on the surface texture, degree of agglomeration, particle clustering, and morphological heterogeneity of the two samples. In order to achieve a consistent basis for comparison, the Ag and ZnO materials are presented at matched magnifications with similar imaging conditions in order to allow for the morphological features to be assessed under comparable imaging conditions. The micrographs available show structures with heterogeneous and strongly aggregated structures in both samples and are therefore mainly employed for qualitative morphological comparison and not definitively for a primary nanoparticle size distribution. The SEM images of both Ag and ZnO nanoparticles at different magnifications are shown in Figure 5, which clearly demonstrates their surface morphology and aggregation behavior.

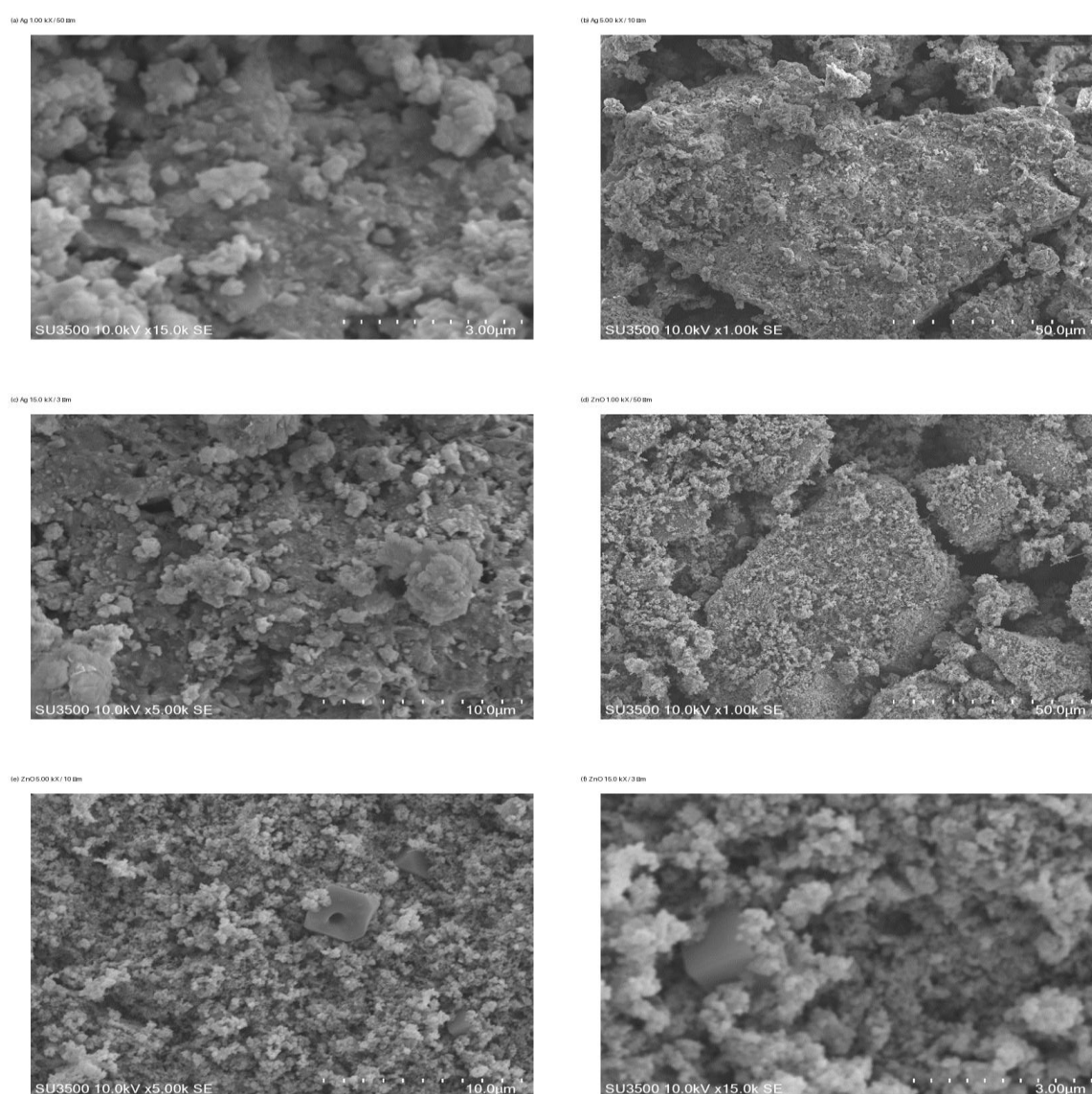


Figure 5: Matched-scale SEM Comparison of AgNPs and ZnO NPs: (a,d) 1.00 kX/50 µm; (b,e) 5.00 kX/10 µm; (c,f) 15.0 kX/3 µm

At 1.00 kX, both NPs present large agglomerated masses rather than isolated particles. At 5.00 kX, the granular organization of the aggregates becomes clearer. At 15.0 kX, finer irregular surface structures are visible, but individual primary NPs remain insufficiently resolved for a consistent particle-size distribution. The matched scale range is significant because it allows morphology to be compared without introducing a magnification bias. Ag displays a rough, heterogeneous granular surface with irregular clusters, while ZnO shows a similarly rough and strongly aggregated surface with larger irregular domains and fine granular material distributed across them. The shared aggregation behaviour is compatible with reports that plant-derived surface species, drying history and nanoparticle–nanoparticle interactions can influence the final morphology (Vidyasagar et al., 2024), (Bhattacharjee et al., 2026), (Mousa et al., 2024), (Sharma et al., 2025). The images should not be used to claim a numerical nanoscale particle diameter. Recent studies that report particle size from SEM generally use substantially higher-resolution fields together with image analysis or TEM/DLS confirmation (Takcı et al., 2023), (Adhavan et al., 2024), (Barretto et al., 2025).

EDX Distinguishes the Elemental Signatures of the Two Products

Energy-dispersive X-ray spectroscopy was performed to determine the elemental composition detected within the analyzed regions of the jujube-mediated Ag and ZnO samples and to provide elemental evidence complementary to the structural and morphological characterization. In the Ag sample, the EDX spectrum is examined primarily for the presence of Ag together with oxygen and other elements detected during the measurement, while the ZnO spectrum is evaluated for the corresponding Zn and O signals. Because EDX is a localized, semi-quantitative technique, the measured elemental percentages represent the analyzed region rather than necessarily the bulk composition of the entire sample. In addition, EDX cannot independently establish the oxidation state of an element, distinguish metallic Ag from all possible Ag-containing chemical states, or demonstrate lattice substitution and defect chemistry. Therefore, are warranted in interpreting the signal that can be attributed to the sample preparation and instrumental contributions. The EDX spectra and elemental composition of the two types (Ag and ZnO) of nanoparticles obtained using the jujube are presented in Figure 6 and present a direct comparison of the elemental signatures of the two materials.

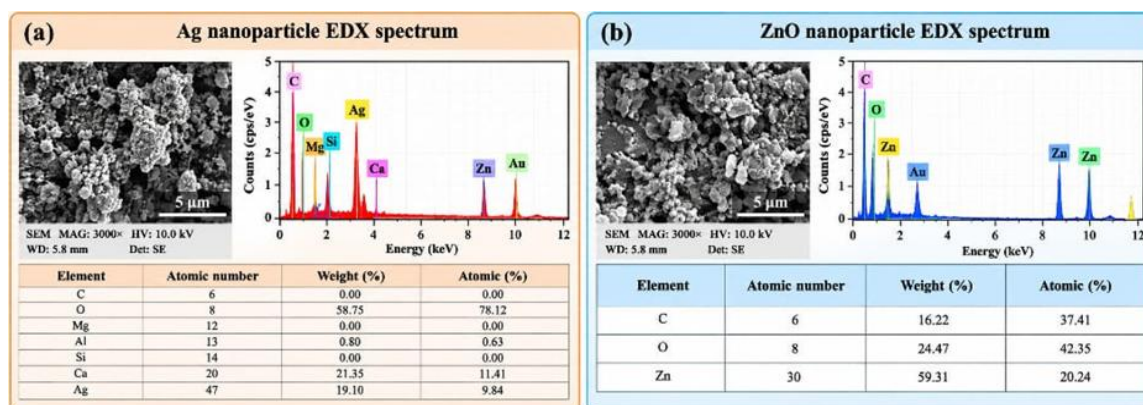


Figure 6: EDX Spectra for (a) Jujube-mediated AgNPs and (b) Jujube-mediated ZnO NPs

The Ag EDX output reports Ag as the dominant normalized element at 53.13–53.39 mass %, together with O at 24.24–24.44 mass % and Ca at 22.06–22.17 mass %. A small Al contribution of 0.56 mass % is reported in one quantification. The ZnO EDX output gives Zn at 86.87–91.11 mass %, with O at 8.77–8.89 mass %; carbon is reported at 4.36 mass % in one spectrum.

The strong Ag signal provides direct elemental evidence for silver in the analyzed Ag sample, while the Zn and O signals in the ZnO sample are consistent with the ZnO phase identified independently by XRD. The additional Ca signal in the Ag spectrum should not be described as Ag doping or lattice incorporation because EDX alone cannot establish that conclusion. It may arise from residual plant-derived material, the analyzed region or sample/substrate contributions. Likewise, carbon in the ZnO spectrum is treated as an additional detected element rather than proof of a specific organic coating. Au peaks visible in the spectra are treated cautiously because Au can be associated with sample preparation or measurement conditions.

The value of combining EDX with XRD is therefore clear: XRD identifies the crystalline phase, whereas EDX identifies the elements detected in the probed volume. Recent plant-mediated studies similarly use XRD and EDX as

complementary evidence rather than treating either method as sufficient for chemical-state determination (Fatima et al., 2026), (Palanivel et al., 2026), (Tiwari et al., 2024), (Sivakumar et al., 2025).

Quantitative Comparison of the Present Five-technique Dataset

To bring together the principal findings obtained from the individual characterization techniques, the measured structural, optical, morphological, and elemental characteristics of the jujube-mediated Ag and ZnO nanoparticles were compared using a common set of descriptors. This comparison is important because the preceding XRD, FTIR, UV–Vis, SEM, and EDX analyses provide complementary information, but each technique addresses a different aspect of the synthesized materials. Then, the differences between the metallic Ag and semiconducting ZnO phases can be compared within the same experimental context. Only properties directly related to the present measurements, such as the principal XRD reflections, optical response, morphology from SEM observations, and major elemental composition, are compared. This comparative summary is summarized in Table 1.

Table 1: Direct Comparison of the Measured Structural, Optical, Morphological and Elemental Characteristics of Jujube-Mediated Ag and ZnO NPs

Property	AgNPs	ZnO NPs	Interpretive significance
XRD phase	fcc Ag	hexagonal wurtzite ZnO	Different crystal systems
Principal XRD peaks (°)	38.27, 44.45, 64.55, 77.57	31.91, 34.55, 36.38, 47.60, 56.78, 63.02	Phase-specific fingerprints
Optical result	Metallic nanoparticle response	Edge ≈ 392.5 nm; ≈ 3.16 eV	Metal vs semiconductor
SEM scale series	1/5/15 kX; 50/10/3 μ m	1/5/15 kX; 50/10/3 μ m	Direct morphology comparison
SEM morphology	Rough, granular, strongly aggregated	Rough, granular, strongly aggregated	Shared aggregation tendency
EDX major normalized element	Ag 53.13–53.39 wt%	Zn 86.87–91.11 wt%	Elemental confirmation
Other detected elements	O, Ca; minor Al	O; C in one spectrum	Must be interpreted cautiously

Table 1 indicates that the main features of the two materials are at the structural and optical levels, and the SEM images demonstrate a strong similarity in both materials with respect to rough, granular, and aggregated morphology. The XRD results confirm the presence of the fcc phase of Ag, which is distinct from the hexagonal phase of wurtzite ZnO, whereas the UV–Vis results show that the optical response of a metallic Ag system is different from that of a semiconducting ZnO system. The EDX results show extra elemental evidence, with Ag having the highest percentage of element in the Ag sample, whereas the ZnO sample has the highest percentage of Zn and O. These measurements together provide complementary information to aid the discrimination between the two nanomaterials, and each characterization technique has its own analytical interpretation.

(2023–2026), certain studies were studied, with a particular focus on the plant source, type of nanoparticles, main characterization methods, and reported structural/physicochemical properties. This comparison is not meant to rank the materials reported nor to make direct comparisons of the results obtained under different synthesis and measurement conditions. Rather, the table lists the commonly used characterization techniques in the recent research and demonstrates the relation of the five techniques used in the current study with the existing studies on plant-mediated Ag and ZnO nanoparticles. Studies using the combination of XRD, FTIR, UV–Vis, SEM, and EDX are of particular interest since they directly correspond with the analytical framework employed in the present study. Table 2 summarizes the selected literature and how they relate to the present work.

Comparison with Recent Literature

To contextualize the present Ag–ZnO comparison in the context of recent research on plant-mediated nanoparticles

Table 2: Selected Recent Studies on Plant-mediated Ag and ZnO Nanoparticles (2023–2026) and their Relationship to the Present Five-technique Comparison

Recent study	Material/source	Main reported characterization	Relationship to present work
Salvia officinalis (2023)	AgNPs	FE-SEM, XRD, FTIR, UV–Vis; ~ 20 nm	Recent Ag multi-technique benchmark
Sambucus ebulus (2023)	AgNPs	UV–Vis, FTIR, XRD, SEM, EDX	Shows full elemental/structural workflow
Corallocarpus epigaeus (2023)	AgNPs	UV–Vis, XRD, FTIR, SEM, EDX	Comparable five-technique Ag study
Allium cepa peel (2024)	ZnO	UV–Vis, FTIR, EDX, FE-SEM, XRD	Comparable five-technique ZnO study
Eranthemum roseum (2024)	ZnO	UV, FTIR, XRD, SEM-EDAX, TEM	Confirms complementary characterization
Peta and Singh (2025)	ZnO	XRD, SEM, EDX, FTIR, UV–Vis, TEM	Full physicochemical ZnO benchmark
Allophylus concanicus (2025)	ZnO	UV–Vis, FTIR, PXRD, FE-SEM, EDX	Wurtzite plus morphology/elemental evidence
Jatropha curcas (2025)	ZnO	XRD, FTIR, SEM, EDX, UV–Vis	Comparable integrated ZnO workflow
Ziziphus spina-christi (2025)	AgNPs	FTIR, UV–Vis, SEM and additional characterization	Botanical relevance to jujube genus
Thymus vulgaris (2026)	ZnO	XRD, SEM-EDX, FTIR	Recent structural/surface benchmark
Cassia absus (2026)	ZnO	UV–Vis, XRD, FTIR, SEM-EDX	Recent full characterization benchmark
Gomphrena globosa (2026)	ZnO	UV–Vis, FTIR, XRD, SEM, EDX, XPS	Shows current expansion to multi-technique analysis
Present work	Ag + ZnO / jujube	XRD, FTIR, UV–Vis, matched SEM, EDX	One botanical platform; direct five-level Ag–ZnO comparison

As presents in Table 2, XRD, FTIR, UV-Vis, SEM, and EDX have been used in recent plant-mediated nanoparticle studies (Takcı et al., 2023; Karan et al., 2023; Veera et al., 2023; Mishra et al., 2024; Islam et al., 2024; Mousa et al., 2024; Adhavan et al., 2024; Tiwari et al., 2024; Bekele et al., 2024; Singh et al., 2024; Pugazhenthiran et al., 2024; Dafalla et al., 2025; Khattak et al., 2024), but the number and type of these techniques employed differ from one report to another. The literature thus provides a helpful methodology for the current study but cannot provide a direct numerical basis for ranking the various materials. A key aspect of the present study is the application of a common jujube experimental framework, which allowed the use of five complementary characterization procedures to compare both Ag and ZnO. This enables comparison of these differences in one experiment in terms of crystal structure, surface-associated chemistry, optical response, morphology, and elemental composition. The literature comparison thus confirms the relevance of the present approach, but the interpretation is restricted to those properties that are directly derived from the measurements carried out.

What the Combined Evidence Says

The five techniques come together to a consistent picture. XRD can be used to distinguish the wurtzite ZnO from FCC Ag. The surface chemistry of plants is present in both products as revealed by FTIR, but the low-frequency inorganic signatures are not. UV-Vis then reveals the most direct optical contrast between the two materials: Ag is a metallic nanoparticle system, while ZnO has an optical edge characteristic of semiconductors. The EDX analysis indicates the dominant elements that are characteristic of the two products, while SEM reveals both products are in the form of agglomerated structures, which are heterogeneous.

This is a more informative convergence than any single spectrum. For instance, the XRD wurtzite pattern and the Zn/O EDX signal are more meaningful when viewed in the context of the ZnO optical edge. In a similar fashion, the Ag optical response is read along with the diffraction sequence in the fcc and the Ag-rich EDX result. A comparison is then shifted from confirmation of synthesis to structure–surface–optical–morphological–elemental relationship.

The results also reveal a key drawback of the concept of a generic 'green nanoparticle' terminology. Ag and ZnO are not equal and similar. The crystal structures, electronic responses, and compositions of elements still differ in basic ways. Chemical properties of the botanicals can also affect surface stabilization and growth, but the material properties are still determined by the inorganic phase.

Significance and Broader Scientific Interpretation

The study is as much methodological as compositional. The analysis allows for a comparison within one botanical context, which eliminates one major source of variation, which would make cross-study comparison difficult—differences between plant species. Remaining contrast can then be more easily discussed in terms of the inorganic material itself, although the synthesis parameters and the history of the sample are still relevant.

The second meaning is the clear distinction between the types of evidence. The phase assignment is performed with XRD, morphology with SEM, the detection of surface-attached functional groups with FTIR, and optical behavior with UV-Vis. This prevents the common error of making a statement that is beyond the scope of the analysis given.

The third significance is the matched SEM design. Showing them all at the same three scales of observation allows the

reader to tell whether aggregation, surface roughness, and granular organization are prevalent or different depending on the material. This yields a more controlled visual comparison than the random juxtaposition of unrelated SEM images.

Lastly, the study offers a practical selection framework. If a target application requires a metallic optical response, Ag offers a different physical basis from ZnO; if a semiconductor absorption edge and oxide surface are desired, ZnO belongs to a different functional category. The paper therefore compares materials without reducing the comparison to a single winner.

Limitations

The present interpretation has deliberate boundaries. SEM images do not provide sufficient resolution for a reliable primary-particle size distribution, so numerical particle sizes are not assigned from the supplied micrographs. EDX confirms detected elemental composition but cannot independently establish oxidation state, lattice substitution, oxygen vacancies or the chemical identity of surface-bound species. FTIR bands are therefore interpreted at the functional-group level rather than assigned to individual jujube metabolites. The ZnO value of approximately 3.16 eV is reported as an optical edge, not a formal Tauc band gap, because the supplied data do not independently provide all quantities needed for a rigorous absorption-coefficient-based analysis (Umar et al., 2026).

Further work could add TEM with particle-size analysis, elemental mapping, XPS for oxidation-state and surface-chemical information, and controlled photocatalytic or antimicrobial tests. These measurements would allow the present characterization framework to be connected more directly to application performance (Dwivedi et al., 2026).

CONCLUSION

One jujube-derived synthesis framework produced two clearly different nanomaterial systems. The Ag product exhibited the fcc silver diffraction sequence and a metallic optical response, while the ZnO product exhibited the hexagonal wurtzite phase and an optical edge near 392.5 nm corresponding to approximately 3.16 eV. FTIR showed that the surface chemistry of the plants was still present in both materials. The rough and heterogeneous nature of the morphologies and strong aggregation of both samples could be confirmed by taking matched-scale SEM images, while the EDX also gave strong elemental signatures for both Ag and Zn/O. The main contribution is not in the synthesis of either material, but rather in the direct comparison of the five techniques. The findings reveal that the structure and electronic properties of nanomaterials based on a common botanical platform are still fundamentally different. This study combines aspects of phase, surface chemistry, optical response, morphology, and elemental composition to gives more comprehensive basis for comparing metallic and semiconductor nanoparticles synthesized using the green approach and lays an important foundation for future research and application-oriented studies.

DECLARATIONS

Ethical approval: Not applicable.

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AUTHOR CONTRIBUTIONS

Hamza Mustapha Umar: Conceptualization, methodology, literature search, data curation and original drafting, Software and formal analysis.

Jamila Lamido Sumaila: Supervision, validation, reviewing and editing, investigation and project administration.

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