

Green Biogenic Synthesis of Sn-ZrO₂ Nanocomposites Using *Musa paradisiaca* Peel Extract Under Sonication for Biological and Adsorption Efficacy

Diksha Bhardwaj

SS Jain Subodh PG College

shobhana sharma

drshobhanasharma@subodhpgcollege.com

SS Jain Subodh PG College <https://orcid.org/0000-0001-8927-3280>

Research Article

Keywords: *Musa paradisiaca*, antimicrobial, adsorption capacity, antioxidant, Sn-ZrO₂ nanocomposites

Posted Date: September 23rd, 2024

DOI: <https://doi.org/10.21203/rs.3.rs-4946370/v1>

License:   This work is licensed under a Creative Commons Attribution 4.0 International License.

[Read Full License](#)

Abstract

The production of nanoparticles using plant extracts has been the subject of much exploration and study in recent times since it is a cost-effective and environmentally friendly method that reduces the use of hazardous chemicals. In this work, *Musa paradisiaca* (banana) peel extract was used to synthesize Sn-ZrO₂ nanocomposites under ultrasonic irradiation. As a capping and reducing agent in the manufacture of Sn-ZrO₂ nanocomposites, banana peel extract is crucial. Sn-ZrO₂ nanocomposites were synthesized in a green manner were effectively evaluated using a FT-IR spectroscopy, UV-Vis spectrophotometer, X-ray diffraction analysis (XRD), energy-dispersive X-ray spectroscopy and scanning electron microscopy (SEM-EDS). Studies have been conducted on the antimicrobial properties of synthesized ZrO₂ nanocomposites doped with tin against both Gram positive and Gram negative pathogenic bacteria and fungus. Furthermore, free radical scavenging activity against the DPPH and ABTS assay was used to assess the antioxidant activity of green Sn-ZrO₂ nanocomposites. The biomimetic synthesised Sn-ZrO₂ nanocomposites demonstrated robust antioxidant activity and significant antimicrobial activity that was on par with standard. Further, Sn-ZrO₂ nanocomposites shows excellent adsorption capacity of malachite green dye.

Introduction

Nanostructures are essential research tools in various fields, and nanotechnology is a rapidly expanding discipline with diverse applications in science and technology (Haleem et al. 2023). A great deal of research has been conducted on metal and metal oxide nanoparticles because of their exceptional electrical, optical, magnetic, catalytic, and medicinal properties (Bukhari et al. 2021). Conventional techniques for creating metal and metal oxide nanoparticles use stabilizing and reducing chemical agents, which can be costly and harmful to the environment (Nair et al. 2022). As a result, scientists are currently searching for different green synthesis techniques which minimize the hazardous substances used in the nanoparticles-producing process (Ying et al. 2022). In recent years, there has been extensive research on the eco-friendly, minimal-use method of green synthesis of metals and metal oxides nanoparticles employing plant extracts (Shafey et al. 2020).

Zirconium oxide (ZrO₂) nanoparticles are a highly valuable material in various fields, particularly in the dentistry (Kumari et al. 2022). Their unique surface chemistry, high chemical and thermal stability, cost-effectiveness, non-hazardous and sustainable nature, clean photocatalytic properties, and impressive morphologies have significantly impacted both academia and industry (Hassaan et al. 2023). ZrO₂ is a valuable material for water pollutant removal due to its high electron mobility, direct band gap, anisotropic growth, chemical stability, high photocatalytic efficiency, and ease of morphological control. Zirconium oxide is environmentally friendly and possesses outstanding biocompatibility (Bannunah 2023). The usefulness of zirconia is limited by two intrinsic properties: a high band gap and quick electron-hole pair recombination (Khattab et al. 2021). The synthesis of metal nanoparticles (Ag, Au, Sn, Cu, Ru, Pd, etc.) doped on metallic oxide surfaces has recently attracted a lot of interest in the fields of

material science and nanotechnology due to its significantly enhanced applications in a variety of fields (Szczyglewska et al. 2023).

Furthermore, studies show that tin-doping controls the cytotoxicity of zirconia nanoparticles by killing human cancer cells alone while leaving healthy cells unharmed (Barbasz et al. 2024). It was recently discovered that Sn-ZrO₂ generate a reactive oxygen species (ROS) that can destroy microbial colonies in the absence of light irradiation (Mammari et al. 2022). Sn-ZrO₂ nanocomposites formation is a good choice because of their unique optical-physiological and biological properties, ease of synthesis at a low cost, high availability, and low toxicity.

Sn-ZrO₂ nanocomposites have been synthesized using a variety of methods, including the thermal decomposition, sol-gel process, co-precipitation and electrochemical oxidation process (Narayanan et al. 2019; Bharti and Sadhu 2022). Although, some of these physio-chemical methods not only violate environmental regulations but also cause poor dispersibility and irreversible nanoparticle agglomeration, which reduces biological activity (Joudeh and Linke 2022). Consequently, the synthesis of different nanomaterials utilizing plant extracts has recently caught the interest of researchers as a means of getting around these limitations (Ying et al. 2022). However, less research has been done on the synthesis of Sn-ZrO₂ nanocomposites utilizing plant extracts.

The synthesis of nanocomposites typically requires two or more phases and a lengthy reaction procedure, although plant mediated synthesis support green approaches (Ying et al. 2022). The ultrasonic energy used as a non-conventional source act as a workable and environmentally beneficial alternative for material production (Shen et al. 2023). Some research indicates that the cavitation action of ultrasonic waves during nanomaterial manufacturing reduced the reaction time and produced smaller particles (Sandhya et al. 2021). During cavitation, bubbles form and burst, rapidly producing large quantities of non-aggregated nanoparticles (Khairani et al. 2023).

In light of the many uses and paucity of research on plant-mediated nanocomposites synthesis and as part of our continuing endeavour on the designing and green synthesis of functional nanocomposites (Bhardwaj et al. 2021; Bhardwaj et al. 2019), we have shown here for the first time a green banana peel extract assisted synthesis of Sn-ZrO₂ nanocomposites under sonication. Biomolecules included in banana peel extract serve as stabilizing and reducing agents in the synthesis of nanomaterials (Ohiduzzaman et al. 2024; Bao et al. 2021).

Materials and Methods

Bananas were collected from the local area of Jaipur district, Rajasthan, India. The chemicals used in this study were zirconyl nitrate [ZrO(NO₃)₂.xH₂O], stannous chloride (SnCl₄), ethanol, ZrO₂, 2, 2-Diphenyl-1-picrylhydrazyl (DPPH), ABTS (2,2'-azino-bis(3-ethylbenzothiazoline-6-sulfonic acid)), etc. were purchased from Merck Chemical Company (Darmstadt, Germany) and used as such without further purification.

Characterization methods and Instruments

UV-Vis, FTIR, XRD, and SEM-EDS studies were used to characterize Sn-ZrO₂ nanocomposites that were green-synthesised. Using a quartz cuvette filled with de-ionized water as a reference, UV-Vis NIR spectrophotometer was employed. FTIR spectra were captured in a spectral range of 4000-400 cm⁻¹ using KBr pellets. The X-ray diffractometer, which was outfitted with a CuK α radiation ($\lambda=1.54060$ Å) was used to perform XRD measurements. Surface morphology and form of the nanocomposites were evaluated using FE-SEM. The FE-SEM and EDS detector are connected so that elements included in nanoparticles can be identified and their chemical composition can be examined. The ultrasound assisted reactions were performed using an ultrasonic processor probe system. For ten minutes, the operating conditions involved a 30-second on and 30-second off pulse with 50% amplitude.

Preparation of *Musa paradisiaca* (Banana) peel extract

After gathering the *Musa paradisiaca* peels, they were carefully cleaned under running water to get rid of any associated dust particles, and then dried. About 20 gm of dried banana peel were powdered, and 100 ml of deionized water was added. In order to prepare the peel extract, the mixture was heated at 80°C for ten minutes. After allowing the combination to cool to room temperature, Whatman No. 1 filter paper was used to filter the mixture. After the residue was eliminated, the filtrate was utilized to create nanocomposites.

Synthesis of Sn-ZrO₂ nanocomposites using *Musa paradisiaca* peel extract

To create Sn-ZrO₂ nanocomposites in an environmentally friendly manner, a cylindrical glass vessel containing a precursor solution of 0.1M zirconyl nitrate and 15 ml deionized water was subjected to a 10-minute sonication period. Subsequently, a 1 mM stannous chloride solution was applied dropwise while being continuously sonicated to a 25 ml banana peel extract. The solution turned gray after ten minutes as a result of surface plasmon resonance (SPR) activation, which showed that Sn-ZrO₂ nanocomposites were forming. The precipitation of Sn-ZrO₂ nanocomposites was completed by centrifuging the solution for 20 minutes at 6000 rpm. After three water washes to eliminate byproducts, the precipitate was dried in an oven at 80 °C for an entire night, and it was then annealed for two hours at 500 °C.

Antimicrobial activities

The traditional well-diffusion method was employed to examine the antimicrobial potential of produced Sn-ZrO₂ nanocomposites, as previously described (Sharma et al. 2018; Sharma et al. 2019; Sharma et al. 2022). Two distinct fungi, *C. albicans* and *C. tropicalis*, were evaluated for their antifungal activity, while pathogenic microorganisms classified as Gram-negative (*K. pneumonia* & *P. aeruginosa*) and Gram-positive (*B. subtilis* & *S. aureus*) were tested for their antibacterial activity. Every strain was evenly swabbed onto the sterilized nutritional agar petriplates using cotton swabs. Then, using a sterile plastic rod, 8 mm diameter wells were pierced into the inoculation plates. Four concentrations (20, 40, 60, and

80 µg/ml) of produced Sn-ZrO₂ nanocomposites were added, accordingly, to the specified wells using a micropipette. After incubating for 24 hours at 37°C, the antimicrobial activity was assessed by measuring the diameter of the inhibitory zone in millimeters (mm) using a standard scale. The antimicrobial activity of the resulting Sn-ZrO₂ nanocomposites was compared with that of ZrO₂ nanoparticles in order to measure the effectiveness of Sn loading in nanocomposites and also compared with reference standard.

Antioxidant activity

The antioxidant potential of the green produced ZrO₂ nanoparticles and Sn-ZrO₂ nanocomposites was evaluated and compared with standard using DPPH and ABTS tests.

DPPH assay

According to a previous approach (Verma et al. 2022), the antioxidant activity of green synthesized Sn-ZrO₂ nanocomposites and ZrO₂ nanoparticles was examined using DPPH assay. One milliliter of DPPH solution (0.1 millimole of DPPH in methanol) was filled with different concentrations of synthesized Sn-ZrO₂ nanocomposites and ZrO₂ nanoparticles, and the test tubes were labeled appropriately. After shaking the reaction mixture, it was left at room temperature for 30 minutes in a dark environment. At 517 nm, the absorbance was measured spectrophotometrically.

ABTS assay

The ABTS free radical scavenging activity of ZrO₂ nanoparticles and green synthesised Sn-ZrO₂ nanocomposites was examined using the previously reported methodology, with some minor adjustments (Haq et al. 2021). By reacting 2.45mM of potassium persulfate (K₂S₂O₈) with 7.mM of the ABTS stock solution, ABTS radical cation (ABTS⁺·) stock solution was prepared. The absorbance at 734 nm was measured following an overnight incubation period at room temperature. ZrO₂ nanoparticles and synthesized Sn-ZrO₂ nanocomposites were added individually with ABTS⁺· at varying concentrations, and they were once more incubated for 15 minutes in a dark environment. As a control solution, ABTS reagent was employed without sample.

Batch Adsorption Studies: Malachite green (MG) dye was made as a stock solution (100 ppm) in deionized water, and subsequently diluted to yield a range of samples from 1 to 12 ppm. The effects of various parameters on the removal of MG dye using Sn-ZrO₂ nanocomposites during the batch adsorption method are investigated. These parameters include adsorbent dosage (5, 10, 15, 20, 25, 30, 35 and 40 mg), contact time (5, 10, 15, 20, 25, 30 min), pH (2 to 12), and temperature (303, 323 and 353 K).

The adsorption capacity of MG dye was determined using Equation 1, while the removal efficiency (%) was calculated with Equation 2.

$$(q_e) = (C_o - C_e) V/M \quad \text{Equation (1)}$$

$$\text{Removal (\%)} = (C_o - C_e) / C_o \times 100 \quad \text{Equation (2)}$$

where M (mg) is the mass of the Sn-ZrO₂ nanocomposites, V (L) is the volume of MG dye obtained in an aqueous solution, and C_o (mg/L) and C_e (mg/L) are the initial and equilibrium concentrations, respectively, of MG dye.

Results and discussion

UV–Vis Spectrophotometer: Fig. 1, comprises the room-temperature optical absorption of Sn-ZrO₂ nanocomposites in the range of 200–800 nm. The sharp absorption peak seen at around 260 nm can be attributed to ZrO₂ (Chelliah et al. 2023). The synthesized nanocomposites demonstrated absorbance band from 280-550 nm shows deposition of Sn nanoparticles on the surface of nanocomposites successfully (Sohail et al. 2020).

FTIR analysis: Fig. 2 reveals the FTIR spectrum of green synthesis Sn-ZrO₂ nanocomposites. The characteristic broad peaks of OH groups are found at 3428.71 and 1628.34 cm⁻¹ corresponds to the water molecules that have been absorbed on the surface of the nanoparticles. The stretching and bending vibrational modes of the water molecule are responsible for these broad peaks (Sagadevan et al. 2016). The weak bands at 2922.36, 2852.34, and 1384.31 cm⁻¹ were associated with the vibrations of organic residuals (Alharthi et al. 2020). The absorption band that was most prominent and sharpest emerged at 1121.69 and 617.74, cm⁻¹ potentially indicating a correlation with the Zr–O bonds. The bending vibration of hydroxyl groups attached to ZrO₂ is responsible for the peaks at 1121.69 cm⁻¹ and 617.74 cm⁻¹. The Zr–O vibration is represented by the band at 617.74 cm⁻¹, and the breadth of the band indicates that the ZrO₂ powders are nano crystals (Yakout et al. 2014).

XRD: X-ray diffraction measurements were used to investigate the crystallinity and phase form of the synthesised nanomaterials. Fig. 3 demonstrate the XRD pattern of Sn-ZrO₂ nanocomposites and bare ZrO₂ nanoparticles. The diffraction peaks in a wide range angle of 2θ are at 30.64°, 35.22°, 50.26°, and 60.17° corresponds to the crystal planes of (101), (110), (112), and (211), respectively, attributed to the preparation of monoclinic phase of ZrO₂ nanoparticles (Horti et al. 2020) (JCPDS card no. 01-075-2550). Comparison of XRD pattern reveals the appearance of strong intense peaks at 2θ = 30.10° and 35.05° to be (101) and (110) crystal planes of Sn doping on ZrO₂ as shown in Fig. 3 (Długosz et al. 2021). The XRD patterns do not exhibit distinctive peaks associated with Sn, indicating that all Sn atoms have successfully integrated into the ZrO₂ lattice. Additionally, the absence of any other diffraction peaks confirms the synthesized nanocomposites high purity.

SEM and EDS analyses

The detailed morphology, particle size, and shape of the biomorphic Sn-ZrO₂ nanocomposites were examined using SEM analysis. The results revealed a non-uniform distribution of spherical tin particles on the surface of zirconia nanoparicles. The average size of Sn-ZrO₂ nanocomposites is 25nm-50nm (Fig. 4a, b). The elemental composition of the Sn-ZrO₂ nanocomposites was determined by EDS analysis, confirming the presence of zirconium (Zr), tin (Sn), and oxygen (O) as shown in Fig. 5. Additional presence of elements (calcium) is also observed due to the presence of some phytochemicals from extract.

Adsorption performance of Sn-ZrO₂ nanocomposites: This experimental work was conducted using a 10 ppm MG dye solution. 30 mg of Sn-ZrO₂ nanocomposites were put to a beaker containing 20ml of MG dye solution. The mixture is shaken constantly for 25 minutes or until equilibrium is reached. The Sn-ZrO₂ nanocomposites was used to study the adsorption of MG dye from an aqueous solution at different dye concentrations, contact times, dosages of the adsorbent, pH levels, and temperatures. The adsorbent was changed from 5 to 40 mg/L while all other parameters remained same. The pH was adjusted to a range between 3 and 10 ppm using 0.1 M HCl and 0.1 M NaOH solutions. The shake took longer than five minutes to complete. The adsorbate solution was taken out and filtered once the allotted time had elapsed in order to isolate the adsorbent. Following filtering, a UV-Vis spectrophotometer that had previously been calibrated was used to measure the solution's concentration at 615 nm.

Alterations in adsorbent dose: Doses are crucial during the adsorption process. To investigate the effect of the Sn-ZrO₂ nanocomposites dosage on the adsorption of MG dye (10 mg/L), adsorbent dosages ranging from 5 mg to 40 mg were used. The removal effectiveness was increased from 5 to 40 mg of Sn-ZrO₂ nanocomposites, as shown in Fig. 6(a). This is because larger surface areas and more active sites are present in adsorbent. It was shown that the Sn-ZrO₂ nanocomposites had an optimal dose of 30 mg. Once the optimal adsorbent dose has been reached, the removal efficiency falls.

Variation with pH: Since pH influences the surface charge of the adsorbate (MG dye) and Sn-ZrO₂ nanocomposites adsorbent, it plays a significant part in adsorption processes. The influence of pH on the effectiveness of nanocomposites' removal of MG dye is shown in Fig. 6b. To adjust the required pH, 0.1 M sodium hydroxide or 0.1 M hydrochloric acid was used. As the pH rose from 8 to 10, the removal efficiency significantly declined after increasing from 3 to 8.

Effect of temperature: Temperature is thought to be a significant element that affects how well the MG is adsorbed and removed. At various temperatures between 303 and 353 K, the adsorbent dosage (30 mg/L), pH (8), contact period is 25 min, and constant agitation speed (450 rpm) were maintained in order to assess the impact of temperature on MG dye adsorption. As the temperature was elevated from 303 to 353 K, the rate of MG adsorption on Sn-ZrO₂ nanocomposites decreased, as shown in Fig. 7(a). This suggests that the adsorption process was somewhat endothermic.

Influence of contact time: Analyzing the effect of the time of contact is important because the results of this type of study provide basic information about the rate at which the adsorption process reaches

equilibrium. The effect of altering the contact time within the range of 15 to 20 minutes on the adsorption capacity was examined, keeping all other parameters fixed. The experiment started with fast dye adsorption, which gradually slowed down when the equilibrium condition was approached after around 15-20 minutes, based on the results displayed in Fig 7(b).

Fig. 8 outlines a proposed mechanism for the formation of Sn-ZrO₂ nanocomposites. Amorphous hydrous oxide precipitates are formed when zirconium nitrate is hydrolyzed in aqueous circumstances, resulting in Zr(OH)₄, which is naturally unstable and prone to condensation processes (Muthulakshmi et al. 2023; Chelliah et al. 2023). These condensation reactions are catalyzed by the hydroxyl groups present in banana peel extract, which are renowned for their antioxidant properties.

Meanwhile, in the aqueous solution, tin chloride quickly separates into tin and chloride ions. As seen in the Fig. 8, the reducing phytochemicals in the extract bind and cap the tin ions to produce stable nanoparticles. The primary organic substances accountable for this process include the carotenoids and other phytonutrients found in banana peel extract, as well as anthocyanins, delphinidin, cyaniding, and catecholamines (Hikal et al 2022). The resultant Sn-ZrO₂ nanocomposites are then subjected to a 500°C calcination process in order to remove remaining phytochemical residue and water molecules.

Antimicrobial activities of synthesised Sn-ZrO₂ nanocomposites

Green synthesized Sn-ZrO₂ nanocomposites and ZrO₂ nanoparticles were tested against Gram positive and Gram negative bacteria, including *B. subtilis*, *S. aureus*, *K. pneumonia* and *P. aeruginosa*. Fig. 9 illustrates the zone of inhibition observed in bacteria due to the synthesized Sn-ZrO₂ nanocomposites at four different concentrations, compared to ZrO₂ nanoparticles. At an 80 µg/mL concentration of Sn-ZrO₂ nanocomposites, the largest zone of inhibition was recorded for *K. pneumoniae* (21 mm), followed by *B. subtilis* (20 mm). The smallest inhibitory zone was observed for *S. aureus* (5 mm) at a 20 µg/mL concentration of Sn-ZrO₂ nanocomposites. Through conducting studies with varying concentrations of nanocomposites, we discovered that the zone of inhibition rises as the concentration of Sn-ZrO₂ nanocomposites increases (Table 1). Bacterial membrane integrity is further compromised by lipid peroxidation, which is influenced by elevated levels of ROS. As the concentration of nanoparticles rises, the breakdown of the bacterial cell wall causes the bacteria to die (Ozdal et al. 2022). The likelihood that the nanoparticles will penetrate and harm the bacterial membrane increases with their size (Ozdal et al. 2022). The passage of nanoparticles across the plasma membrane has been facilitated by the presence of ion channels and transporter protein (Chen et al. 2020). The increase level of ROS affects lipid peroxidation in bacteria which further influence the integrity of bacterial membrane. The destruction of the bacterial cell wall results bacterial death with increase in concentration of nanoparticles (Juan et al. 2021).

In comparison to ZrO₂ nanoparticles, the Sn-ZrO₂ nanocomposites exhibits a larger zone of inhibition. When tin ions are released from a Sn-ZrO₂ nanocomposites, it strengthens its ability to connect with

bacterial enzymes that inactivate bio cells by breaking through their cell walls and damaging the bacteria. (Nikolova et al. 2020).

Table 1: Zone of inhibition (mm) at various concentrations of green-synthesised Sn-ZrO₂ nanocomposites and ZrO₂ nanoparticles.

Concentration	Zone of Inhibition in mm							
	Gram negative bacteria				Gram positive bacteria			
	<i>K. pneumoniae</i>		<i>P. aeruginosa</i>		<i>B. subtilis</i>		<i>S. aureus</i>	
	ZrO ₂	Sn-ZrO ₂	ZrO ₂	Sn-ZrO ₂	ZrO ₂	Sn-ZrO ₂	ZrO ₂	Sn-ZrO ₂
20µg/ml	8	12	5	8	7	9	4	5
40 µg/ml	10	13	7	10	12	14	6	8
60 µg/ml	14	17	10	15	16	18	9	12
80 µg/ml	16	21	11	18	18	20	10	13

Similarly, ZrO₂ nanoparticles and green-synthesised Sn-ZrO₂ nanocomposites were tested for their antifungal properties against two different fungi, *C. albicans* and *C. tropicalis*, as shown in Fig. 10. The synthesized Sn-ZrO₂ nanocomposites had strong antifungal activity against *C. albicans*, but only weak activity against *C. tropicalis*. As shown in Table 2, a relatively small amount of green Sn-ZrO₂ nanocomposites (20 µg/mL) was sufficient to disrupt the fungal cell membrane and ultimately kill the fungi. Comparing the antifungal activity of the synthesized Sn-ZrO₂ nanocomposites to ZrO₂ nanoparticles, it demonstrates a greater zone of inhibition of Sn-ZrO₂ nanocomposites much like the antibacterial assay. The higher antifungal activity of synthesised Sn-ZrO₂ nanocomposites was partly attributed to the smaller particle size attained through sonication. This is because smaller particles have a larger surface to volume ratio, which permits more drug molecules to be adsorbed on the surface. These molecules are anticipated to act as a powerful agent in breaking down cell walls (Bruna et al. 2021). The findings show that, in comparison to ZrO₂ nanoparticles, synthesized Sn-ZrO₂ nanocomposites is a more effective antimicrobial agent with a greater potential to kill germs.

Table 2: Zone of inhibition (mm) at different concentrations of green synthesised Sn-ZrO₂ nanocomposites and ZrO₂ nanoparticles against *C. albicans* and *C. tropicalis*

Concentration	Zone of Inhibition in mm			
	<i>C. albicans</i>		<i>C. tropicalis</i>	
	ZrO ₂	Sn-ZrO ₂	ZrO ₂	Sn-ZrO ₂
20µg/ml	4	8	2	4
40 µg/ml	6	9	4.2	6.5
60 µg/ml	9.2	11	6	8.3
80 µg/ml	11.5	13	9	10.4

Nonetheless, *Musa paradisiaca* has long been a well-known traditional herb used in medicinal field. Its exceptional biological potentials are an added benefit, and combined with the potent biological properties of tin and ZrO₂, these properties would greatly encourage the green synthesis of Sn-ZrO₂ nanocomposites utilizing this well-known herb. Previous research has also shown that biosynthesised nanoparticles have potent antimicrobial efficacy than pure chemically synthesized nanoparticles. (Khan et al. 2020).

Antioxidant activity of Sn-ZrO₂ nanocomposites

Free radicals are neutralized by an antioxidant substance, which halts the oxidation process. Green synthesised Sn-ZrO₂ nanocomposites and ZrO₂ nanoparticles were tested against DPPH at various doses in an antioxidant assay (Fig. 11a). Significantly, Sn-ZrO₂ nanocomposites showed higher radical scavenging activity than ZrO₂ nanoparticles, indicating that the inclusion of tin particles improves the antioxidant nature of nanocomposites by effectively separating electron-hole pairs (Tran et al. 2022). The findings demonstrated that the Sn-ZrO₂ nanocomposites inhibits DPPH activity in a dose-dependent manner, means that radical scavenging assay enhances with the increase in concentration of the nanocomposites.

The antioxidant experiment was conducted against ABTS using varying quantities of ZrO₂ nanoparticles and green synthesised Sn-ZrO₂ nanocomposites (Fig. 11b). Peels of *Musa paradisiaca* are rich in bioactive substances (polyphenols and oils containing essential fatty acids) that may be able to be scavenged because of their hydroxyl groups (Widoyanti et al. 2023). Similar to DPPH scavenging, dose-dependent action for ABTS was also observed. At greater concentrations, the green-synthesised Sn-ZrO₂ nanocomposites demonstrated stronger activity in blocking the ABTS radical than ZrO₂ nanoparticles.

Musa paradisiaca peel extract contains phytochemicals, which are well-known for their antioxidant qualities. Tin and ZrO₂'s inherent antioxidant properties also contributes to the extract's increased scavenging activity, making it more powerful and active. Based on the aforementioned findings, it can be concluded that the environmentally friendly green Sn-ZrO₂ nanocomposites, synthesized using *Musa paradisiaca* peel extract under ultrasound irradiation, is a more viable option for antioxidant drugs

compared to ZrO_2 nanoparticles and serves as a superior alternative to chemically synthesized options.

Plausible mechanism responsible for the different applied dimensions of Sn-ZrO_2 nanocomposites

Fig. 12 illustrates a plausible mechanism for the application of Sn-ZrO_2 nanocomposites in the adsorption potential, antimicrobial activity and antioxidant activity. Through metabolic processes, biogenic Sn-ZrO_2 nanocomposites most likely interacts with the membranes and cell walls of bacteria. They are more likely to produce ROS, which can lead to a variety of problems, including the deactivation of vital enzyme and protein functions. Consequences include rupture of the cell membrane, cytoplasmic leakage, damage to proteins, DNA, and mitochondria, and finally, cell death (Kumar et al. 2020). The Sn-ZrO_2 nanocomposites, which was created from banana peel extract, demonstrated superior efficacy in scavenging a range of ROS when tested for antioxidant activity using the ABTS and DPPH free radical assay (Kumar et al. 2020). The adsorption mechanism of MG dye on nanocomposites surfaces is influenced by various interactions, which are affected by specific phytochemicals. These include π - π stacking interactions between the surface of Sn-ZrO_2 nanocomposites and aromatic rings of MB, hydrogen bonding interactions between the functional groups on the nanocomposites surface and the nitrogen atoms of MG dye, and electrostatic interactions between the positively charged nitrogen atoms present on the dye and the negatively charged functional groups on the nanocomposites surface (Trieu et al. 2023).

Conclusion

This work presents the synthesis of Sn-ZrO_2 nanocomposites by means of a straightforward, economical, and environmentally sustainable method that employs *Musa paradisiaca* peel extract as a bio-reductant under ultrasonic irradiation. The reduction and stability of the nanocomposites were accomplished using the aqueous peel extract that contained phytoconstituents. The newly synthesized Sn-ZrO_2 nanocomposites was characterized by using FTIR, UV-Vis, XRD, and SEM-EDS techniques. The Sn-ZrO_2 nanocomposites was tested for antimicrobial and antioxidant properties, and dose-dependent variation was observed. When compared to ZrO_2 nanoparticles, the green-synthesised Sn-ZrO_2 nanocomposites shown superior biological activities that were comparable to benchmark. It is observed that Sn-ZrO_2 nanocomposites possess excellent adsorption capacity than ZrO_2 for MG dye. The current sonochemical synthesis process has many benefits, including low temperature, fast reaction times, and good surface dispersibility of the doped metal, which results in smaller particles with higher yields.

Declarations

Acknowledgements

The authors are highly thankful to MRC, MNIT Jaipur for providing spectroscopic facilities, and Applied Seminal Jaipur for doing antimicrobial and antioxidative studies of the samples.

Authors' contributions

S.S. - conceptualization, methodology, formal analysis, investigations, resources, supervision, writing original draft, visualization; D.B.— conceptualization, methodology, formal analysis, investigations, resources, data curation, supervision, visualization, writing — review and editing. All authors contributed to the manuscript and approved the final version for publication.

Funding

None

Data Availability

All supporting data are available in the article.

Ethics approval Not applicable.

Consent to participate Not applicable.

Consent for publication All authors approved the final manuscript.

Competing interests The authors declare no competing interests.

References

1. Alharthi F A, Alghamdi A A, Al-Zaqri N, H S. Alanazi, A A Alsyahi, A E Marghany, N Ahmad (2020) Facile one-pot green synthesis of Ag–ZnO Nanocomposites using potato peel and their Ag concentration dependent photocatalytic properties. *Sci Rep* 10: 20229. <https://doi.org/10.1038/s41598-020-77426-y>
2. Bannunah A M (2023) Biomedical Applications of Zirconia-Based Nanomaterials: Challenges and Future Perspectives. *Molecules*, 28(14): 5428. <https://doi.org/10.3390/molecules28145428>
3. Bao Y, He J, Song K, Guo J, Zhou X, Liu S (2021) Plant-Extract-Mediated Synthesis of Metal Nanoparticles. *J. Chem.*, 2021:| 6562687. <https://doi.org/10.1155/2021/6562687>
4. Barbasz A M, Dyba B (2024) Direct Interaction of Zirconia Nanoparticles with Human Immune Cells. *Biophysica*, 4(1): 83-91; <https://doi.org/10.3390/biophysica4010006>
5. Bhardwaj D, Singh A, Singh R (2019). Eco-compatible sonochemical synthesis of 8-aryl-7,8-dihydro-[1,3]-dioxolo[4,5-g]quinolin-6(5H)-ones using green TiO₂. *Heliyon*. 5 (2), e01256. <https://doi.org/10.1016/j.heliyon.2019.e01256>.
6. Bhardwaj D, Singh R (2021) Green biomimetic synthesis of Ag–TiO₂ nanocomposite using *Origanum majorana* leaf extract under sonication and their biological activities. *Bioresour. Bioprocess.* 8: 1. <https://doi.org/10.1186/s40643-020-00357-z>

7. Bharti K, Sadhu K K (2022) Syntheses of metal oxide-gold nanocomposites for biological applications. *Res. Chem.* 4:100288. <https://doi.org/10.1016/j.rechem.2022.100288>
8. Bruna T, Maldonado-Bravo F, Jara P, Caro N (2021) Silver Nanoparticles and Their Antibacterial Applications. *Int J Mol Sci.* 22(13): 7202. doi: 10.3390/ijms22137202
9. Bukhari A, Ijaz I, Gilani E, Nazir A, Zain H, Saeed R, Alarfaji S S, Hussain S, Aftab R, Naseer Y (2021) Green Synthesis of Metal and Metal Oxide Nanoparticles Using Different Plants' Parts for Antimicrobial Activity and Anticancer Activity: A Review Article. *Coatings* 11(11): 1374. <https://doi.org/10.3390/coatings11111374>
10. Chelliah P, Wabaidur S M, Sharma H P, Majdi H S, Smail D A, Najm M A, Iqbal A, Lai W-C (2023) Photocatalytic Organic Contaminant Degradation of Green Synthesized ZrO₂ NPs and Their Antibacterial Activities. *Separations*, 10: 156. <https://doi.org/10.3390/separations10030156>
11. Chen L, Yang J, Li X, Liang T, Nie C, Xie F, Liu K, Peng X, Xie J (2020) Carbon nanoparticles enhance potassium uptake via upregulating potassium channel expression and imitating biological ion channels in BY-2 cells. *J Nanobiotechnol.* 18: 21. <https://doi.org/10.1186/s12951-020-0581-0>
12. Długosz O, Banach M, (2021) ZnO–SnO₂–Sn nanocomposite as photocatalyst in ultraviolet and visible light. *Appl Nanosci.* 11: 1707–1719. <https://doi.org/10.1007/s13204-021-01788-6>.
13. Haleem A, Javaid M, Singh R P, Rab S, Suman R (2023) Applications of nanotechnology in medical field: a brief review. *Global Health Journal*, 7: 70-77. <https://doi.org/10.1016/j.glohj.2023.02.008>
14. Haq S, Afsar H, Ali M B, Almalki M, Albogami B, Hedfi A (2021) Green Synthesis and Characterization of a ZnO-ZrO₂ Heterojunction for Environmental and Biological Applications. *Crystals*, 11(12):1502; <https://doi.org/10.3390/cryst11121502>
15. Hassaan M A, El-Nemr M A, Elkatory M R Ragab S, Niculescu V-C, Nemr A E (2023) Principles of Photocatalysts and Their Different Applications: A Review. *Top Curr Chem (Z)* 381: 31. <https://doi.org/10.1007/s41061-023-00444-7>
16. Hikal W M, Said-Al Ahl H A H, Bratovcic A, Tkachenko K G, Sharifi-Rad J, Kačániová M, Elhourri M, Atanassova M (2022) Banana Peels: A Waste Treasure for Human Being. *Evid Based Complement Alternat Med.*, 2022: 7616452. doi: 10.1155/2022/7616452. eCollection 2022
17. Horti N C, Kamatagi M D, Nataraj S K, Wari M N, Inamdar S R (2020) Structural and optical properties of zirconium oxide (ZrO₂) nanoparticles: effect of calcination temperature. *Nano Express* 1: 010022. DOI 10.1088/2632-959X/ab8684
18. Joudeh N, Linke D (2022) Nanoparticle classification, physicochemical properties, characterization, and applications: a comprehensive review for biologists. *J Nanobiotechnol* 20: 262. <https://doi.org/10.1186/s12951-022-01477-8>
19. Khairani I Y, Mínguez-Vega G, Doñate-Buendía C, Gökce B (2023), Green nanoparticle synthesis at scale: a perspective on overcoming the limits of pulsed laser ablation in liquids for high-throughput production. *Phys. Chem. Chem. Phys.*, 25: 19380-19408. DOI: 10.1039/D3CP01214J
20. Khan M, Shaik M R, Khan S T, Adil S F, Kuniyil M, Khan M, Al-Warthan A A, Siddiqui M R H, Tahir M N (2020) Enhanced Antimicrobial Activity of Biofunctionalized Zirconia Nanoparticles. *ACS Omega* 5:

1987–1996.

21. Khattab E-S R, El Rehim S S A, Hassan W M I, El-Shazly T S (2021) Band Structure Engineering and Optical Properties of Pristine and Doped Monoclinic Zirconia (m-ZrO₂): Density Functional Theory Theoretical Prospective. *ACS Omega* 6: 30061–30068. <https://doi.org/10.1021/acsomega.1c04756>
22. Kumar H, Bhardwaj K, Kuča K, Kalia A, Nepovimova E, Verma R, Kumar D (2020) Flower-based green synthesis of metallic nanoparticles: applications beyond fragrance. *Nanomaterials*, 10(4): 766. <https://doi.org/10.3390/nano10040766>
23. Kumari N, Sareen S, Verma M, Sharma S, Sharma A, Sohal H S, Mehta S K, Park J, Mutreja V (2022) Zirconia-based nanomaterials: recent developments in synthesis and applications. *Nanoscale Adv.* 4(20): 4210–4236. doi: 10.1039/d2na00367h
24. Lastra C J M P, Plou F J, Pérez-Lebeña E (2021) The Chemistry of Reactive Oxygen Species (ROS) Revisited: Outlining Their Role in Biological Macromolecules (DNA, Lipids and Proteins) and Induced Pathologies. *Int. J. Mol. Sci.* 22(9): 4642. <https://doi.org/10.3390/ijms22094642>
25. Mammari N, Lamouroux E, Boudier A, Duval R E (2022) Current Knowledge on the Oxidative-Stress-Mediated Antimicrobial Properties of Metal-Based Nanoparticles. *Microorganisms*, 10(2): 437. <https://doi.org/10.3390/microorganisms10020437>
26. Muthulakshmi N, Kathirvel A, Senthil M, Subramanian (2023) Green synthesis of zirconia nanoparticles and their characterization, anticancer activity and corrosion inhibition properties. *R, J. Ind. Chem. Soc.*, 100 (10): 101076. <https://doi.org/10.1016/j.jics.2023.101076>
27. Nair G M, Sajini T, Mathew B (2022) Advanced green approaches for metal and metal oxide nanoparticles synthesis and their environmental applications. *Talanta Open*, 2022: 100080. <https://doi.org/10.1016/j.talo.2021.100080>
28. Narayanan K, Sakthivel C, Inbaraj P (2019) MgO-ZrO₂ Mixed Nanocomposites: Fabrication Methods and Applications. *Mater. Today Sustain.*, 3-4(2): 100007. 10.1016/j.mtsust.2019.100007
29. Nikolova M P, Chavali M S (2020) Metal Oxide Nanoparticles as Biomedical Materials. *Biomimetics*, 5(2), 27; <https://doi.org/10.3390/biomimetics5020027>
30. Ohiduzzaman M, Khan M N I, Khan K A, Paul B (2024) Biosynthesis of silver nanoparticles by banana pulp extract: Characterizations, antibacterial activity, and bioelectricity generation. *Heliyon*, 10: e25520. <https://doi.org/10.1016/j.heliyon.2024.e25520>
31. Ozdal M, Gurkok S (2022) Recent advances in nanoparticles as antibacterial agent. *ADMET DMPK*. 10(2): 115–129. doi: 10.5599/admet.1172
32. Sagadevan S, Podder J, Das I (2016) Hydrothermal synthesis of zirconium oxide nanoparticles and its Characterization. *J Mater Sci: Mater Electron* 27:5622–5627. DOI 10.1007/s10854-016-4469-6
33. Sandhya M, Ramasamy D, Sudhakar K, Kadirgama K, Haruna W S W (2021) Ultrasonication an intensifying tool for preparation of stable nanofluids and study the time influence on distinct properties of grapheme nanofluids – A systematic overview. *Ultrason Sonochem.* 73: 105479. doi: 10.1016/j.ultsonch.2021.105479

34. Shafey A M E (2020) Green synthesis of metal and metal oxide nanoparticles from plant leaf extracts and their applications: A review. *Green Processing and Synthesis*, 9: 304-339.
<https://doi.org/10.1515/gps-2020-0031>
35. Sharma S (2022) Structure-activity relationship of some pentacoordinated Tributyltin(IV) complexes derived from sterically hindered Schiff bases of heterocyclic β -diketones. *J. Ind. Chem. Soc.*, 99(6): 100464. <https://doi.org/10.1016/j.jics.2022.100464>
36. Sharma S, Kumar P, Jain A, Saxena S (2018) Synergy Between DFT Calculations and Experimental Studies on the Optimized Structures and the Antibacterial Potential of Some Novel Tetra- and Penta Coordinated Organic- Inorganic Hybrid Complexes of Titanium(IV). (2018), *Appl. Organomet. Chem.*, 32(6): e4321. <https://doi.org/10.1002/aoc.4321>
37. Sharma S, Kumar R, P Kumar, Jain A, Saxena S (2019) New insights into the predicament of DFT assisted optimized energy, stability and distortions of optimized topologies of some novel complexes of Zirconium (IV) and enhancement of antimicrobial potential. *Appl. Organomet. Chem.*, 33(10): e5080. <https://doi.org/10.1002/aoc.5080>
38. Shen L, Pang S, Zhong M, Sun Y, Qayum A, Liu Y, Rashid A, Xu B, Liang Q, Ma H, Ren X (2023) A comprehensive review of ultrasonic assisted extraction (UAE) for bioactive components: Principles, advantages, equipment, and combined technologies. *Ultrasonics Sonochemistry*, 101: 106646. <https://doi.org/10.1016/j.ultsonch.2023.106646>
39. Sohail M, Baig N, Sher M, Jamil R, Altaf M, Akhtar S, Sharif M (2020) A Novel Tin-Doped Titanium Oxide Nanocomposite for Efficient Photo-Anodic Water Splitting. *ACS Omega*, 5: 6405–6413. <https://dx.doi.org/10.1021/acsomega.9b03876>.
40. Szczyglewska P, Feliczak-Guzik A, Nowak I (2023) Nanotechnology–General Aspects: A Chemical Reduction Approach to the Synthesis of Nanoparticles. *Molecules*. 28(13): 4932. doi: 10.3390/molecules28134932
41. Talam S, Karumuri S R, Gunnam N (2012) Synthesis, Characterization, and Spectroscopic Properties of ZnO Nanoparticles. *ISRN Nanotechnol.* 372505. <https://doi.org/10.5402/2012/372505>
42. Tran T V, Nguyen D T C, Kumar P S, Din A T M, Jalil A A, Vo D-V N (2022) Green synthesis of ZrO₂ nanoparticles and nanocomposites for biomedical and environmental applications: a review. *Environ Chem Lett.* 20(2): 1309–1331.
43. Trieu, N D T, Nguyen, T T N, Nguyen, T T T, Nguyen, T C D, Tran T V (2023) A comparative study on the malachite green dye adsorption of chemically synthesized and green MgFe₂O₄ nanoparticles using gerbera floral waste extract. *Environ Sci Pollut Res.* <https://doi.org/10.1007/s11356-023-29779-w>
44. Verma D, Sharma S, Vashishtha M (2022) Evaluation of optimized molecular structure-antimicrobial and antioxidant efficacy relationship of Schiff Bases. *Environ. Sci. Poll. Res.* <https://doi.org/10.1007/s11356-022-23633-1>
45. Widoyanti A A E, Chaikong K, Rangsinth P, Saengratwatchara P, Leung G P-H, Prasansuklab A (2023) Valorization of Nam Wah Banana (*Musa paradisiaca* L.) Byproducts as a Source of Bioactive

Compounds with Antioxidant and Anti-inflammatory Properties: In Vitro and In Silico Studies. *Foods*, 12(21): 3955; <https://doi.org/10.3390/foods12213955>

46. Yakout S M, Hassan H S (2014) Adsorption Characteristics of Sol Gel-Derived Zirconia for Cesium Ions from Aqueous Solutions. *Molecules*, 19: 9160-9172. doi:10.3390/molecules19079160
47. Ying S, Guan Z, Ofoegbu P C, Club P, Rico C, He F, Hong J (2022) Green synthesis of nanoparticles: Current developments and limitations. *Environmental Technology & Innovation*, 26: 102336. <https://doi.org/10.1016/j.eti.2022.102336>
48. Ying S, Guan Z, Ofoegbu P C, Clubb P, Rico C, He F, J Hong (2022) Green synthesis of nanoparticles: Current developments and limitations. *Environ. Technol. Innov.*, 26: 102336. <https://doi.org/10.1016/j.eti.2022.102336>

Figures

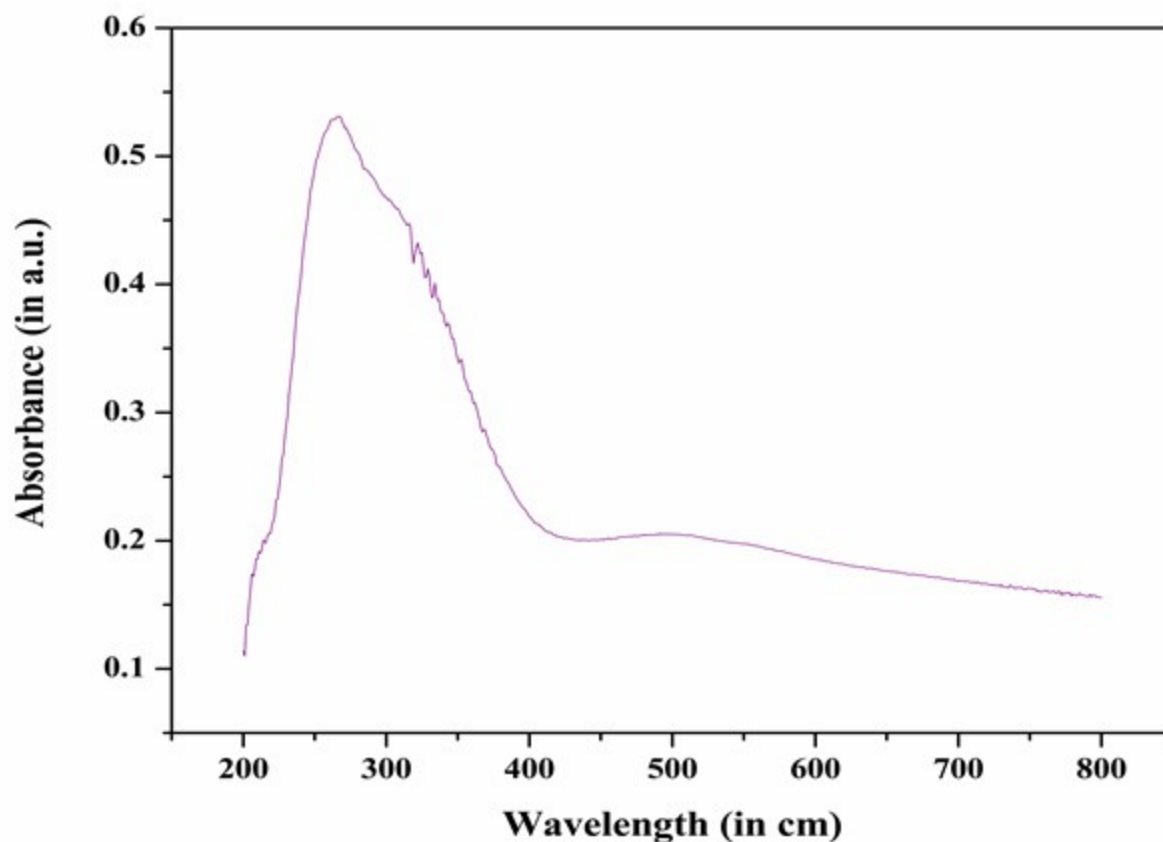


Figure 1

UV-Vis absorption spectrum for Sn-ZrO₂ nanocomposites

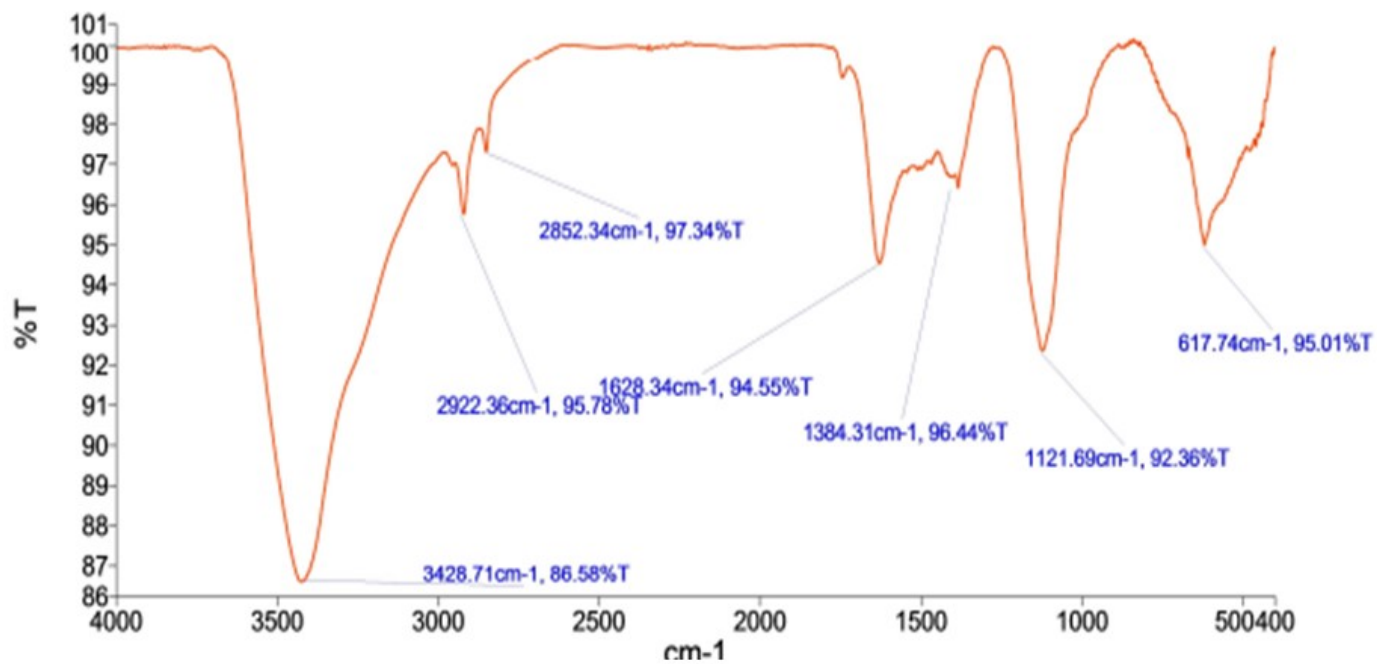


Figure 2

FTIR spectrum for green synthesised Sn-ZrO₂ nanocomposites

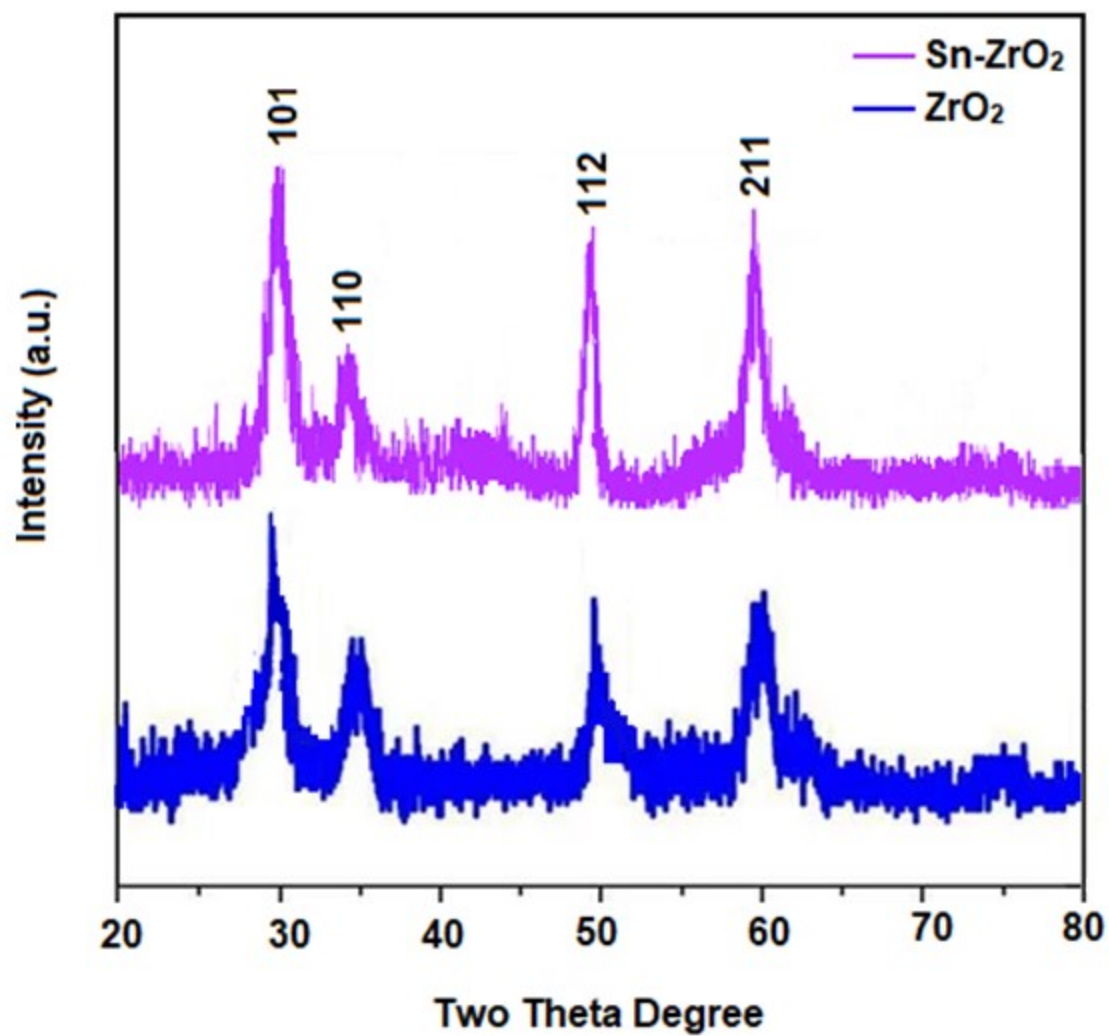


Figure 3

XRD patterns of Sn-ZrO₂ nanocomposites and ZrO₂ nanoparticles

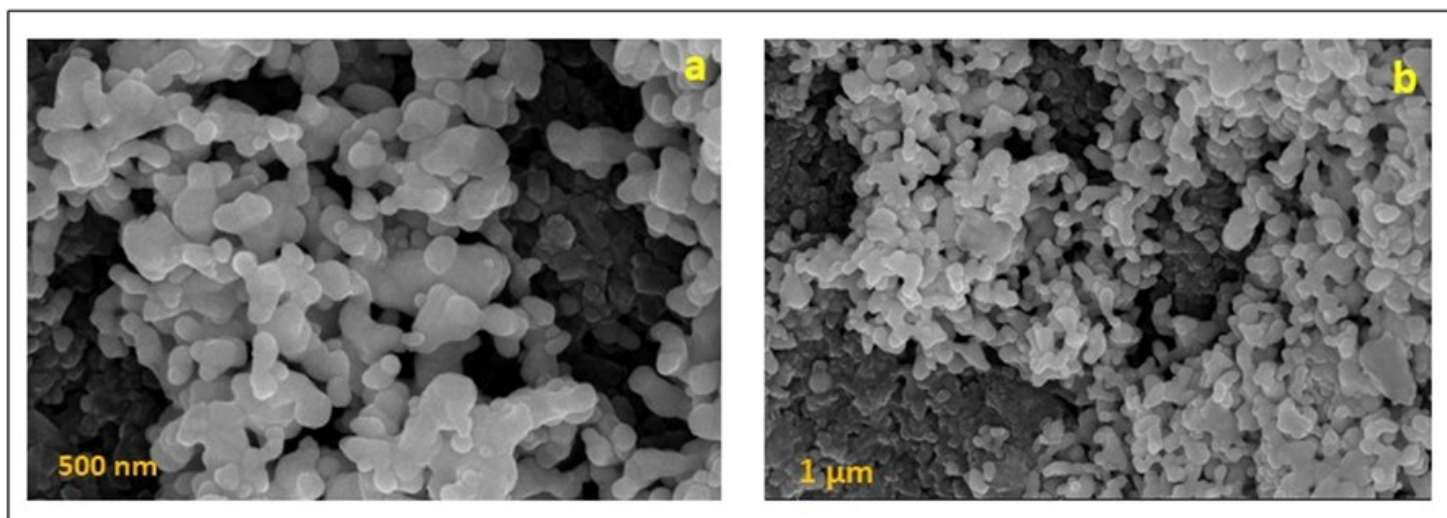


Figure 4

(a) SEM image of Sn-ZrO₂ nanocomposites with magnification at 500nm; (b) SEM image of Sn-ZrO₂ nanocomposites with magnification at 1μm.

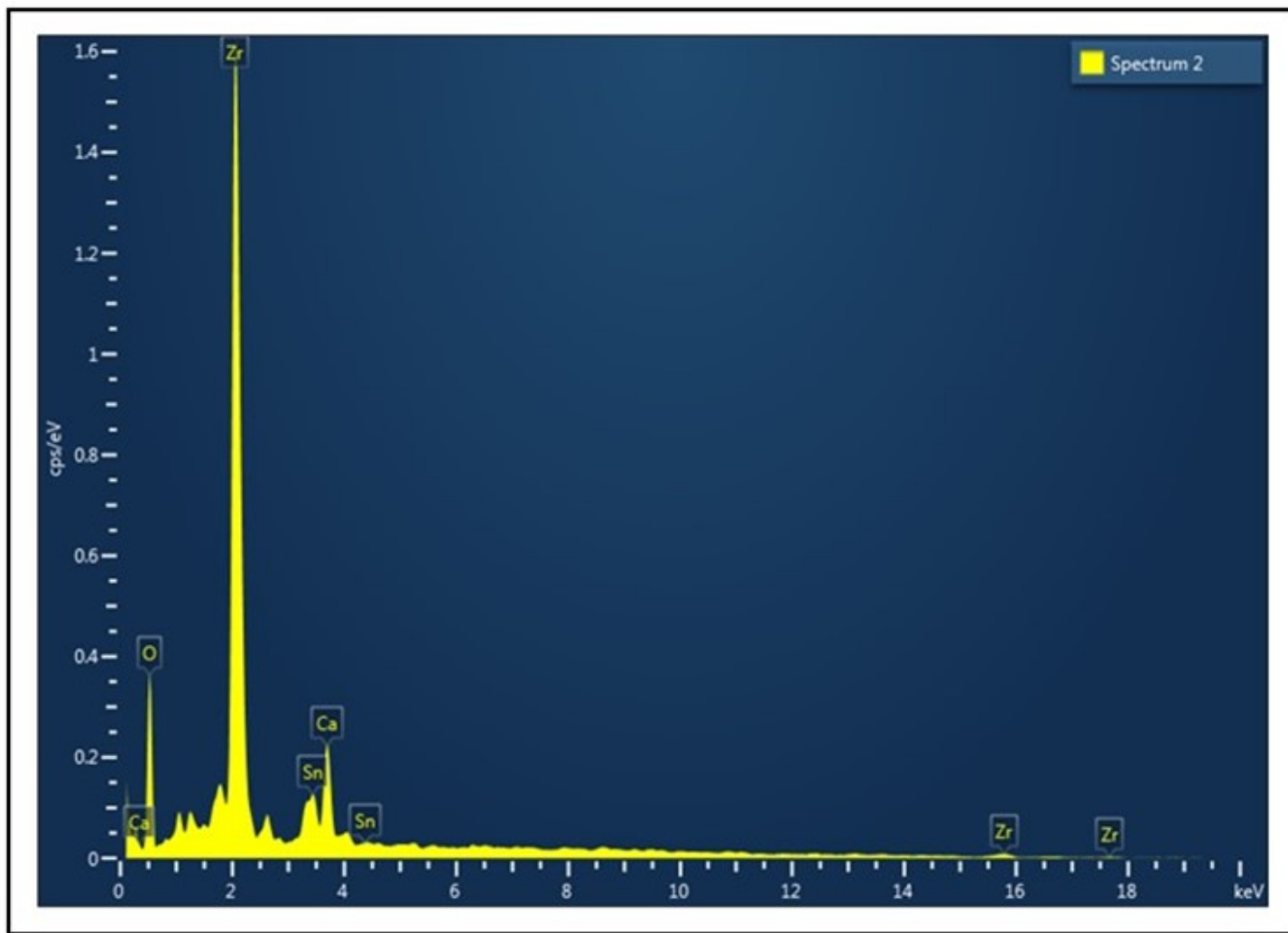
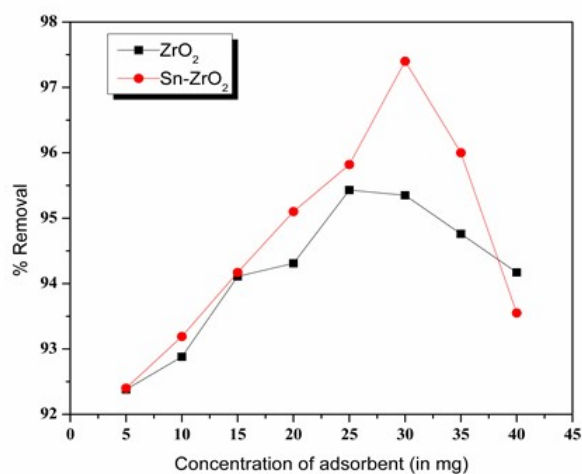
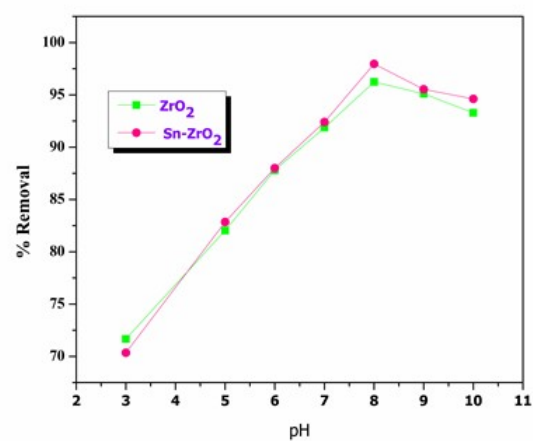


Figure 5

EDS spectrum of green synthesised Sn-ZrO₂ nanocomposites



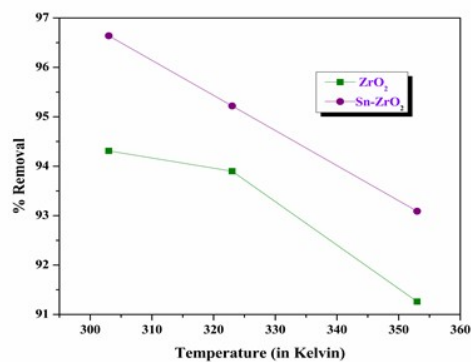
(a)



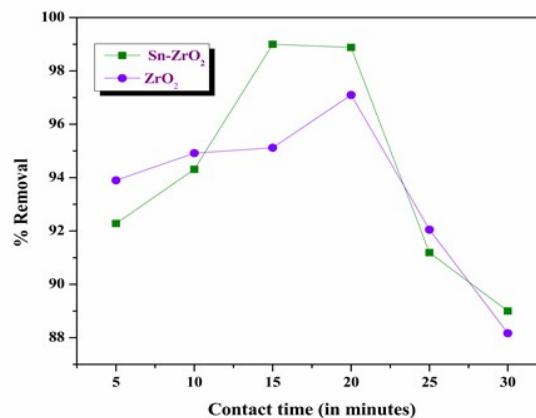
(b)

Figure 6

(a) Removal percentage of malachite green with different adsorbent dosage and (b) Variation of removal percentage of malachite green with variable pH range



(a)



(b)

Figure 7

(a) Alteration of removal (%) with temperature and (b) Change in removal (%) with time

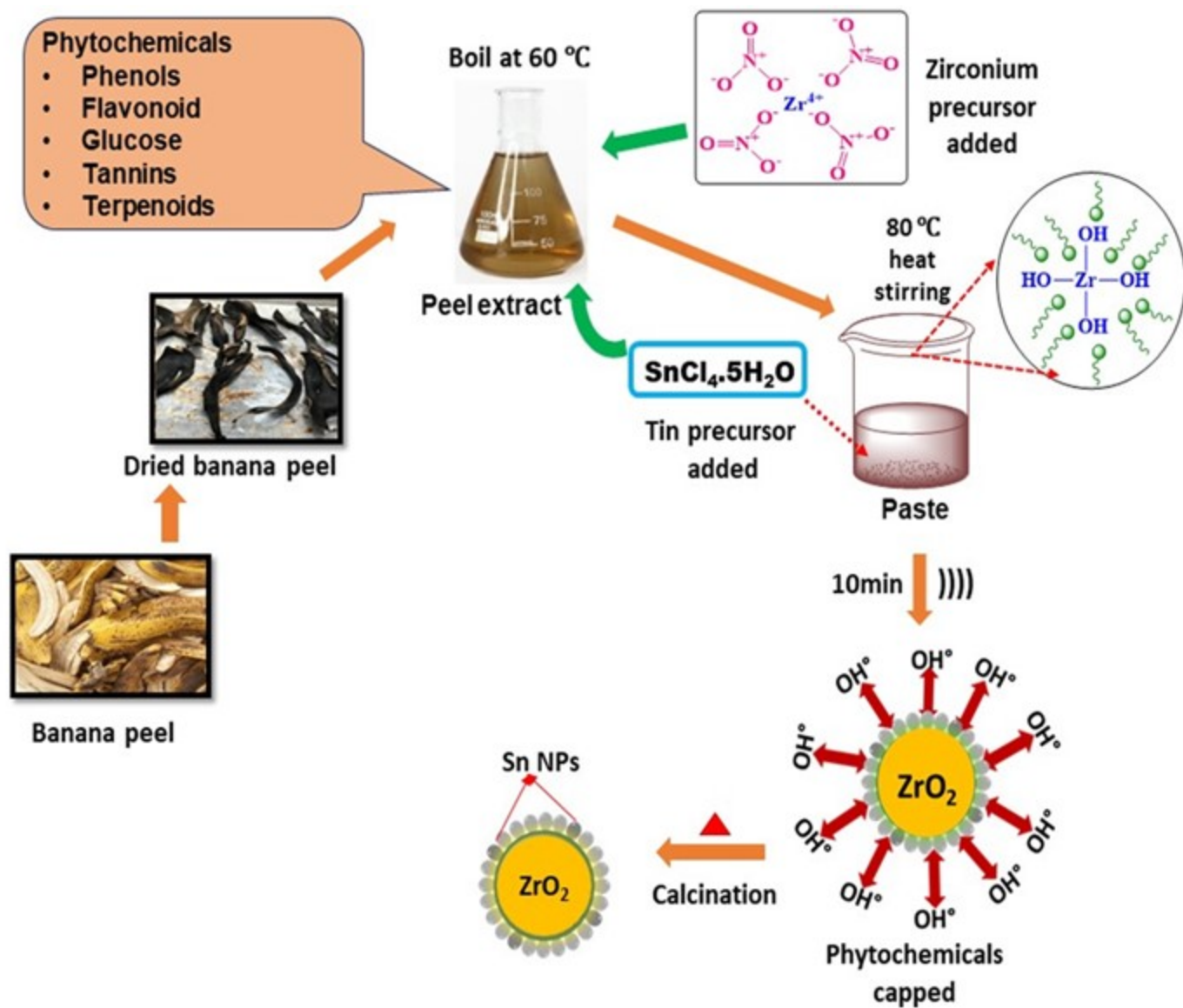
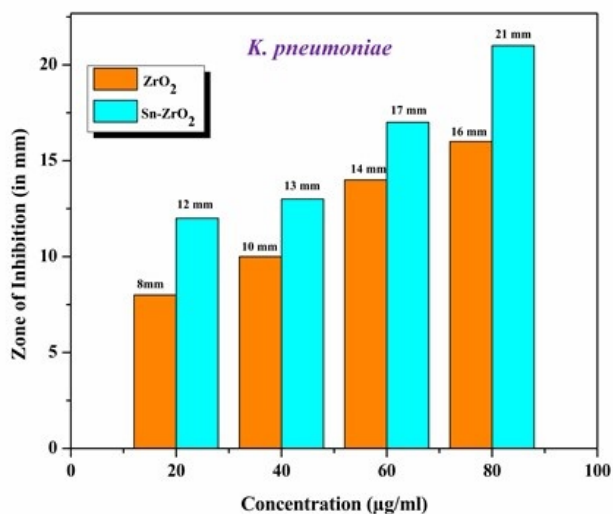
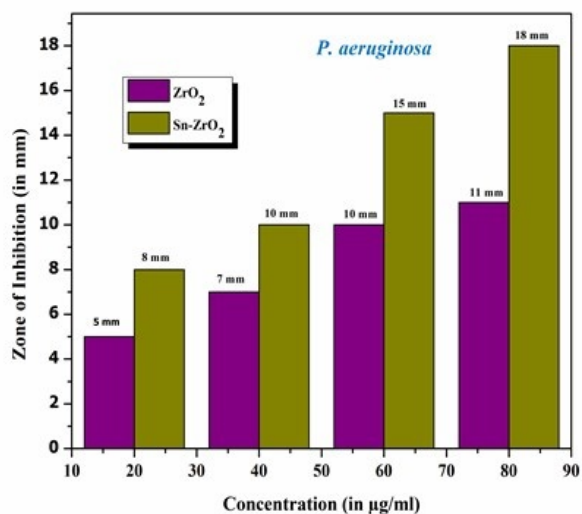


Figure 8

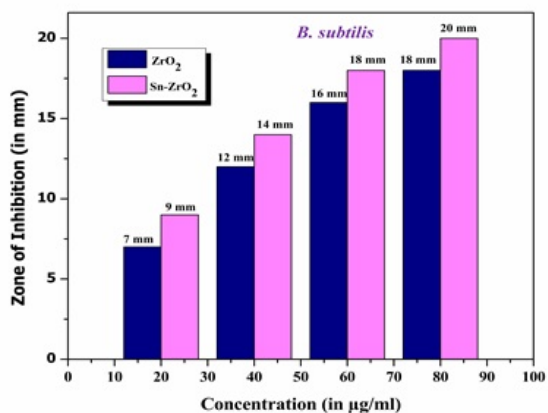
Mechanism for the formation of Sn-ZrO₂ nanocomposites using banana peel extract



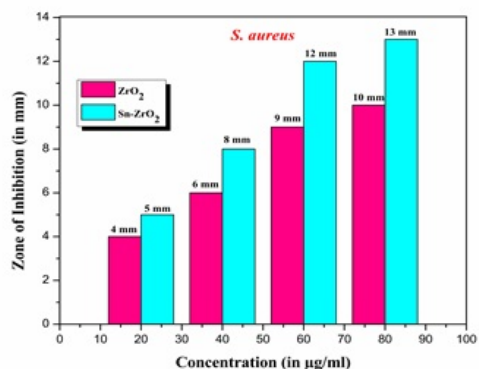
(a)



(b)



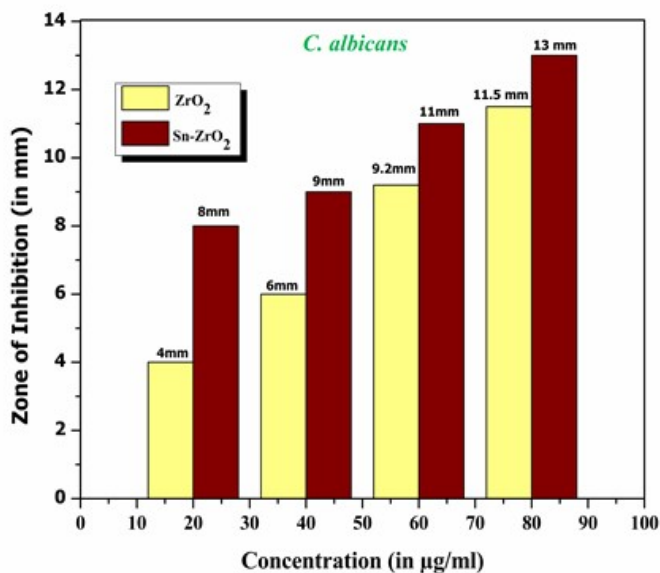
(c)



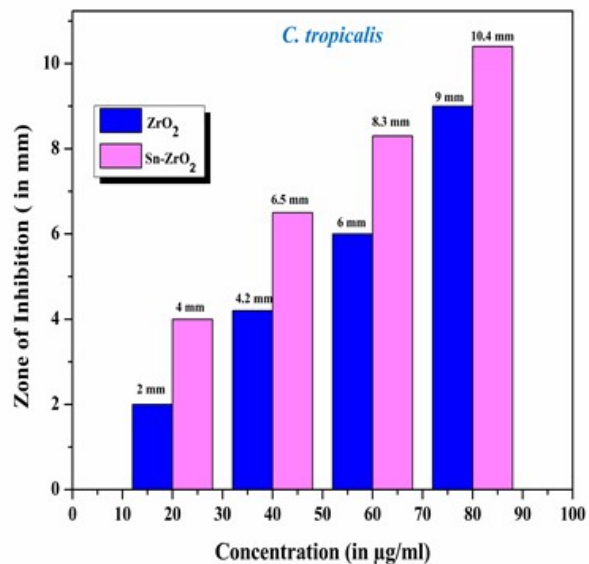
(d)

Figure 9

Green-synthesised Sn-ZrO₂ nanocomposites and ZrO₂ nanoparticles exhibit antibacterial activity against four pathogens: (a) *K. pneumoniae*, (b) *P. aeruginosa*, (c) *B. subtilis*, and (d) *S. aureus*, at varying doses.



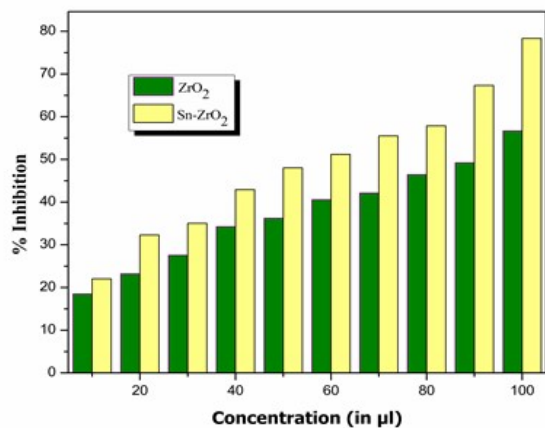
(a)



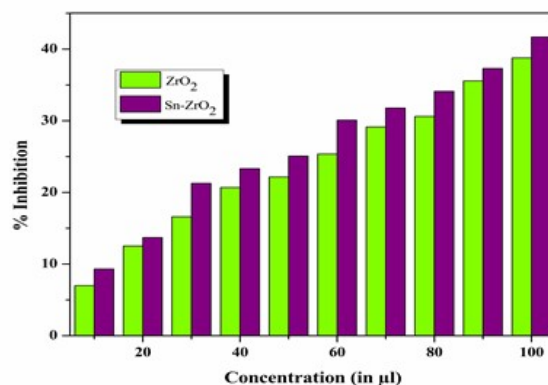
(b)

Figure 10

Antifungal activity of green synthesised Sn-ZrO₂ nanocomposites and ZrO₂ nanoparticles at different concentrations against two fungi (a) *C. albicans* and (b) *C. tropicalis*



(a)



(b)

Figure 11

Comparision of antioxidant activity of green synthesised Sn-ZrO₂ nanocomposites with bare ZrO₂ at different concentrations showing by (a) DPPH and (b) ABST assay

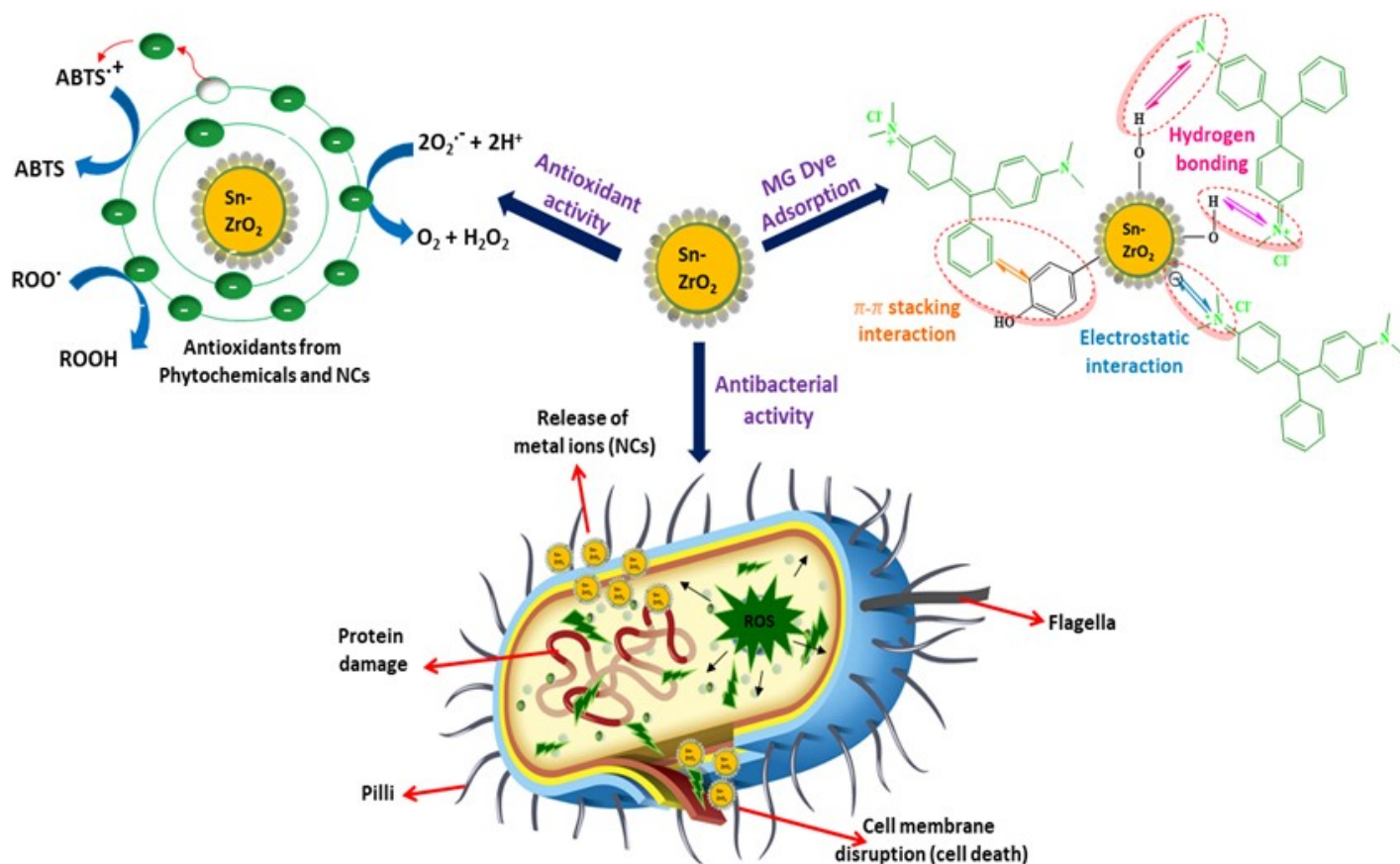


Figure 12

Plausible mechanism for the applied dimensions of Sn-ZrO₂ nanocomposites in the fields of adsorption, antioxidation and antimicrobial potential.

Supplementary Files

This is a list of supplementary files associated with this preprint. Click to download.

- [abstractforBioresource2.jpg](#)