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Solanum melongena leaf extract based zinc oxide nanoparticles synthesis using green chemistry concepts

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Nanoparticles of zinc oxide (ZnO NPs) have been synthesised from naturally available Eggplant, *Solanum melongena* leaf extract. The methodology has been optimized to obtain ZnO NPs which as are characterized using UV-Visible, X-ray diffraction (XRD), Scanning Electron Microscope (SEM) and FT-Infra red (FTIR) tools to confirm their nano dimensions and chemical properties. The SPR band is obtained at 389 nm in UV-visible absorption spectrum confirmes the formation of ZnO NPs while the presence of –OH, –C–O, $–CH_2$ and –COO groups at vibrational frequencies of 3500, 105, 3000 and 1640 cm^{-1}, respectively are observed from FTIR. Further, the SEM images show regular flakes like structure, and the average distribution of the nanoparticle is found to be around 100 nm. The newly synthesised ZnO NPs using leaf extract of *Solanum melongena* show considerable activity against both Gram-negative and Gram-positive bacteria. The ZnO NPs is proved to be more potent against *Staphylococcus aureus* than *E. coli*.

Keywords: Antibacterial activity, Eggplant, Nanoparticles, *Solanum melongena*, Zinc oxide

In the recent advancement of nanotechnology, the synthesis of metal nanoparticles (NPs) has evinced interest due to the growing need for fabrication of nano devices by green synthesis method. The classification of NPs based on their dimensions, morphology and chemical composition have shown encouraging properties such as antifungal and antibacterial activity. NPs or dendrimers and their nanocomposites have been explored for a variety of potential applications such as sensing devices, biosensors, storage devices and optical switching devices[1-6]. ZnO-NPs have a wide range of applications from electronic devices which are transparent to chemical and electrochemical sensors.

ZnO NP is a widely used photocatalyst employed in breaking down big environmental pollutants and in the field of gas sensors it is applied as thin layers to obtain superior sensitivity and selectivity. ZnO is used in the food industry as an additive and in sunscreens to protect from UV radiation penetration into the skin[7-10]. The metal nanoparticles synthesised from plant extracts are found to be the ideal candidates for industrial synthesis and scale up. The advantage of nanoparticles prepared by green synthesis is that it provides control over the size and shape of the particles along with the highly stability of the solution. ZnO NPs can be produced using a variety of techniques from simple precipitation to thermal decomposition[1]. Currently, green methods are preferred due to the high cost of conventional materials and the pollution caused by these chemicals used in the synthesis, mainly solvent vapours from organic formulations that are toxic in nature. In green methods, the major disadvantage is that the reaction rates are slow and non uniformity in the collection of a batch of leaves and its consistency needs to be ensured[11-13]. The ZnO NPs have ideal semiconducting properties where the band gap range is about 3.36 eV making it an ideal candidate for electrical and electronic instrumental applications[14,15]. ZnO NPs process antimicrobial properties even with a few micro litres of the solution where the multiplication of pathogenic microbes is inhibited. This is well documented in literature, and it is effectively active against the Gram-negative and Gram-positive bacteria. Dobrucka & Dugaszewska (2015) have reported synthesis of ZnO NPs using *Trifolium pratense* flower extract and have evaluated its

antimicrobial properties[16]. Also, Santhoshkumar *et al*. (2017) have used *Passiflora caerulea* leaf extract to study its effect on pathogens causing urinary tract infection[17].

Anbuvannan (2017) has reported synthesis of ZnO nanoparticles using *Solanum nigrum* leaves[18]. On these lines, here, we explored production of ZnO NPs from *Solanum melongena* leaf extracts adopting green chemistry concepts. The prepared ZnO NPs have been characterized to study their absorption and vibrational properties, crystal and morphological structure with antifungal and antibacterial activity.

Materials and Methods

Materials

Fresh leaf samples of Eggplant *Solanum melongena* were collected from the Salem District, Tamil Nadu, India. AR grade chemicals from Merck were used in these experiments.

Preparation of the ZnO nanoparticles with leaf extract

The leaves were washed with distilled water to clean the surfaces from dust particles and later air dried. 30 g of the dried leaves were transferred to a 500 mL glass beaker and boiled with 300 mL of distilled water. This was carried out until the solution colour changes to light yellow. This solution was allowed to cool to 25°C and then it was filtered. Now, to 60 mL of *S. melongena* leaf extract, 0.1 M of zinc nitrate was added followed by continuous stirring using a magnetic stirrer and the temperature was maintained at 60°C. Heating was continued until the formation of yellow precipitation was converted as a paste and it further confirmed that the zinc nitrate was reduced. This was followed by sintering in air at 400°C for 4 h. This resulted in the formation of white coloured powder that was further mechanically ground to fine uniform powders. The schematic representation of synthesis of the ZnO NPs is shown in Scheme 1. The resulting powders were characterised for their molecular, crystalline and morphological properties.

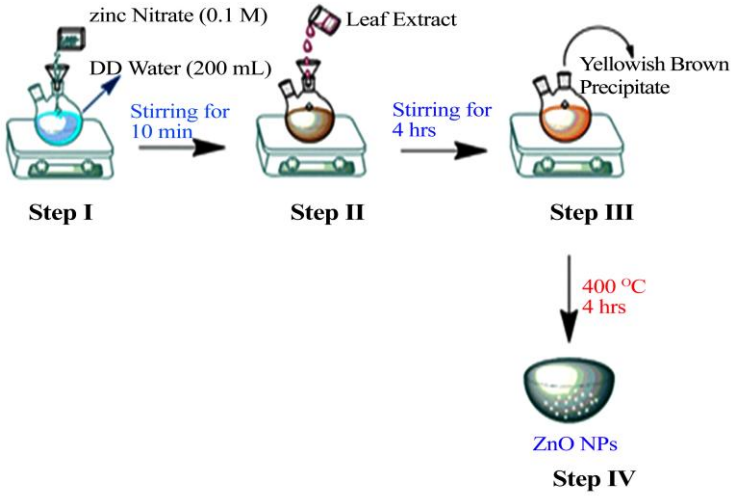
Antibacterial assay

The synthesized ZnO NPs were assessed for their antimicrobial resistance with standard and clinical strain of Gram-positive and Gram-negative bacteria. The standard strains that were used in this study include *Staphylococcus aureus*, *Escherichia coli*, *Pseudomonas aeruginosa* clinical strains: *S. aureus* and *P. aeruginosa*) following the agar based 8 mm wells using diffusion method. This was followed by measuring the intensity of the solutions in the range 0.8 to 1.0 at 600 nm wavelength for optical density measurements. This was followed by incubation of the plates at 35±1°C for about 18 h. The antibacterial activity of ZnO NPs was calculated by measuring Minimum Inhibitory Concentration (MIC) and Minimum Bactericidal Concentration (MBC). Based on the spread of the micro-organisms the inhibition zone was calculated.

Results and Discussion

UV-visible studies

The UV absorption spectra for the ZnO NPs were recorded using the wavelengths 200-900 nm. Fig. 1A confirms the presence of characteristic ZnO-NPs by the presence of a peak obtained at 389 nm whereas



Scheme 1 — Synthesis of ZnO NPs from *Solanum melongena* leaf extracts

the peak at 290 nm relates to the freshly prepared leaf extract of *S. melongena*. The formation of ZnO-NPs can be further confirmed by the peak with intense absorption peak arising out of the electronic transition occurring in these nanoparticles[19]. The band gap energy was found to be 3.35 eV for the synthesised ZnO NPs due to increase in the size of the particles. These molecular spectroscopic properties enable the commercial use of ZnO NPs in various biomedical applications.

Fourier Transform Infrared Spectroscopy (FTIR)

The FTIR bands obtained for ZnO NPs synthesized by green route as given in Fig. 1B shows an intense broad peak at 3500 cm^{-1} due to alcoholic –OH stretch of residual organics. The alcoholic nature is confirmed by the –C-O stretch occurring at about 1050 cm^{-1}. The alkyl $–CH_2^-$ vibrations were weak and found below 3000 cm^{-1}. The peak at about 1640 cm^{-1} belongs to C=O stretching group of acids. The wide peak at 3500 cm^{-1} includes the –OH stretching bands of acids. The intense sharp peak at 1400 cm^{-1} is assigned to $–CH_2^-$ bending modes. The –COO- vibration at about 1200 cm^{-1} is not clearly evident. The FTIR spectrum is shown in Fig. 1B. These results confirmed that during calcinations at 400ºC, the organics around the ZnO NPs were not completely expelled[20]. It's evident that the synthesised material remains as visible yellow colour due to the sedimentation of the NPs.

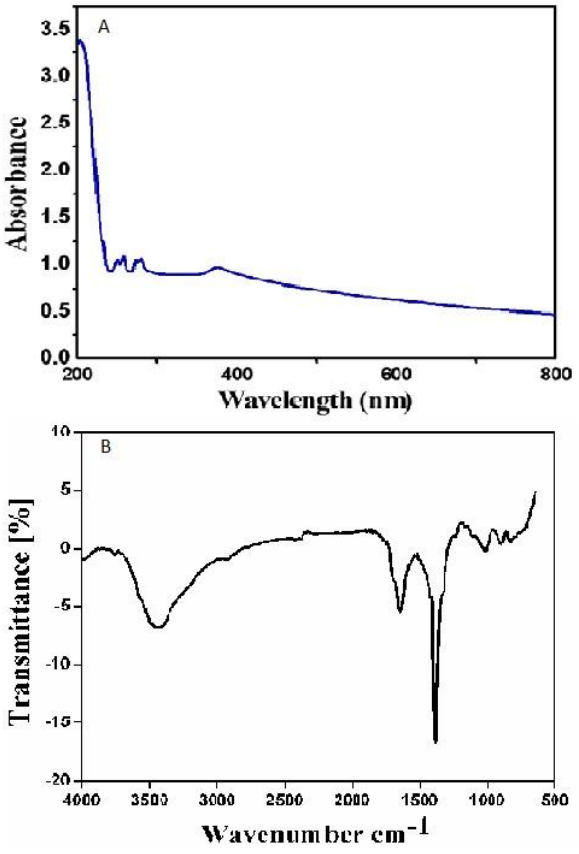


Fig. 1 — (A) Absorption spectrum and (B) FTIR spectrum of ZnO-NPs synthesised using *Solanum melongena* leaf extracts

XRD analysis

X-ray diffraction patterns shows (Fig. 2) the enhanced crystallinity effect with diffraction peaks associated with zinc oxide corresponding to (100), (002), (101), (102), (110), (103), (200), (112) and (201) and the peaks were indexed based on JCPDS file card No. 36-1451 and hexagonal (wurtzite) structure. This further confirms the formation of pure crystalline ZnO NPs.

Scanning Electron Microscopy (SEM)

The surface morphology of the synthesized ZnO NPs was analysed with SEM and is presented in Fig. 3. The micrographs indicate the formation of a regular

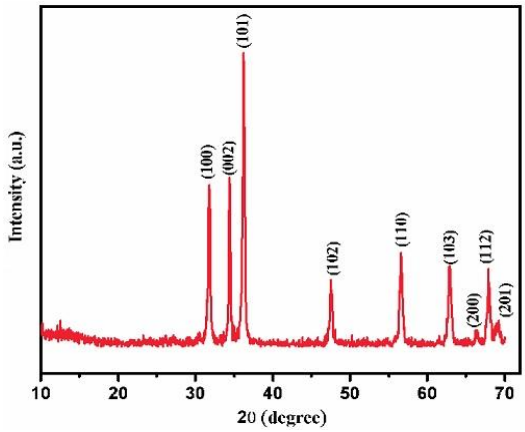


Fig. 2 — X-ray diffraction pattern of ZnO-NPs synthesised using *Solanum melongena* leaf extracts

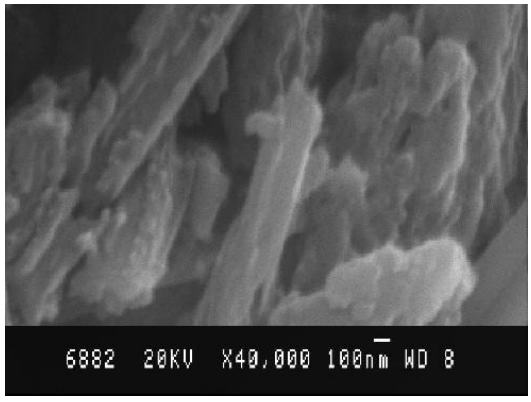


Fig. 3 — Scanning electron micrograph showing the surface morphology of the ZnO-NPs

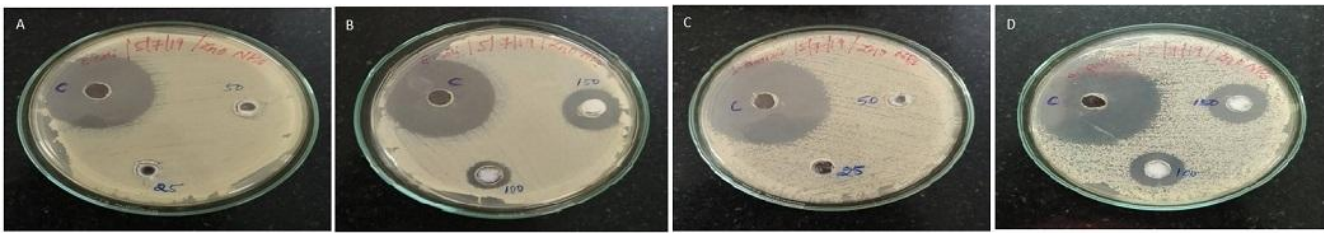


Fig. 4 —Zone of inhibition of (A & B) *E. coli* and (C & D) *S. aureus*

stick-like structure with an average size of the particle ranging around 100 nm. The ZnO NPs have a uniform distribution of nanoparticles with flakes like morphology.

Antimicrobial studies

The antibacterial studies were carried out using *Staphylococcus aureus* Gram-negative bacterium, *E. coli*, *Klebsiella pneumoniae* and *Pseudomonas aeruginosa* Gram-negative bacteria, the process of sterilization of the disks and materials were carried out in an autoclave. Nutrient agar was medium used for carrying out the cultures *S. aureus* and *E. coli* at 37°C using an incubator. Optical density measurements were carried out to study the proliferation activity in the ranges 0.8 to 1.0 at 600 nm. Minimum Inhibitory Concentration and Minimum Bactericidal Concentration were used to characterize the antibacterial properties. The bacteria were mopped uniformly on top of the plates using a sterile inoculation loop. After allowing the bacteria to dry (within 5-10 min) test solutions of ZnO of various concentrations (different particle sizes) were dropped within a disk of 8 mm diameter and zone of inhibition was measured after an incubation period of 18 h[21,22]. The following images are the zone of inhibition of *E. coli* (Fig. 4 A & B) and *S. aureus* (Fig. 4 C & D) bacterium whereas the *K. pneumoniae* and *P. aeruginosa* did not show any zone of inhibition since it has no resistance towards it. The linear increase in the zone of inhibition of *E. coli* and *S. aureus* as shown in the Fig. 5 A & B, respectively.

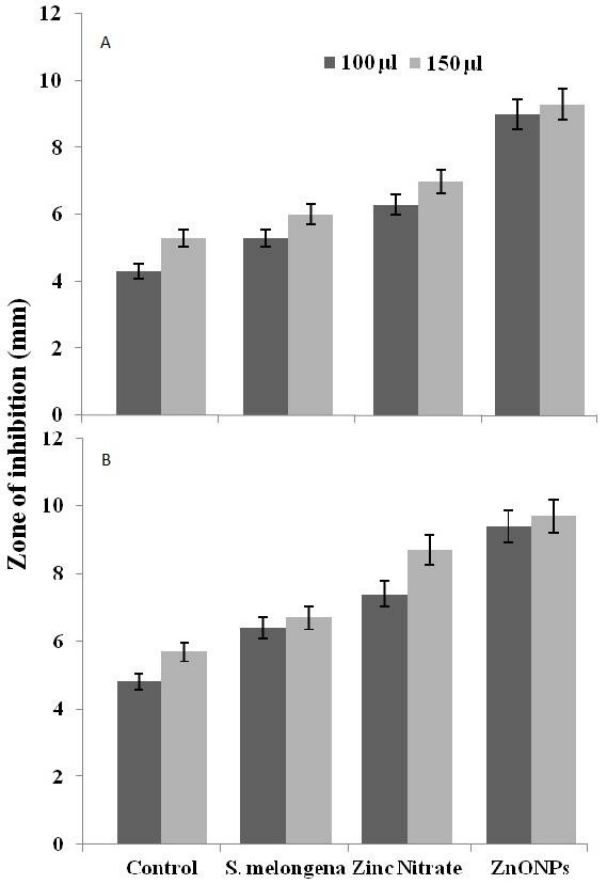


Fig. 5 — Graphs for linear increase in the zone of inhibition for (A) *E. coli* and (B) *S. aureus*

Conclusions

The ZnO nanoparticles were successfully synthesized using a green extract of *Solanum melongena* in an ecofriendly manner without the use of toxic chemicals and solvents. The various phytochemical constituents present in the extract act as reducing and capping agent on the formation of ZnO. The synthesized ZnO NPs were found to show electronic properties and typical vibration features from UV–visible and FTIR studies. The crystalline nature of the ZnO NPs was confirmed by XRD, and the morphological features, using SEM. The obtained ZnO NPs exhibited superior antibacterial activity against both Gram-negative and Gram-positive bacteria. The synthesized ZnO NPs using leaf extract of *S. melongena* proved to be more potent against *Staphylococcus aureus* than *E. coli* species.

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Conflict of interest

The authors declare no conflict of interests in this study.

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