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# Green Synthesis of ZnO nanoparticles using *Solanum procumbens* leaf extract and its structural, optical and anti-inflammatory studies

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## ABSTRACT

*The green synthesis approach utilizes natural plant extracts or biological sources, reducing the reliance on harmful chemicals and making it a more sustainable method for nanoparticle production. This method often involves readily available, low-cost plant materials, making it a more economical alternative to traditional chemical synthesis techniques. Nanoparticles which are synthesized using green methods exhibit enhanced biocompatibility, making them more suitable in pharmaceuticals and environmental remediation. The present investigation describes the synthesis of ZnO nanoparticles using Solanum procumbens leaf extract as the reducing agent. The synthesized ZnO nanoparticles were characterized by XRD, UV-Visible spectroscopy and FTIR techniques. The XRD pattern of the synthesized nanoparticles exhibited a wurtzite hexagonal structure of grain size 62 nm. The UV-Vis spectrum showed an absorption peak around 374 nm. By applying the Tauc method, the band gap energy of the ZnO nanoparticle was 3.30 eV. The anti-inflammatory activity of ZnO nanoparticles was determined using the Bovine serum albumin (BSA) denaturation assay at different concentrations of ZnO NPs, which showed inflammatory activity with the% of inhibition value of 92.72 µg/mL at 250 mL concentration.*

***Keywords****: zinc oxide nanoparticles, green approach, anti-inflammatory, Solanum procumbens.*

## 1. Introduction

In the past decade, the rapid advancement of nanotechnology across fields such as science, medicine, chemistry and biotechnology has led to the reduction of bulk materials to the nanoscale [1-4]. This miniaturization alters their structure and enhances their physico-chemical, optical properties [5]. Nanomaterials have found numerous applications, including drug delivery, bio-imaging, diagnostics, gene therapy, nanomedicine, bio-sensing, catalysis, photocatalysis, magnetic resonance imaging, cancer cell treatment, pharmaceuticals, and memory storage devices [6–8]. As the demand for nanoparticles with varying shapes and sizes grows, they can be synthesized through various methods, including irradiation, physical

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techniques, chemical processes, and biological methods [9]. Common physical synthesis methods include microwave processing [10], solvo-thermal [11], and ultrasonic processing [12], while chemical methods like hydrothermal, sol-gel synthesis, laser ablation, and lithography are also widely used [13–17]. However, nanoparticles produced through chemical or physical means can pose risks in certain applications [18]. In contrast, nanoparticles synthesized using green methods are more eco-friendly, cost-effective, and biocompatible, making them suitable for large-scale production. Plant parts such as roots, stems, leaves, flowers, and fruits, which contain various phytochemicals, serve as stabilizing and reducing agents in the green synthesis of nanoparticles [19].

Among various metal nanoparticles, Zinc Oxide (ZnO) stands out for its significant applications in medicine and sensor technology. Zinc is known for its strong interaction with electromagnetism and its unique electronic properties. It serves as a cofactor in numerous catalytic and structural processes. ZnO nanoparticles are characterized by high electron mobility, a large exciton binding energy, a broad band gap, and excellent optical transmittance [20–21]. In the medical field, ZnO nanoparticles are widely used in products like sunscreen lotions, as well as for their therapeutic properties, including anti-inflammatory, wound-healing, anti-cancer, anti-fungal, antioxidant, and antibacterial effects [22–23].

In this work, the leaf extract of *Solanum procumbens* is used as a reducing agent for synthesizing ZnO nanoparticles. *Solanum procumbens*, a member of the Solanaceae family, has been utilized in traditional medicine for treating conditions like colds, coughs, asthma, and thyroid disorders. It is commonly used at home for relieving cold and cough symptoms. This plant is known for its anti-inflammatory, antioxidant, antipyretic, anticancer, anti-asthma, and antibacterial properties [24]. The liquid extract of *Solanum procumbens* has been found to contain a variety of bioactive compounds including flavonoids, steroids, coumarins and glycoalkaloids, triterpenoids, sugars, amino acids, saponins, phenolic compounds, and anthraquinones. Additionally, important chemical constituents such as sobatum, solanine, solasodine, and diosgenin are present [25].

## 2. Materials and Methods

Zinc acetate dihydrate and sodium hydroxide were obtained from Sigma–Aldrich, India. Fresh leaves of *Solanum procumbens* were harvested from Marthandam in Kanyakumari district.

### 2.1 Preparation of *Solanum procumbens* extract

Medicinal leaves of *Solanum procumbens* were collected from Kanyakumari District. The leaves were carefully washed, shade-dried, and ground into a fine powder. Ten grams of the powdered leaves were mixed with distilled water (100 mL) and heated on a magnetic stirrer at 70°C for 30 min. The resulting solution was filtered, cooled and utilized for the synthesis of ZnO nanoparticles.

### 2.2 Synthesis of ZnO nanoparticles using *Solanum procumbens* leaf extract

About 25 mL of *Solanum procumbens* extract was mixed with zinc acetate and sodium hydroxide (1:2 molar ratio). The resulting yellow solution was stirred for 3 h and then left to stand undisturbed for 24 h. The resulting precipitate was washed with deionized water, and dried in a hot air oven at 250°C for 2 h. The synthesized zinc oxide nanoparticles were ground into a fine powder using a mortar for subsequent characterization.

### 2.3 Instrumentation

The particle size of the synthesized nanoparticles was determined from the XRD using a powder X-ray diffractometer with Cu Kα radiation, covering a 2θ range of 10° to 80°. The optical absorption spectrum of the nanoparticles was measured using a UV-visible spectrophotometer. FTIR spectroscopy was used to examine the functional groups present in the ZnO nanoparticles, using a PerkinElmer FTIR spectrometer. The anti-inflammatory efficacy of ZnO nanoparticles was evaluated through Bovine serum albumin (BSA) denaturation assay.

## 3. Results and Discussion

### 3.1 Structural studies of ZnO nanoparticles using S*olanum procumbens*

Structure and phase purity of ZnO nanoparticles using *Solanum procumbens* leaf extract are shown in Fig. 1. From the diffraction patterns, it is very well understood that it has a hexagonal phase (wurtzite structure) by comparison with the data from JCPDS card No. 89-1397[26], and no indication of a secondary phase or impurity peaks. The XRD pattern indicates the crystalline nature of the nanoparticles. The sharp, intense diffraction peaks appearing at 31.29 $^o$, 33.95$^o$, 36.04 $^o$, 47.05 $^o$, 56.09 $^o$, 62.38 $^o$, 65.90 $^o$, 67.45 $^o$, 68.60 $^o$, 72.03 $^o$, and 76.48 $^o$ correspond with those from (100), (002), (101), (102), (110), (103), (200), (112), (201), (004) and (202) orientations, respectively. The synthesized nanoparticles show a particle size of 62 nm which was calculated using Scherer's equation [27].

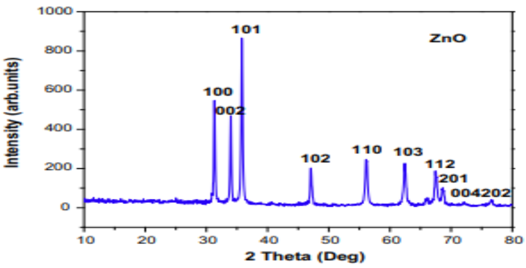


**Figure 1XRD pattern of synthesized ZnO sample using *Solanum procumbens***

### 3.2 Optical studies of synthesized ZnO nanoparticles using *Solanum procumbens* extract

UV-Vis spectroscopy was also conducted to confirm the formation of ZnO nanoparticles. In the absorption spectrum of synthesized nanoparticles (Figure-2), the peak was observed at 374 nm, which attributes to the intrinsic band-gap of ZnO absorption [28]. This absorption is associated with the intrinsic band-gap transition of ZnO, specifically the excitation of electrons. The observed peak at 374 nm corresponds to the characteristic UV absorption for ZnO, which has a wide band-gap typically ranging from 3.2 eV to 3.4 eV, depending on the size of the particle and synthesis conditions. This peak is indicative of the formation of ZnO nanoparticles and confirms their optical properties, with the specific wavelength being consistent with ZnO's well-known electronic structure. The position and peak intensity can also provide insights into the size and morphology of the ZnO nanoparticles, as quantum size effects often shift the absorption towards shorter wavelengths in smaller particles. The band gap of a material, which refers to the energy difference between the excitation bands, can be estimated using a Tauc Plot [29] and is 3.3 eV (Figure 3).

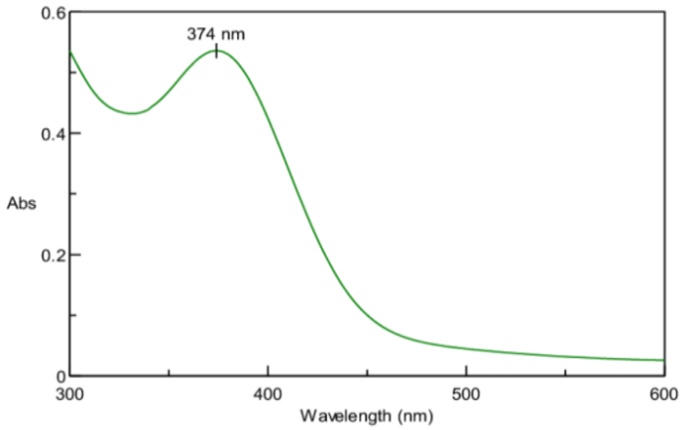


**Figure 2. UV-Vis absorption spectrum of ZnO nanoparticles using *Solanum procumbens* leaf extract**

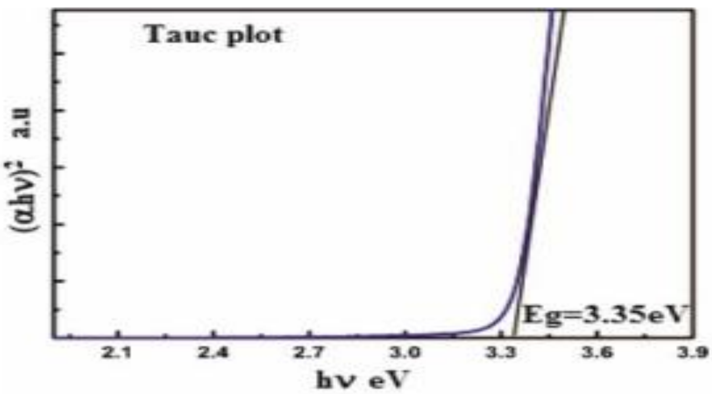


**Figure 3. Tauc plots of ZnO nanoparticles using *Solanum procumbens* leaf extract**

### 3.3 FTIR Analysis of ZnO nanoparticles using *Solanum procumbens* leaf extract

FTIR was performed in order to study and determine the functional groups of synthesized ZnOnanoparticles using *Solanum procumbens* leaf extract**.** Figure 4 shows the FTIR spectrum of synthesized ZnO nanoparticles that were obtained from the green synthesis procedure. FTIR spectrum was observed at 414 $cm^{-1}$ that is attributed to Zn-O stretching vibration. It is a characteristic absorption for ZnO, confirming the presence of zinc oxide in the sample [30]. The peaks at 1339 $cm^{-1}$ and 1556 $cm^{-1}$ are due to symmetric and asymmetric O-C-O stretching vibration of adsorbed carbonate anions respectively. The presence of carbonate suggests that the ZnO nanoparticles may have carbonate groups adsorbed on their surface, which could be a result of the interaction with the leaf extract during the green synthesis process. Meanwhile, the peaks at 1047 $cm^{-1}$ indicate the O-H bending. This peak corresponds to the lattice vibration of carbonate, which further supports the idea of carbonate being present in the synthesized ZnO nanoparticles [31]. The carbonate could also play a role in stabilizing the nanoparticles or influencing their morphology. Overall, the FTIR spectrum confirms the successful synthesis of ZnO NPs and suggests the presence of functional groups from the leaf extract, which may assist in the stabilization and formation of the nanoparticles.

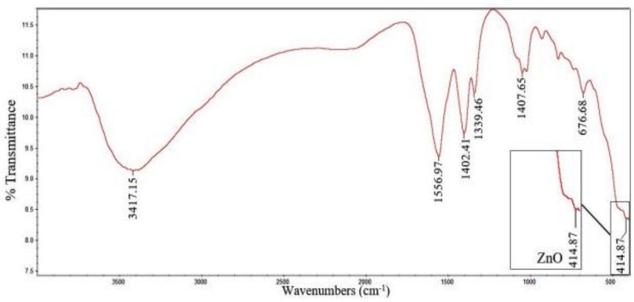


**Figure 4. FTIR spectrum of ZnO nanoparticles using *Solanum procumbens* leaf extract**

### 3.4 Anti-inflammatory activity of ZnO nanoparticles using *Solanum procumbens* leaf extract

Anti-inflammatory property was examined using Bovine serum albumin (BSA) denaturation assay. The inhibition of protein denaturation (%) was determined using the following formula: Inhibition of denaturation (%) = $(A_{control} - A_{sample} / _{control}$ x100, where,

$A_{control}$= Absorbance of the control; $A_{sample}$= Absorbance of the tested compounds.

The anti-inflammatory activity is exhibited in Fig.5.As the sample concentration increases from 50 µg/mL to 250 µg/mL the inhibition percentage also increases. At the lowest concentration (50 µg/mL, the inhibition is 72.45%, indicating moderate anti-inflammatory activity. The highest concentration tested (250 µg/mL shows the strongest inhibition at 92.72%, indicating the sample exhibits significant anti-inflammatory effects at higher concentrations. A high percentage of inhibition indicates that the sample may have strong anti-inflammatory effects, which is applicable for treating inflammatory diseases such as arthritis, allergies, or inflammatory bowel disease. This suggests that the sample might act similarly to anti-inflammatory drugs, either by blocking the production of pro-inflammatory mediators (such as cytokines or prostaglandins) or by interfering with inflammatory cell activity. This effect would be desirable in the development of anti-inflammatory therapies.

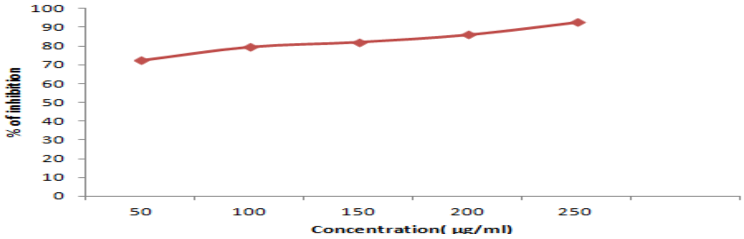


**Fig. 5 Anti-inflammatory activity of ZnO nanoparticles using S*olanum procumbens* leaf extract**

## 4. Conclusion

This work introduces a simple, cost-effective, safe and environmentally friendly method for the large-scale synthesis of ZnO nanoparticles using *Solanum procumbens* via a green route. XRD analysis confirmed the crystalline nature of the biosynthesized ZnO nanoparticles. Evidence of ZnO nanoparticle formation was confirmed by a noticeable colour change and a peak around 374 nm in the UV-Vis spectrum. FTIR analysis identified several vibrational functional groups corresponding to the components present in the leaf extract and ZnO nanoparticles. Additionally, the green synthesized ZnO nanoparticles showed significant inflammatory activity, with the percentage of inhibition value of 92.72 µg/mL at 250 concentration. Moreover, the method employed for synthesizing stable ZnO nanoparticles using *Solanum procumbens* offers a safer and more economical alternative to traditional methods, highlighting its potential applications in biomedical research, arthritis, allergic reactions and autoimmune diseases.

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