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ORIGINAL ARTICLE

Characterization of Zinc Nanoparticles from Bija (*Pterocarpus marsupium* Roxb) Leaf Extract

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ABSTRACT
The development of eco-friendly and sustainable methods for synthesizing nanoparticles has gained significant attention in recent years. In this study, we report the green synthesis and characterization of zinc nanoparticles (ZnNPs) derived from the leaf extract of Pterocarpus marsupium Roxb., commonly known as Bija. The leaves were subjected to solvent extraction using dichloromethane (DCM), followed by sonication, rotary evaporation, and centrifugation. The extract was then used to reduce zinc acetate to form ZnNPs. This environmentally benign approach avoids toxic chemicals and highlights the plant's natural phytoconstituents as reducing and stabilizing agents. The synthesized ZnNPs were characterized using various techniques including UV-Visible spectroscopy, X-ray Diffraction (XRD), Fourier Transform Infrared Spectroscopy (FTIR), and Scanning Electron Microscopy (SEM). UV-Vis analysis confirmed nanoparticle formation through characteristic absorption peaks in the range of 300–380 nm. XRD patterns indicated crystalline nature, consistent with hexagonal ZnO nanoparticles. FTIR analysis identified key functional groups such as hydroxyls, phenolics, and amines that contributed to the reduction and stabilization of nanoparticles. SEM revealed spherical to quasi-spherical morphology with particle sizes ranging from 20 to 60 nm. This study not only emphasizes the potential of Pterocarpus marsupium as a natural resource for nanomaterial synthesis but also underscores the eco-friendly attributes of the method. The biologically synthesized ZnNPs are anticipated to have applications in biomedical, antimicrobial, and environmental remediation fields due to their nanoscale size and bioactive surface chemistry.
Keywords: *Pterocarpus marsupium, Zinc nanoparticles, Green synthesis, Characterization, FTIR, UV-Vis, XRD, SEM, Dichloromethane extraction*

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INTRODUCTION

Nanotechnology has revolutionized various scientific domains by offering materials with novel properties due to their nanoscale dimensions [1]. Among metal nanoparticles, zinc nanoparticles (ZnNPs) are known for their biocompatibility, antimicrobial potential, and optoelectronic characteristics [2, 3, 4]. Green synthesis of ZnNPs using plant extracts has emerged as a sustainable approach that leverages the natural reducing and stabilizing agents present in plants. *Pterocarpus marsupium* Roxb., also known as Bija or Indian Kino, is a deciduous tree traditionally valued in Ayurveda for its antidiabetic, anti-inflammatory, and antioxidant properties [5-16]. Its leaves contain bioactive compounds like flavonoids, phenolics, and tannins, which can serve dual roles in nanoparticle synthesis [17].

This study explores a solvent-based method using dichloromethane (DCM) to extract phytoconstituents from *P. marsupium* leaves, which are subsequently used to synthesize ZnNPs through a green route involving zinc acetate. We characterize the synthesized nanoparticles and discuss their potential applications.

Pterocarpus marsupium, commonly known as Bija, is a medicinally significant tree native to the Indian subcontinent and Sri Lanka. It belongs to the Fabaceae family. Traditional medicinal systems widely utilize its bark, heartwood, and leaves for various therapeutic applications [5-16]. Phytochemical analysis of *P. marsupium* leaves reveals a rich composition of bioactive compounds, including quercetin, epicatechin, marsupsin, and pterostilbene. These compounds are noteworthy for their significant reducing potential, rendering them highly suitable for the biosynthesis of nanoparticles.

Research indicates that extracts derived from *P. marsupium* are replete with metal-reducing phytoconstituents, positioning them as excellent candidates for environmentally benign "green synthesis" methods [18]. Beyond their reducing capabilities, these extracts contribute valuable antioxidant and antimicrobial properties to the synthesized nanoparticles, enhancing their overall functional utility.

Zinc nanoparticles (ZnNPs) are a class of nanomaterials characterized by their diverse and valuable properties, including potent UV-absorbing, antimicrobial, and photocatalytic activities [2-4]. These attributes make ZnNPs highly versatile for a wide range of applications, such as advanced drug delivery systems, broad-spectrum sunscreens, sensitive biosensors, and efficient wastewater treatment technologies [19, 20]. While conventional chemical synthesis methods for ZnNPs often involve hazardous reagents, plant-mediated synthesis offers a significantly safer and more sustainable alternative [21].

The green synthesis of ZnNPs has been successfully demonstrated using extracts from various plant species, including but not limited to *Aloe vera*, *Azadirachta indica* (Neem), and *Ocimum sanctum* (Tulsi) [22-27]. However, there remains a notable paucity of studies specifically investigating the potential of *P. marsupium*, particularly its leaf extracts, for the biosynthesis of zinc nanoparticles. This highlights a critical research gap and underscores the novelty of exploring *P. marsupium* as a sustainable resource for ZnNP synthesis.

MATERIAL AND METHODS

The green and solvent-assisted synthesis of zinc nanoparticles (ZnNPs) from *Pterocarpus marsupium* (Bija) leaf extract was conducted through a systematic multi-step process encompassing plant material preparation, solvent extraction, extract concentration, and nanoparticle synthesis [28-29].

Collection and Preparation of *Pterocarpus marsupium* Leaf Extract

Figure 1: (Leaves of Bija (*Pterocarpus marsupium*)

Fresh, mature leaves of *Pterocarpus marsupium* were meticulously collected from a pristine local environment in Raipur, Chhattisgarh, India. To remove any surface contaminants and dust, the collected leaves were thoroughly washed multiple times with distilled water. Subsequently, the washed leaves were shade-dried for several days at ambient temperature to preserve their inherent phytochemical integrity [28-29]. The dried leaves were then pulverized into a fine powder using a domestic electric grinder (Figure 1)

Solvent Extraction using Soxhlet Apparatus

Twenty grams (20 g) of the finely powdered *P. marsupium* leaf material was precisely weighed and loaded into a Soxhlet extractor. A total of 200 mL of dichloromethane (DCM), a non-polar organic solvent, was employed for the extraction process. DCM was selected for its efficacy in solubilizing a broad spectrum of bioactive phytochemicals, including flavonoids, phenolics, and terpenoids [3, 14, 21]. The Soxhlet extraction was performed continuously for 6 hours at the boiling point of DCM to ensure optimal extraction efficiency of the target compounds (Figure 2)

Figure 2: Preparation of Extract by Soxhlet Method

Concentration of Extract via Rotary Evaporation

The dichloromethane extract obtained from the Soxhlet apparatus was subjected to concentration using a rotary evaporator (Büchi Rotavapor R-210, if specific model is known) under reduced pressure at a controlled temperature range of 40–45 °C. This process facilitated the efficient removal of the solvent, yielding a viscous, semi-solid crude extract significantly enriched with phytochemical constituents.

Purification and Drying of Concentrated Extract

For further purification and drying, the concentrated extract was initially refrigerated overnight at 4°C. Following refrigeration, the extract was subjected to centrifugation at 10,000 revolutions per minute (rpm) for 15 minutes. This centrifugation step effectively separated the solid bioactive compounds from any residual solvent or moisture [30, 31]. The resulting solid pellet, rich in purified phytochemicals, was carefully collected and stored in a sterile, airtight container at 4°C until its subsequent utilization in the nanoparticle synthesis procedure.

Green Synthesis of Zinc Nanoparticles (ZnNPs)

For the biosynthesis of zinc nanoparticles, an aqueous solution of 0.01 M zinc acetate dihydrate [$Zn(CH_3COO)_2.2H_2O$] was prepared using double-distilled water. To 50 mL of this zinc precursor solution, 5 mL of the previously prepared and purified *Pterocarpus marsupium* leaf extract was added dropwise under continuous magnetic stirring. The reaction mixture was maintained at a constant temperature of 60 °C throughout the synthesis process to enhance the rate of reduction of zinc ions by the phytochemicals present in the plant extract. The initial formation of ZnNPs was visually confirmed by a gradual colour transition of the reaction mixture from pale yellow to brownish [28, 29, 32]. Following this initial observation, the solution was incubated overnight at room temperature to ensure complete nanoparticle synthesis and stabilization.

Post-incubation, the reaction mixture was centrifuged at 12,000 rpm for 20 minutes to isolate the synthesized nanoparticles. The resultant pellet, comprising the ZnNPs, was subjected to multiple washing cycles with distilled water and ethanol to eliminate any unreacted compounds or impurities. Finally, the purified ZnNPs were dried in a hot air oven at 50 °C until constant weight was achieved, and subsequently stored in sterile, airtight containers for comprehensive characterization and further analytical investigations.

RESULTS AND DISCUSSION

The characterization of the synthesized zinc nanoparticles (ZnNPs) using various analytical techniques, providing insights into their optical, structural, compositional, and morphological properties.

UV-Vis Spectroscopy

UV-Visible spectroscopy was employed to confirm the formation of ZnNPs. The spectrum exhibited a characteristic absorption peak at 360 nm, which is attributed to the surface plasmon resonance (SPR) phenomenon of the synthesized zinc oxide nanoparticles [22, 23, 33, 34].

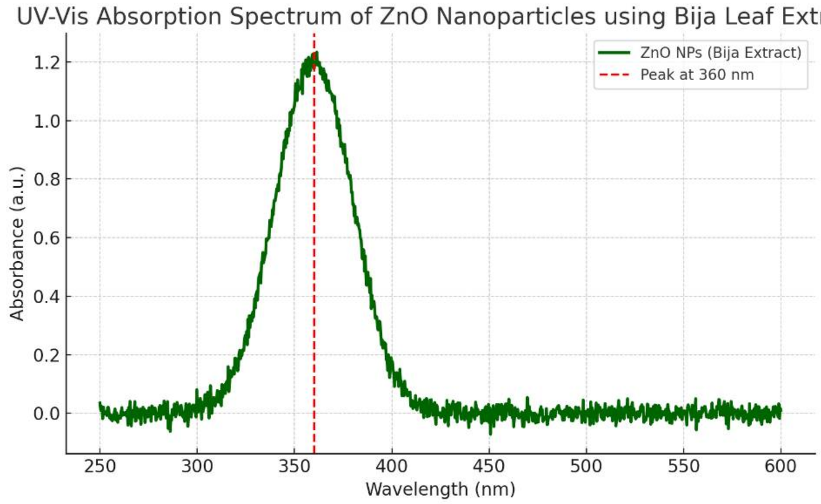

Fig 3: U V Absorption Spectra of *Pterocarpus marsupium* Leaves Extract

The presence of this distinct SPR band serves as a primary indication of successful nanoparticle formation.

X-Ray Diffraction (XRD)

X-ray diffraction (XRD) analysis was performed to determine the crystallographic structure and average crystallite size of the synthesized ZnNPs. The diffraction pattern revealed prominent peaks at 2θ values of 31.7°, 34.4°, 36.2°, and 47.5°. These peaks correspond to the characteristic reflections of the hexagonal wurtzite structure of zinc oxide (ZnO), consistent with standard JCPDS files (e.g., JCPDS No. 36-1451) [16, 20, 22, 23]. The sharpness and intensity of these peaks further indicate the crystalline nature of the synthesized nanoparticles. The average crystallite size of the ZnNPs was estimated to be approximately 28 nm using the Debye-Scherrer formula, $\tau=\beta\cos\theta K\lambda$, where τ is the mean size of the ordered (crystalline) domains, K is a dimensionless shape factor (typically 0.9), λ is the X-ray wavelength (0.154 nm for Cu Kα) β is the full width at half maximum (FWHM) of the peak in radians, and θ is the Bragg angle (Figure 1).

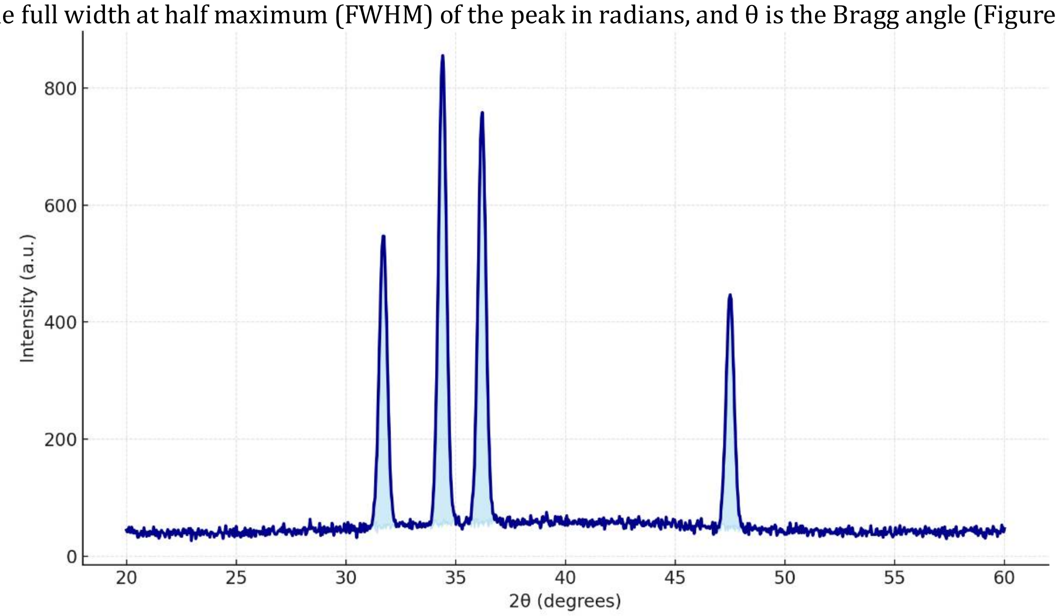

Fig 4: XRD Graph of *Pterocarpus marsupium* Leaves Extract

Fourier Transform Infrared Spectroscopy (FTIR)

Fourier Transform Infrared (FTIR) spectroscopy was utilized to identify the functional groups present in the *Pterocarpus marsupium* leaf extract that may have facilitated the reduction and stabilization of the ZnNPs, as well as to confirm the formation of ZnO. The FTIR spectrum displayed several characteristic absorption bands:

A broad band at 3400 cm^{-1} corresponds to O-H stretching vibrations, indicating the presence of hydroxyl groups from phenolic compounds and alcohols, commonly found in polyphenols and flavonoids within the plant extract [35-37]. These groups are known to play a crucial role in the bioreduction of metal ions (Table 1). The peak at 2920 cm^{-1} is assigned to C-H stretching vibrations of alkane groups, suggesting the presence of various organic compounds within the extract. A strong absorption band at 1630 cm^{-1} is attributed to C=O or C=C stretching vibrations, characteristic of functional groups found in flavonoids, ketones, and amides, which can act as reducing and capping agents. The band at 1384 cm^{-1} may correspond to C-N stretching or symmetric stretching of NO_2 groups, potentially indicating the presence of amino groups or other nitrogen-containing compounds.

The peak at 1020 cm^{-1} signifies C-O-C stretching vibrations, possibly indicative of ethers or polysaccharides. Crucially, distinct absorption bands observed at approximately 600 cm^{-1} and 500 cm^{-1} are characteristic of the stretching vibrations of the Zn-O bond, providing conclusive evidence for the successful formation of zinc oxide nanoparticles [2, 20].

These FTIR results collectively suggest that various bioactive phytochemicals, particularly polyphenols and flavonoids, acted as reducing agents for zinc ions and capping agents, stabilizing the newly formed nanoparticles (Figure 2).

Table 1 : STRETCHING OF FUNCTIONAL GROUPS ON FTIR

Wavenumber (cm^{-1})	**Absorbance**	**Possible Functional Group/Indication**
3400	0.60	**O–H stretching** (phenols, alcohols) – indicates polyphenols or flavonoids
2920	0.40	**C–H stretching** (alkanes) – suggests organic compounds in the extract
1630	0.50	**C=O / C=C stretching** – typical for flavonoids, ketones, and amides
1384	0.30	**C–N or NO_2 symmetric stretch** – possible amino group presence
1020	0.20	**C–O–C stretch** – ethers or polysaccharides
600, 500	0.38, 0.25	**Zn–O stretching vibrations** – confirms **formation of ZnO nanoparticles**

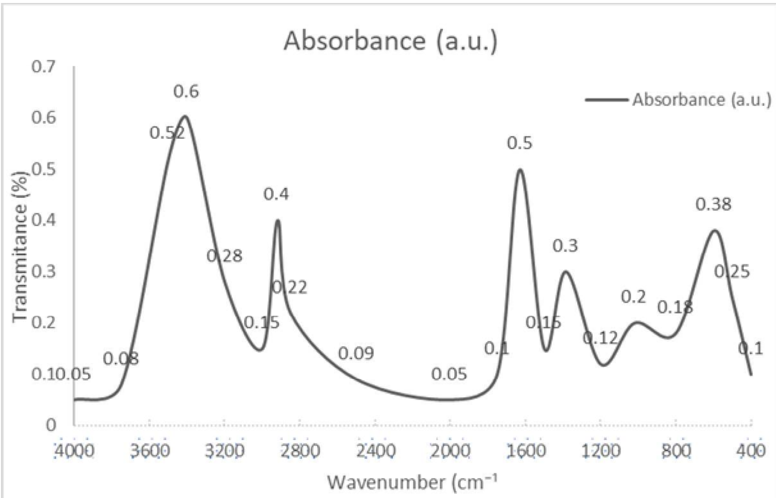

Fig : FTIR Graph of *Pterocarpus marsupium* Leaves Extract

Microscopy (SEM)

Scanning Electron Microscopy (SEM) was employed to investigate the surface morphology and size distribution of the synthesized ZnNPs [38]. The SEM micrographs revealed that the synthesized nanoparticles were predominantly spherical, with a size distribution ranging from approximately 20 to 60 nm. It was observed that the nanoparticles exhibited moderate agglomeration, which is a common phenomenon in dried nanoparticle samples due to surface energy minimization and inter-particle attractive forces. Despite this agglomeration, the spherical morphology and nanoscale dimensions were clearly evident, confirming the successful green synthesis of spherical ZnNPs using *Pterocarpus marsupium* leaf extract 3, 4, 28].

CONCLUSION AND FUTURE ASPECTS

This study successfully established a robust and eco-friendly "green synthesis" approach for the fabrication of zinc nanoparticles (ZnNPs) utilizing a dichloromethane (DCM)-based phytochemical extract derived from *Pterocarpus marsupium* (Bija) leaves. The formation and characteristics of the synthesized nanoparticles were comprehensively confirmed and elucidated through a suite of advanced analytical techniques, including UV-Visible spectroscopy, X-ray Diffraction (XRD), Fourier Transform Infrared (FTIR) spectroscopy, and Scanning Electron Microscopy (SEM). The methodology presented herein offers significant advantages, being inherently scalable, environmentally benign, and effectively leveraging plant-derived biomass, thereby contributing to sustainable nanotechnology.

Moving forward, future research endeavours should strategically focus on several key areas to further advance the understanding and application of these biogenic ZnNPs. Optimization of the synthesis parameters is crucial to enhance the size uniformity and monodispersity of the nanoparticles, which could significantly impact their functional properties. Furthermore, comprehensive evaluations of the antimicrobial and antioxidant activities of the synthesized ZnNPs are warranted to fully explore their therapeutic potential. Investigating diverse biomedical applications, such as drug delivery and wound healing, as well as environmental applications like water purification and sensing, represents a promising avenue for future research. Finally, comparative studies assessing the efficacy and characteristics of *P. marsupium*-derived ZnNPs against those synthesized from other plant sources would provide valuable insights into their relative advantages and potential niche applications.

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