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Synthesis and Zn Doping's Impact on CeO₂ Nanoparticles for Improved Photocatalytic Evaluation, Antibacterial and Anticancer Analyses

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Abstract: This work uses *Psidium guajava* leaf extracts to easily and quickly synthesise Cerium nanoparticles (Ce NPs) and Zn: CeO₂ NPs (Zn-Ce NPs) (PGE). The generated G - CeO₂ and Zn: CeO₂ NPs were examined using X-ray diffraction (XRD), Energy Dispersive Analysis of X-Ray (EDAX), Fourier transformed infrared spectroscopy (FT-IR), UV-Visible spectroscopy (UV-Vis), and Scanning Electron Microscopy (SEM) techniques. The presence of OH, -NH₂, and C=O groups, which were essential for the synthesis of G-CeO₂ and Zn: CeO₂ NPs, was detected by FT-IR spectroscopy. The XRD analysis supports the fluorite cubic structure of the resulting particles for G-CeO₂ and Zn: CeO₂ NPs. The findings of the elemental analysis by EDX demonstrated that the doping effects of Zn²⁺ in G-CeO₂ NPs effectively enhanced the percentages of cerium and oxygen. G-CeO₂ and Zn: CeO₂ nanoparticles were evenly dispersed, and a SEM microscopic investigation also revealed that the produced nanoparticles were spherical in shape. Both the G-CeO₂ and Zn: CeO₂ nanoparticles demonstrated effective antibacterial and antifungal properties. To measure photocatalytic activity, the degradation of methylene blue (MB) in aqueous solution under visible light irradiation was utilised. The findings demonstrated that Zn doping considerably increased Ce NPs' photocatalytic activity. Using Zn dopant, it has been discovered that the optical band gap of Ce NPs has decreased from 3.69 eV to 3.55 eV. Both the G-CeO₂ and Zn: CeO₂ nanoparticles demonstrated effective antibacterial and antifungal properties. By increasing the concentration of both G-CeO₂ and Zn: CeO₂ NPs, the viability of the cancer cells L929 and HCT 116 was partly reduced.

Keywords: XRD, SEM, Photoluminescence, EDAX, Zn:CeO₂ Nanoparticles, Photocatalyst, Cytotoxicity

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Introduction

Nanoparticles and nanomaterials are finding new applications in a number of sectors due to their increased properties based on size, distribution,

and form (Panahi-Kalamuei *et al.*, 2015). Several techniques, including hydrothermal, solvothermal, sol-gel, co-precipitation, and microwave assisted

synthesis were used to create these nanoparticles. Green synthesis techniques, which employ natural resources including plant leaf extracts, bacteria, fungi, and algae to synthesise nanoparticles without producing any toxic byproducts, have recently been described (Mahmud, 2016). Because there is no bacterial activity, no chemical contamination, less energy is used, and the process is simpler and more straightforward, using plant resources which may be more advantageous for creating cerium nanoparticles than using chemical and bacterial techniques. Biosynthesized Ce NPs are generating a lot of attention in the medical industry due to their broad spectrum of antibacterial and antioxidant activities, as well as their eco-friendly, biocompatible, and cost-effective qualities (Rahman and Radhakrishnan, 2019). The production of cerium nanoparticles is of great interest to the scientific community due to their wide range of applications. These cerium nanoparticles are very effective in both diagnosing and treating cancer. A photocatalytic substance with great efficiency is cerium oxide. Because of its potential applications in oxygen sensors, fuel cells, biocatalysts, photocatalysts, optical devices, and UV absorbers, CeO₂-NPs have received a lot of attention in the nanotechnology community (Al-Tuwirqi *et al.*, 2011). Many common components found in plant extracts, including tannins, flavonoids, and terpenoids, serve as stabilising agents during the production of nanoparticles. Through the manufacture of CeO₂ NPs, we have used *Psidium guajava* tree leaf extract as a stabilising agent in this study. A prominent medicinal plant, *Psidium guajava*, is grown extensively across central Asia, particularly in the north-east of Iran. *Psidium guajava* is a notable medicinal plant whose leaves' extract may play a crucial part in the treatment of cancer. *Psidium guajava* is a traditional medicine that has been shown to have cytotoxic effects on cancer cell lines (Al-Tuwirqi *et al.*, 2011).

Materials and Methods

Collecting of plant leaves and extract preparation:

The *Psidium guajava* tree's fresh leaves were gathered in Tamil Nadu, India's Pudukkottai area. The leaves were recognised in the Rapinant Herbarium at the St. Joseph's College (Autonomous) Tiruchirappalli, Centre for Molecular Systematics and stored in the hot air oven at 60°C for 24 to 48 h after being air dried for 10 days in the shade. The dried leaves were powdered after drying. 100 ml of double-distilled water was added to 10 g of finely chopped *Psidium guajava* leaves, and the mixture was then heated for 15 min at 50-60 °C to create the extract. A 250 ml Erlenmeyer flask was used to collect the filtrate after the resultant extract was filtered using Whatman 1 filter paper for this experiment.

Zn: CeO₂ nanoparticle preparation:

The G-CeO₂ and Zn: CeO₂ NPs were made using a green approach. In a typical process, 100 ml of *Psidium guajava* leaves extract was continuously stirred with 0.095 M solutions of Ce (NO₃)₃·6H₂O and 0.005 M solutions of Zn (NO₃)₂·6H₂O. The clear solution entirely changed into a brown precipitate and subsequently took on a yellowish brown hue after being stirred continuously for 6 h at 80 °C. The precipitate was then rinsed with water and ethanol before being dried for 2 h at 80 °C. To produce powdered Zn: CeO₂ NPs, the precipitate was heated in a furnace to 400 °C for 5 h. To create powdered Zn: CeO₂ NPs, the same process was used to create G-CeO₂ nanoparticles without the addition of doping agents.

Characterization of Zn: CeO₂ NPs and G-CeO₂ NPs that are not doped:

The X-ray diffraction (XRD) patterns of the powdered samples were seen using an X-ray diffractometer that used Cu K radiation with a wavelength of 1.540 Å at 40 kV and 40 mA, and a scanning rate of 0.02 cm⁻¹ in the area of 2θ spanning between 20° and 80°. Using a model SHIMADZU-8400 Fourier Transform Infrared Spectrometer, the presence of functional groups in G-CeO₂ NPs and Zn: CeO₂ NPs were evaluated. The IR spectra were recorded in transition mode by diluting the milled powders in KBr, and the wavelength between 4000 and 400 cm⁻¹ was used to assess the

presence of functional groups. A scanning electron microscope (TESCAN VEGA3) with a magnification of 10,000 was used to evaluate the surface morphology of G-CeO₂ NPs and Zn: CeO₂ NPs. Energy-dispersive X-ray analysis (EDX) using a Brucker 129 eV was used to determine the elemental composition (per cent) of undoped G-CeO₂ NPs and Zn: CeO₂ NPs. Before being tested, the samples were mounted on copper stubs using double-sided carbon tapes, and the gold was coated using the sputtering procedure. The optical absorption spectra of the materials were captured using the UV-1650 PC SHIMADZU spectrometer. A spectrofluorometer was used to measure the photoluminescence (PL) spectra of G-CeO₂ NPs and Zn: CeO₂ NPs distributed in water (F-2500 FL Spectrophotometer, Hitachi).

Application Strategies:

Choice of Materials for Photocatalytic Activity:

By destroying MB dye under UV and visible light irradiation, G-CeO₂ NPs and Zn: CeO₂ NPs' photocatalytic activity was assessed. 18 W normal halogen lamp was utilised for visible light. 20 ppm of aqueous MB solution was combined with 1.0 mg of Zn: CeO₂ NPs, and both UV and visible light exposure was applied. Before being exposed to radiation for 80 minutes, the dye-catalyst solution was spun for 30 min in the dark. Using equation (1) (where C₀ and C_t are dye absorbance before and after irradiation at various periods, and C_t is dye absorbance after irradiation at different times), the solution was collected, filtered, and absorbance was recorded at 664 nm (UV-6100, Mapada) to calculate % degradation (t).

$$D (\%) = \frac{C_0 - C_t}{C_0} \times 100 \quad \text{-----1}$$

Antimicrobial test:

Using the well diffusion technique, the antibacterial activity of G-CeO₂ NPs was investigated against gram positive (G+) (*Bacillus subtilis* and *Staphylococcus aureus*) and gram negative (G-) (*Escherichia coli* and *Klebsiella pneumoniae*) bacterial strains. After

adding all the components to the distilled water and boiling to completely dissolve the medium, it is sterilised by autoclaving at 15 lb psi pressure (121°C) for 15 min. The Bacterial broth culture was swabbed on each Petri plate using sterile buds. Then, wells were carved using a well cutter. Leaf extracts from organic solvents were aseptically applied to each well. Prior to this stage, it was incubated overnight at 37 °C to determine the zone of inhibition levels (mm). The positive control was the widely used antibiotic Ciprofloxacin.

MTT Test:

Utilizing the HCT116 and L9293 (4, 5 dimethylthiazol-2-Yl)-2,5diphenyltetrazolium bromide (MTT) Cell viability assay, the cytotoxicity of the G-CeO₂ and Zn: CeO₂ NPs was examined *in vitro*. In order to treat the selected HCT116 and L929 viable cells, the produced G-CeO₂ NPs were suspended with MTT (50 mg) dye that was diluted in 10 ml of PBS and subjected to varied doses (2.5 to 15 g/ml) in a serum free DMEM medium. Three copies of each sample were made, and the cells in each well were grown for 24 h each time. After incubation, the drug-containing cells were rinsed with brand-new culture medium. Next, the MTT (5 mg/ml in PBS) dye was added to each well, and each well was then left at 37°C for an additional 4 h. The absorbance was calculated using a multi-well plate reader at 540 nm. The results were expressed as a percentage of stable cells compared to the control. Calculating the half maximal inhibitory concentrations (IC₅₀) values and analysing the best dosages at various times were done.

Results and Discussion

G-CeO₂ doped Zn: CeO₂ NPs XRD analysis:

The crystalline quality of the green produced Ce and Zn-doped Ce nanoparticles was shown by the

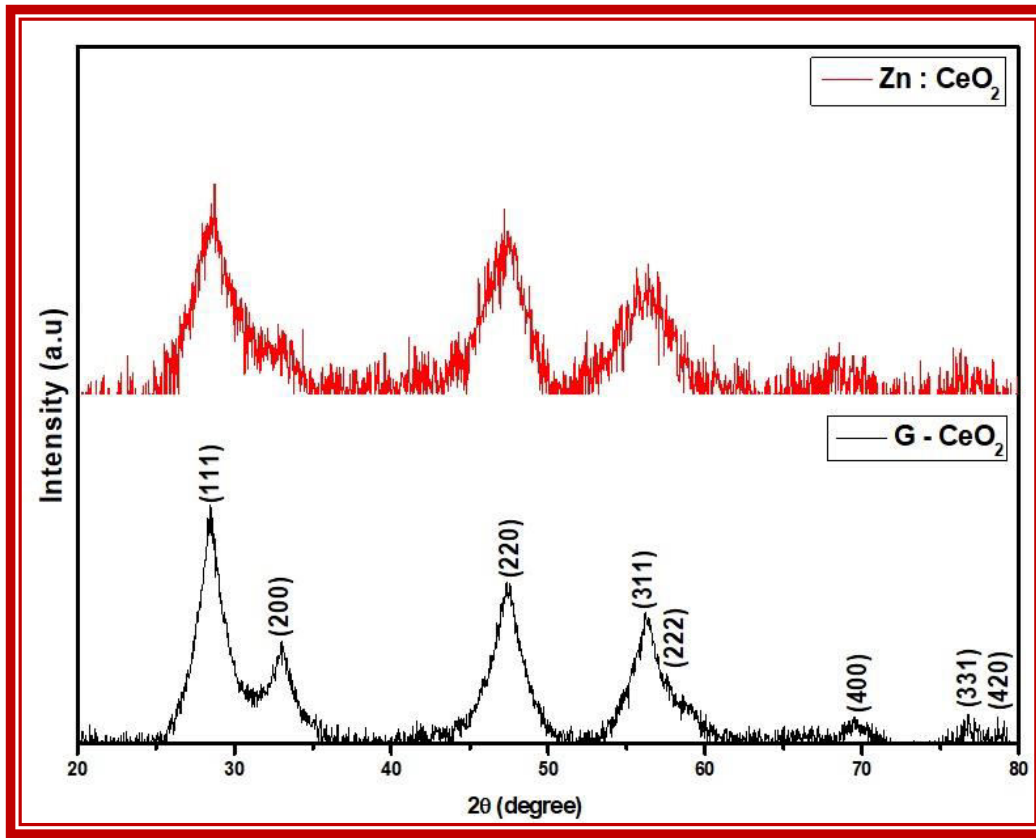


Fig. 1: X-ray diffraction pattern of G -CeO₂ NPs and Zn: CeO₂NPs.

strong and distinct peaks of the G-CeO₂ NPs and Zn: CeO₂ NPs on the XRD curves (Fig. 1). The planes 111, 200, 220, 311, 222, 400, 331 and 420 are ascribed to the obtained diffraction of G-CeO₂ NPs and Zn: CeO₂ nanoparticles at 28.47, 32.91, 47.34, 56.29, 78.92, 69.73, 76.81; and 28.60, 33.1 CeO₂ nanoparticles' face-centered cubic phase matches the JCPDS data card number 01-075-0120 exactly. There is such a greater crystallinity in G-CeO₂ NPs. The highly crystalline nature of G-CeO₂ NPs is due in part to the presence of several organic components used in the NPs synthesis process.

It is possible to determine the lattice constant "a" of G-CeO₂ by applying the relation,

$$\frac{1}{d^2} = \left[\frac{h^2 + k^2 + l^2}{a^2} \right]$$

The lattice characteristics Each sample's value was computed using the formula,

$$a = d\sqrt{h^2 + k^2 + l^2}$$

For G-CeO₂ and Zn: CeO₂ NPs, the computed "a" values are 5.2743 and 5.2693, respectively. The equation $V = a^3$ may be used to get the unit cell volume. For both CeO₂ NPs, the unit cell volume was determined to be 146.7283 and 146.3123.

After making the necessary background modifications based on the X-ray line widening of the diffraction peaks, the average crystallite size D of the sample is calculated using the Debye-formula Scherrer's method.

$$D = \frac{k\lambda}{\beta \cos\theta}$$

Where, λ is the wavelength of X-ray used (1.5405 Å), β is the angular peak width at half maximum in radians and θ is the Bragg's diffraction angle. The newly synthesized powders are nanometric in size, being the G-CeO₂ average crystallite size equal to 13.84 nm. The crystallite size as a function of Cu doping level show that

crystallite size decreased to 10.34 nm, respectively. Klaus-Joerger *et al.* (2001) suggested that a high degree of crystallinity is indicated by the intensity of Zn nanoparticles.

Studies using energy dispersive X-ray analysis and scanning electron microscopy (SEM) (EDAX):

Scanning electron microscopy was used to examine the surface morphology of G-CeO₂ and Zn: CeO₂ nanoparticles. Figure 2 displays the SEM images of G-CeO₂ and 0.005M Zn²⁺ doped in 0.095M CeO₂ nanoparticles. The average particle size of G-CeO₂ and Zn: CeO₂ was estimated from the SEM picture to be around 5 and 7 nm, respectively. G-CeO₂ particles were distributed in an irregular manner in the SEM images, with some particles being solitary and others being clustered. The Zn: CeO₂ NPs demonstrated improved particle dispersion when compared to G-CeO₂ nanoparticles, which matches to the Zn: CeO₂ NPs' impact (Osman *et al.*, 2018).

By using EDX analysis, the elemental makeup and purity of G-CeO₂ NPs and Zn: CeO₂ NPs were analysed. Figure 3 displays the samples' EDX signals and percentage makeup. No impurities were present in the synthesised samples, which is compatible with the XRD data for G-CeO₂ NPs, and a clear and sharp signal was detected for zinc and oxygen, suggesting the existence of a Ce-O host structure. Along with cerium and oxygen signals for Zn: CeO₂ NPs, zinc signals were also found. That proved that Zn had been effectively incorporated into G-CeO₂ NPs. However, other signs for carbon and other elements, such as chlorine, were also found, although in negligible amounts. This might be as a result of the plant extract and biomass used in the sample preparation process (Nurhasanah *et al.*, 2014). The detected atomic percentages of Ce and O were determined to be 31.91 and 67.73 per cent, respectively, in the Zn: CeO₂ NPs sample, whereas Zn's composition was discovered to be 0.36 per cent. The atomic percentages of Ce and O in the G-CeO₂ NPs were determined to be 56.71 and 43.29 per cent, respectively. The doping actions of Zn²⁺

in CeO₂ NPs effectively raise the cerium and oxygen percentage.

Characterization of G- CeO₂ and Zn: CeO₂ NPs' functional groups:

Additionally, FT-IR spectra for G-CeO₂ NPs and Zn: CeO₂ NPs were captured. The spectra for G-CeO₂ NPs and Zn: CeO₂ NPs are shown in Figure 3, and the spectral information for both samples is provided in Table 1. The bands assigned to the FTIR spectra match those which are reported by Banerjee (2015). The wide absorption band seen in the 3750–3000 cm⁻¹ frequency range is attributed to O–H stretching caused by lingering alcohols, water molecules, and Ce–OH. Ce NPs also produce the band seen at 3400 cm⁻¹ (Arumugam *et al.*, 2016). Both CeO₂ nanoparticles showed weak C–H symmetric and asymmetric stretching with centres at 2854, 2856, and 2925 cm⁻¹. The carboxyl group's C=O bond's anti-symmetric and symmetric stretching modes are represented by the bands at 1630 cm⁻¹ and 1627 cm⁻¹, respectively. The band at 1384 cm⁻¹ may be attributed to the symmetric stretching of (ν O–H), bending of (O–H), and N–O stretching, respectively, among bound water molecules (Duan *et al.*, 2018). Ce–O or Ce–Zn stretching is attributed to the band at 550 cm⁻¹. Ce–Zn–O and Zn–O–Ce stretching correspond to the band at 1114 cm⁻¹. The antisymmetric Ce–O–Ce stretching mode of the surface-bridging oxide is responsible for the strong band at 517 cm⁻¹. When the force of the O–H and C=O modes were compared, the assimilation band of CeO₂'s cubic period expanded, appearing at 617 and 616 cm⁻¹ (Wang *et al.*, 2018).

Spectroscopy of UV-Visible Absorption:

Figure 4 displays the UV-Vis absorption peaks of G-CeO₂ and Zn: CeO₂ NPs. At 321 and 311 nm, respectively are the greatest absorption peaks of pure and 0.005M of Zn: CeO₂ (Gomez-Garay *et al.*, 2014). The charge transfer transition from the O₂- to Ce²⁺ orbital in CeO₂ is represented by a high absorption below 400 nm in the spectra (Khan *et al.*, 2014).

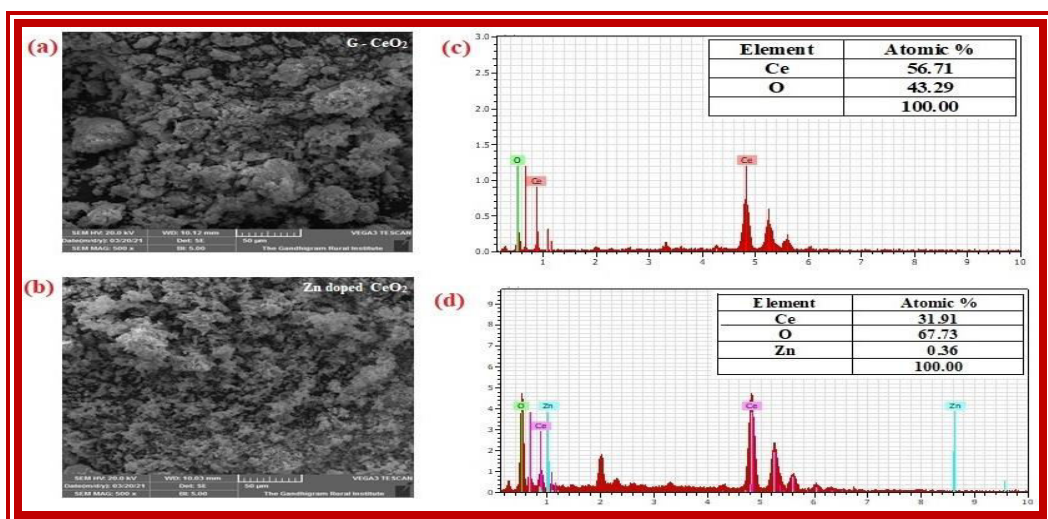


Fig. 2: G - CeO₂ NPs and Zn: CeO₂ NPs morphological and elemental analyses.

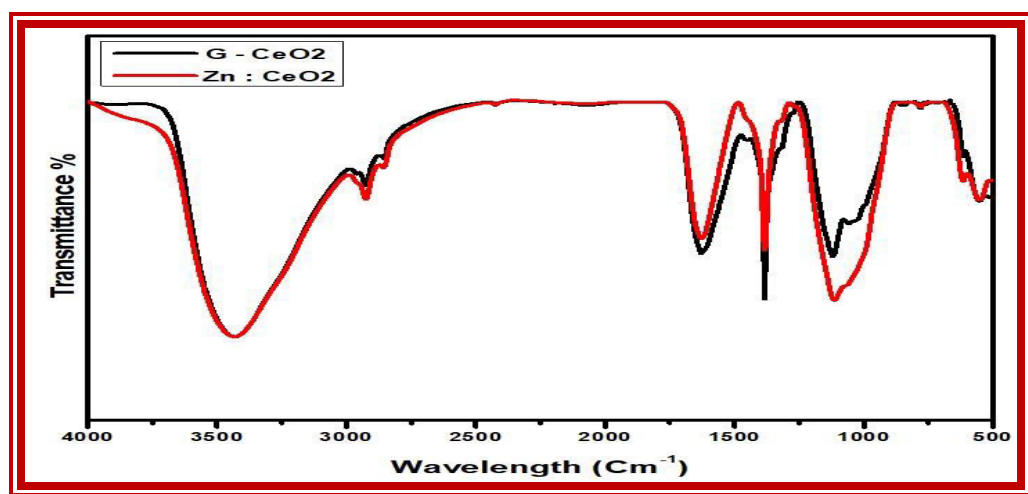


Fig. 3: FTIR spectra of G -CeO₂ NPs and Zn: CeO₂NPs.

Table 1: FTIR spectral data for G-CeO₂ and Zn: CeO₂NPs

G-CeO ₂ NPs and (cm ⁻¹)	Zn: CeO ₂ NPs (cm ⁻¹)	Peak Assignments
3433	3433	O-H stretching -NH ₂ stretching
2925, 2854	2925, 2856	C-H asymmetric and symmetric stretching
2425, 2089	2425, 2089	Strong O=C=O stretching
1384	1383	N-O stretching
1630	1627	H-O-H bending C=O vibration of carboxylic group
1452	1457	C-N stretching and N-H stretching
1121	1114	Ce-Zn-O and Zn-O-Ce stretching
781	781	C-Br vibrations of Br pellets
560	553	Ce-Zn or Ce-O stretching
722, 672, 617 and 517	616	bending mode of Ce-O-C

The UV-Vis absorption spectra in Figure 4 (a) showed that G-CeO₂ NPs had an absorption peak around 311 nm, while Zn: CeO₂ NPs samples had absorption peaks at 321 nm (Patsalas *et al.*, 2003). The successful doping of the Zn element was shown by the blue shift of the absorption peaks of G-CeO₂ NPs and Zn: CeO₂ NPs nanostructures. G-CeO₂ and Zn: CeO₂ NPs were studied for their band gaps using UV-visible transmittance spectroscopy, and the band gap was determined using the Tauc, Davis, and Mott relation, which is provided by $(h\nu)^2 = A(h\nu - E_g)$. Figure 5 shows $(h\nu)^2$ vs. energy ($h\nu$). The band gap may be obtained by extrapolating the straight line to the axis intercept (Davoodi *et al.*, 2013). The extension of the absorption edge in the longer wavelength area indicated the integration of Zn on the CeO₂ lattice. The band gap for G-CeO₂ NPs was computed with a value of 3.69 eV, which is consistent with the value provided in the literature (Javid *et al.*, 2017). The band gap for doped samples was found to be around 3.55 eV, which is close to the findings of Kosacki and Anderson (2000). As seen in Figure 4, when Zn is incorporated into CeO₂, the band gap of G-CeO₂ rises to 3.69 eV and subsequently falls to 3.55 eV. The oxygen defects that result from the transition of Ce⁴⁺ into Ce³⁺ when Zn is introduced into CeO₂ are anticipated to increase, rather than decrease, the band gap of our Zn: CeO₂ nanoparticles (Labhane *et al.*, 2015).

Photoluminescence Study:

Using a 290 nm-excited Xe laser, the photoluminescence spectra of G-CeO₂ NPs and Zn: CeO₂ NPs were captured. For G-CeO₂ and Zn: CeO₂ NPs, the eight PL emission peaks were seen, ranging from a very low wavelength of 350 nm to a greater wavelength of 550 nm. For G-CeO₂ and Zn: CeO₂ NPs, a Gaussian function provided a decent match with eight peaks. Figure 6 illustrates the PL spectra of the CeO₂ NPs values at 395, 420, 438, 454, 480, 494, and 524 nm; and 397, 394, 417, 443, 459, 480, and 521 nm, respectively.

For CeO₂ NPs, three blue emissions were seen at wavelengths of 438 nm, 454 nm, and 480 nm. These emissions were thought to be caused by

localization of energy levels between the Ce 4f band and the O 2p band. The low density of oxygen vacancies in CeO₂ nanoparticles caused a green emission peak at a wavelength of 524 nm. Small shifts in the blue and green emissions for Zn:CeO₂ NPs at 417, 443, and 521 in PL spectra were noticed and compared to the CeO₂ NPs emission values. The defect located between the Ce 4f and O 2p levels is the cause of this change, which resulted in the little shift. These altering emissions proved that Zn had been substituted into the CeO₂ NPs lattice surface.

Studying photocatalysis:

Figures 6a and 6b demonstrate the spectra and effect map of G-CeO₂ NPs and Zn: CeO₂ NPs on the 10 ppm methylene blue (MB) degradation with time under UV-light irradiation (Table 2). The high specific surface area ZnO, both doped and undoped, served as photocatalysts for the breakdown of MB. The distinctive absorbance of MB at 662 nm was used to track the photocatalytic degradation process. Figures 7a and 7b demonstrate that UV spectra initial absorbance value at 662 nm decreased more quickly while the degradation rate of MB remained constant when the time interval from 20 min to 80 min increased. When the clock approached 80 min, the MB has about completed degrading.

Zn:CeO₂ NPs during use with regard to time:

Zn dopant in the quantity of 1×10^{-5} M is employed for the photocatalytic activity. Compared to G-CeO₂ NPs, the dopant improves the photocatalytic activity of Zn: CeO₂ NPs. The photocatalytic activity of MB dye degradation in UV light radiation was 79 per cent for Zn: CeO₂ NPs and 92 per cent for G-CeO₂ NPs, according to the plot of photocatalytic degradation efficiency vs. irradiation period. It seems that when compared to G-CeO₂ NPs, the dopant improves the photocatalytic activity of Zn: CeO₂ NPs (Saranya *et al.*, 2014).

Biological Activity:

CeO₂ NPs for G-CeO₂, Zn, and *E. coli*, *S. aureus*, and *K. Pneumonia*:

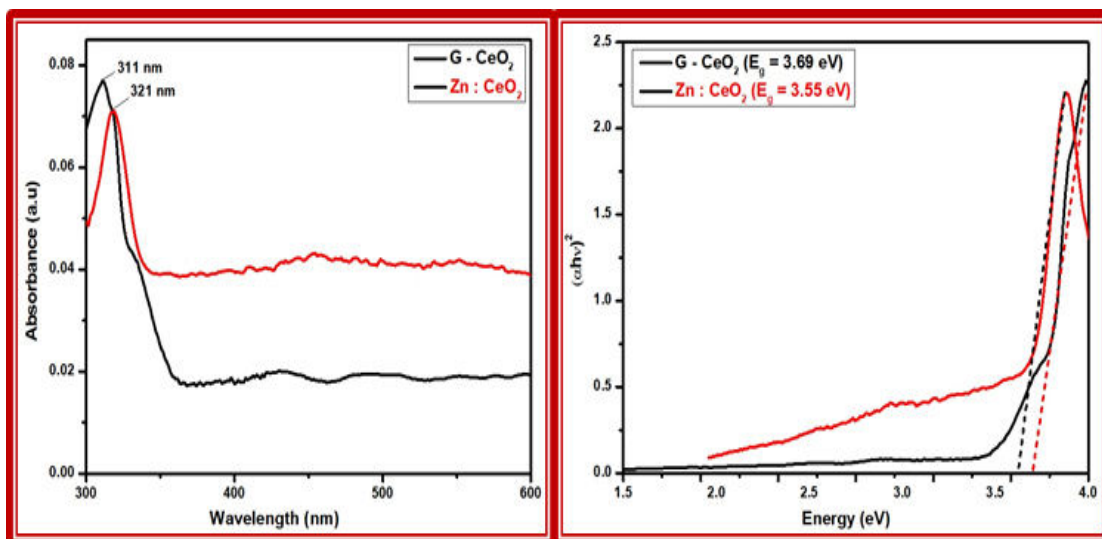


Fig. 4 (a): UV-Visible spectra of G-CeO₂ and Zn:CeO₂NPs; (b): Optical band gap energy calculated from absorption data of G -CeO₂ NPs and Zn: CeO₂NPs.

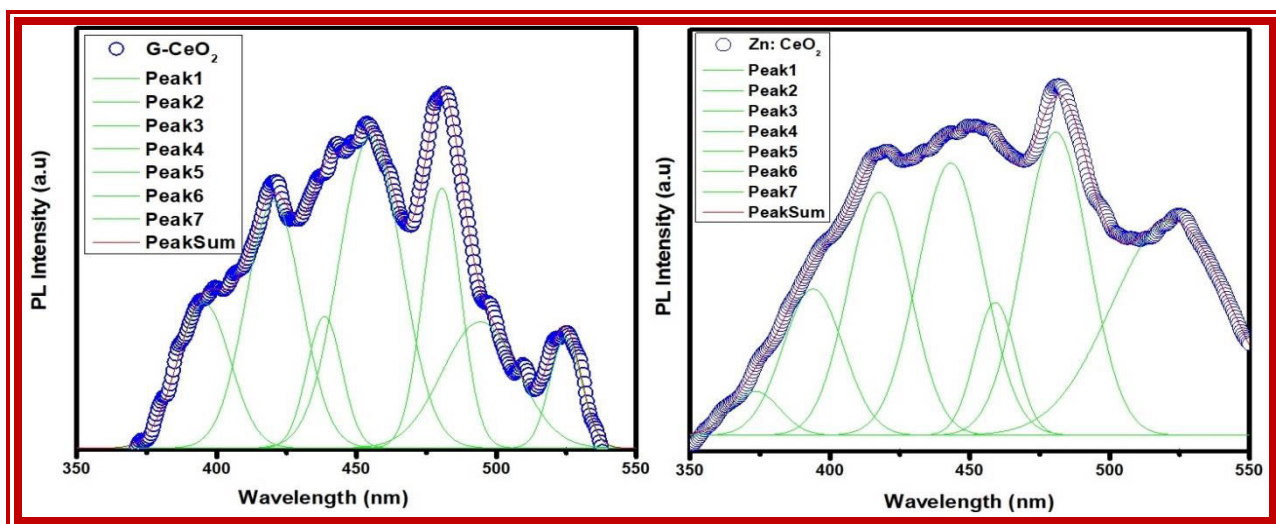


Fig. 5: Photoluminescence Spectra of G -CeO₂ NPs and Zn: CeO₂NPs.

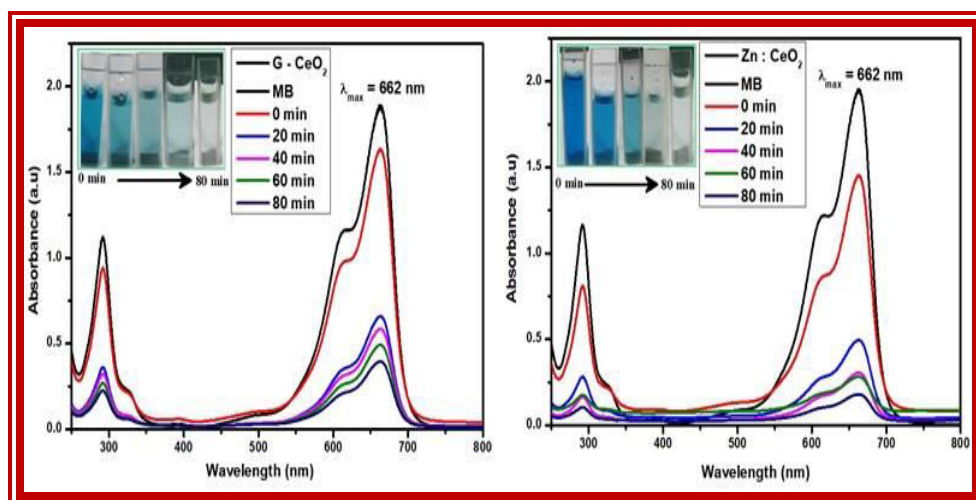


Fig. 6: a) UV-vis absorption Spectrum of Photodegradation of Methylene blue dye for G-CeO₂ NPs and Zn: CeO₂NPs.

Table 2: Effect of methylene blue dye degradation by G-CeO₂ NPs and Zn: CeO₂NPs.

Time (min)	% degradation of methylene blue dye	
	G - CeO ₂	Zn : CeO ₂
0	13	25
20	65.0	74.0
40	69.0	84.0
60	74.0	85.0
80	79.0	92.0

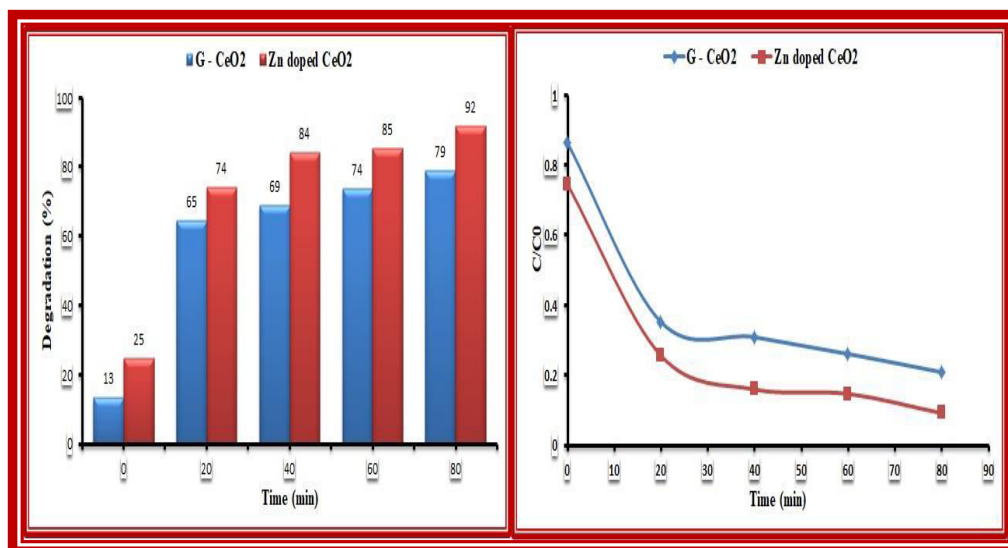


Fig. 7: (a) Photodegradation (%) of methylene blue dye under using Zn: CeO₂NPs; (b) Plot of Photocatalytic degradation efficiency of methylene blue dye Under using Zn:CeO₂NPs with respect to time.

The well diffusion technique, as seen in Figure 8 was used to investigate the antibacterial properties of G-CeO₂ NPs and Zn: CeO₂ NPs evaluated against (G+) bacteria (*B. subtilis*, *S. aureus*), and (G-) bacteria (*E. coli*, *K. pneumoniae*). When the concentrations of G-CeO₂ NPs and Zn: CeO₂ NPs were raised against (G+) and (G-) bacteria (25, 50, 75, and 100 L) (Fig. 9), the zone of inhibitory activity was similarly correspondingly enhanced. The findings showed that Zn: CeO₂ NPs is more active against *B. subtilis*, *S. aureus*, and *K. pneumoniae* and moderately active against *E. coli*. G-CeO₂ NPs is extremely active against *K. pneumoniae* compared to the other investigated bacteria (Kumar and Rani, 2013).

The G-CeO₂ NPs and Zn: CeO₂ NPs demonstrated antibacterial activity as well as

enhanced ciprofloxacin activity. The distraction of the cell membrane, in addition to other factors including the production of Zn²⁺ and ROS, may be the cause of the zone inhibition of bacterial cells, which may lead to the death of the bacteria. In this study, it was shown that Zn: CeO₂ NPs had superior antibacterial activity compared to undoped Ce NPs. Undoped G-CeO₂ NPs and Zn: CeO₂ NPs, on the other hand, have been used to treat urinary tract infections, pneumonia, bloodstream infections, renal failure, and wound infections (Zhang *et al.*, 2008; Zhou *et al.*, 2021).

Determining the lowest inhibitory dose of an antifungal:

The antifungal activity of the synthesised NPs was examined using clinical strains of *C. albicans*. The broth micro dilution method was used in the current study to assess the lowest inhibitory

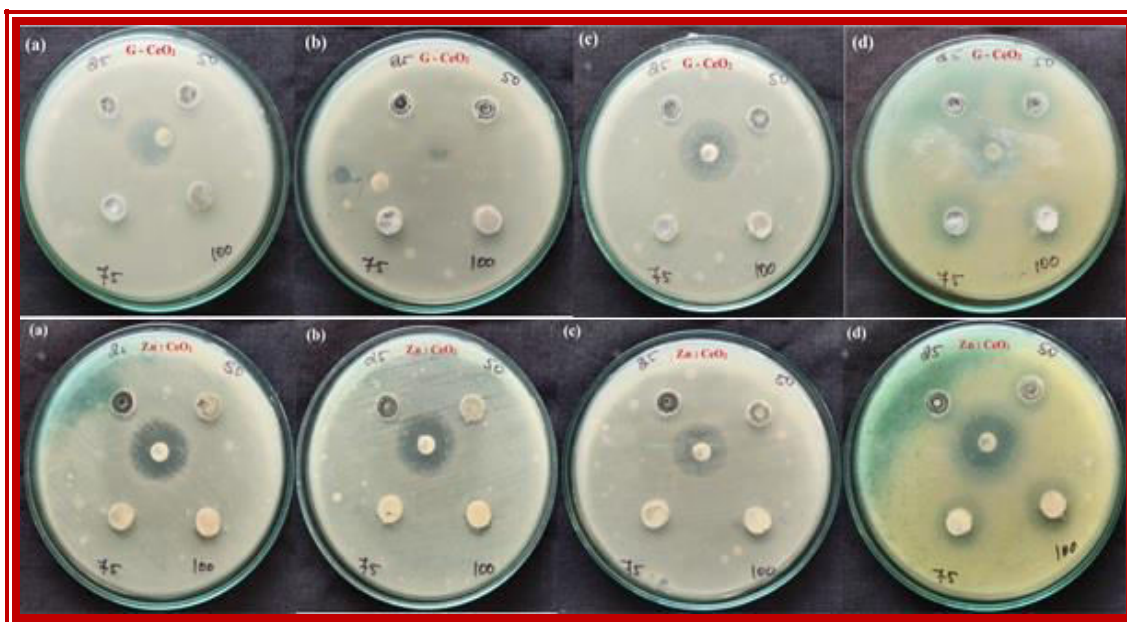


Fig. 8: Antibacterial activity of G-CeO₂ and Zn: CeO₂ NPs.

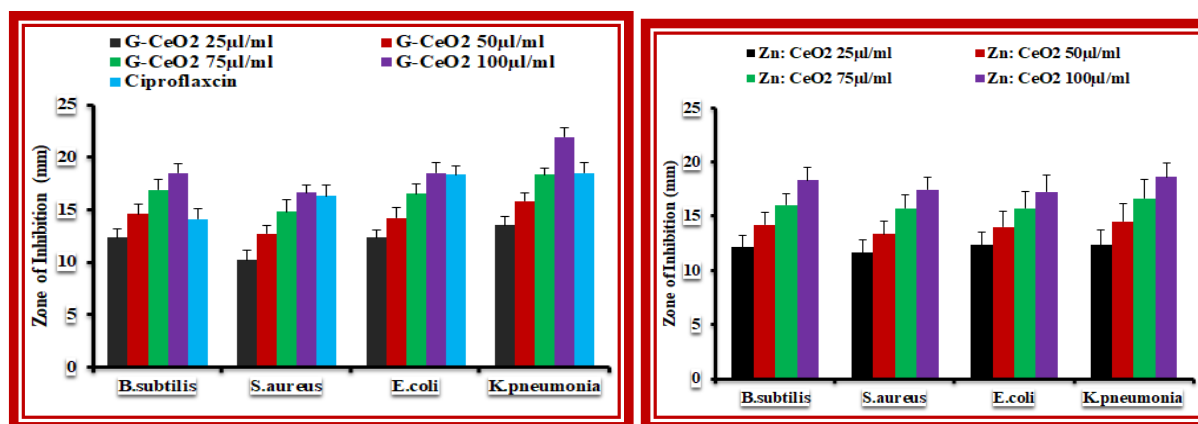


Fig. 9: Zone comparison against various microorganisms of *B. subtilis*, *E. coli*, *S. aureus*, and *K. pneumonia* for G-CeO₂ and Zn: CeO₂ NPs.

concentration of G-CeO₂ NPs, Zn: CeO₂ NPs, and ciprofloxacin medication against clinical strains of *Candida albicans*. The value was assessed for samples that were doped and undoped at concentrations of 25, 50, 75, and 100 L, respectively. The results showed that when compared to ciprofloxacin, Zn: CeO₂ NPs had more strong and efficient antifungal action against isolates of *Candida albicans* (Figs. 10, 11).

Cytotoxicity research on the cancer cell lines L929 and HCT 116:

On cultivated L929 Normal Fibroblast cell line and HCT116 human Colon cancer cell line, the cytotoxic activity of produced G-CeO₂ NPs and Zn:

CeO₂ NPs was investigated by exposing the cells for 24 h at concentrations of 2.5, 5.0, 7.5, 10.0, 12.5, and 15.0 g ml⁻¹. The viability of human colon cancer cells is partly reduced by increasing the concentration of G-CeO₂ and Zn: CeO₂ NPs. Figure 14 illustrates the harmful effects of these produced G-CeO₂ and Zn: CeO₂ nanoparticles on the human colon cancer HCT-116 cell line, with IC₅₀ values of 11.25 g/ml and 12.2 g/ml for G-CeO₂ and Zn: CeO₂ NPs, respectively. The cytotoxicity of G-CeO₂ and Zn: CeO₂ NPs against the normal fibroblast L929 cell line was lower than that of the human colon cancer cells, with IC₅₀ values of 79.71 g/ml and 80.86 g/ml, respectively (Figs. 12, 13).

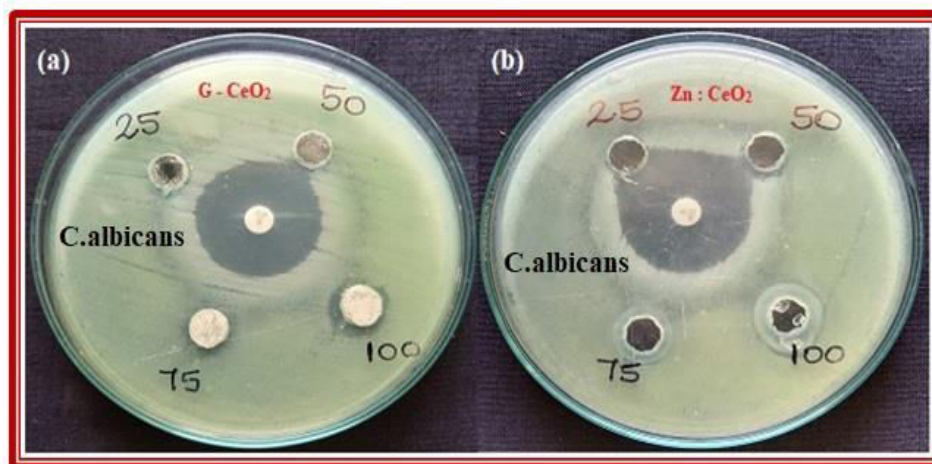


Fig. 10: Antifungal activity of the Green synthesized G-CeO₂ NPs and Zn: CeO₂ against *C. albicans*.

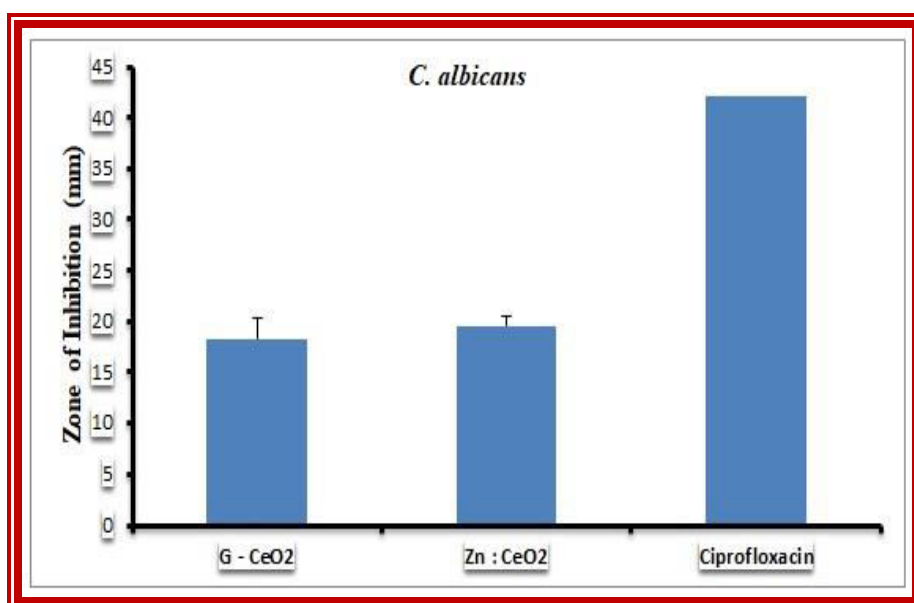


Fig. 11: Size of the Zone of Inhibition formed in the antifungal activity of G-CeO₂ and Zn: CeO₂ against *C. albicans*.

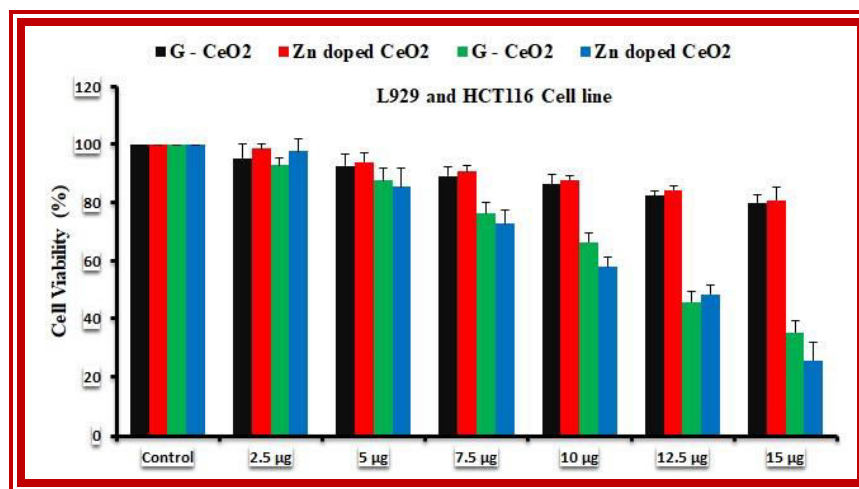


Fig. 12: The effect of green synthesized Zn doped CeO₂ NPs on the cytotoxicity property in Fibroblast L929 cell line and Human colorectal cancer HCT 116 cell lines.

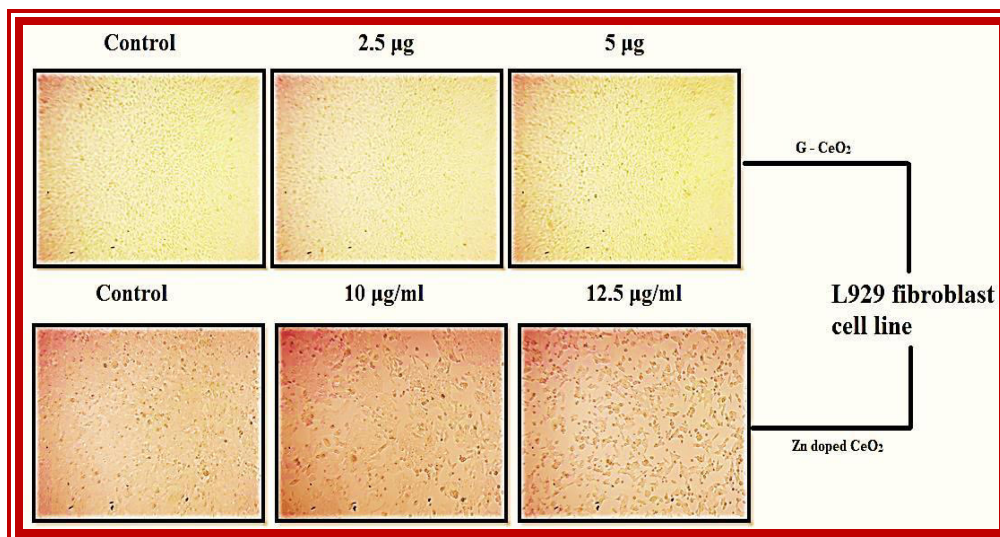


Fig. 13: Cell treated with (a) Control (b) G-CeO₂ and (c) Zn: CeO₂NPs at the respective IC₅₀ Concentrations and the morphologies changes in control and sample treated L929 cells line for 24 h.

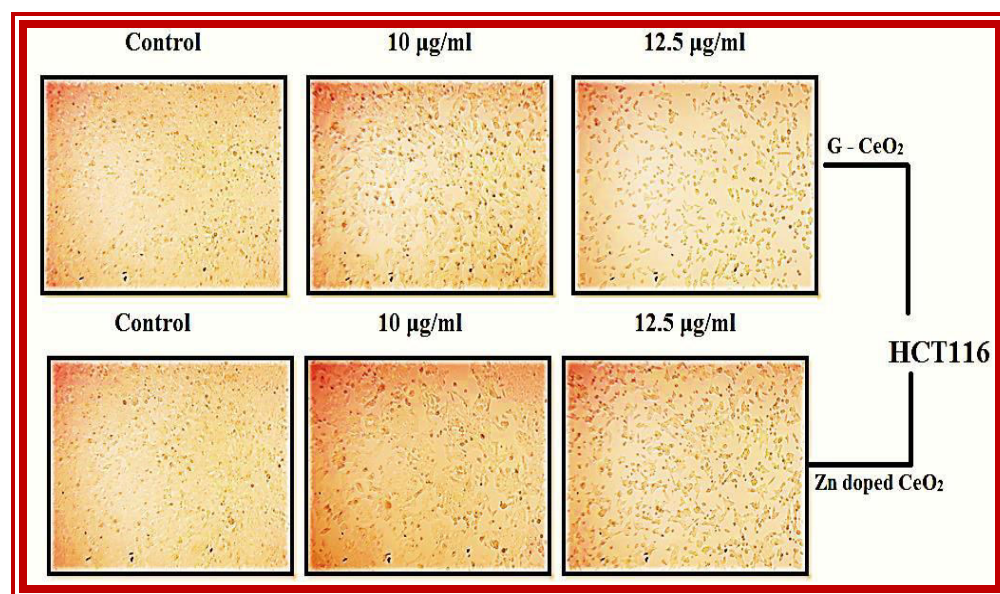


Fig. 14: Cell treated with (a) Control (b) G-CeO₂ and (c) Zn: CeO₂ NPs at the respective IC₅₀ Concentrations and the morphologies changes in control and sample treated HCT 116 cells for 24 h.

According to the HCT-116 human colon cancer cell's structure on Zn, CeO₂ is most likely the source of the oxygen vacancies that ROS production causes (Gnanasangeetha and Saralathambavani, 2013). The increase in oxygen vacancies has previously been linked to the ROS formation. with respect to G-CeO₂ NPs. Higher ROS generation is caused by structural flaws (oxygen vacancies) in the crystal structure of Zn doped metal oxide nanostructures. It was determined to boost the efficacy that against cancer cells, NPs establish a positive charge Zn²⁺ the cell membrane

becomes negatively charged due to ionic interactions. The charge on the metal ions is the most crucial characteristic for the HCT-116 human colon cancer cell death. The aggressive interaction of the Zn: CeO₂ NPs with the negatively charged surface of cancer cell membranes results in cell membrane rupture and the death of cancerous cells. The kind of occurrence that results in the intracellular release of zinc ions is more effective against cytotoxicity and enzyme disruption than G-CeO₂ NPs, and as a consequence, Zn: CeO₂ NPs may be employed as a cancer therapy.

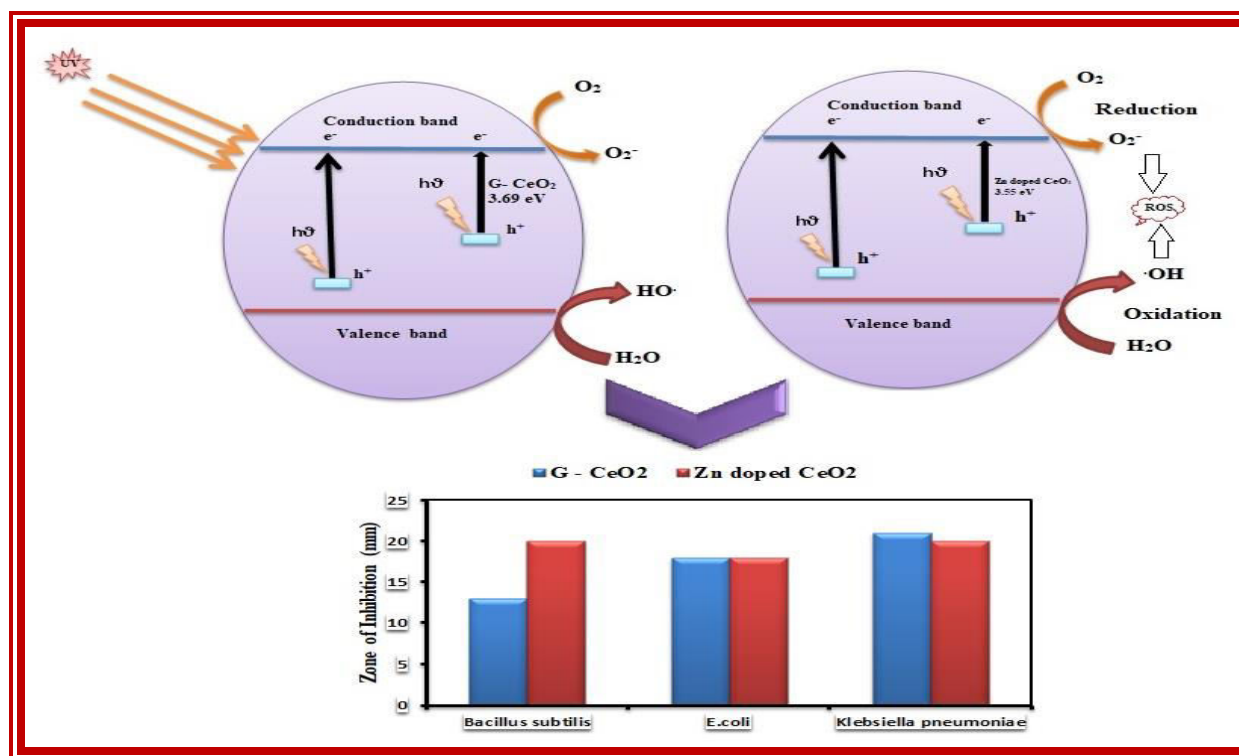


Fig. 15: The mechanism of the generation of reactive oxygen species from G-CeO₂ and Zn: CeO₂ induced by UV light.

Conclusion

In this study, we created a straightforward and affordable green method for producing G-CeO₂ and Zn: CeO₂ NPs using an aqueous leaf extract of *Psidium guajava* (guava leaves). The formation of G-CeO₂ and Zn: CeO₂ NPs was suggested by UV-Vis absorption maxima at 311 nm and 321 nm (Fig. 15). The Zn: CeO₂ NPs absorbance increased. G-optical CeO₂'s direct bandgap energy was previously calculated to be 3.69 eV, while Zn: CeO₂ NPs made with *Psidium guajava* leaf extract had a 3.55 eV value. XRD behaviour reveals the size of doped and undoped ZnO nanoparticles. G-CeO₂ NPs are found to have a crystalline size of 11 nm, whereas Zn: CeO₂ NPs produced from leaf extract have a crystalline size of 7 nm. SEM images also supported the particle size. The particle size of the doped and undoped samples was further shown by SEM micrographs to be in the nanoscale range, with cerium oxide and Zn: CeO₂ NPs averaging 5 nm and 7 nm, respectively. The FT-IR findings showed that the *Psidium guajava* plant extract has a high concentration of bio-organic

chemicals and works effectively as a stabilising agent. There was slight variations in the emission levels of blue and green Zn: CeO₂ NPs and G-CeO₂ NPs. It controls how Zn is transformed into the lattice surface of CeO₂ NPs. G-CeO₂ NPs and Zn: CeO₂ NPs photocatalysts had dye degradation rates of 79.0 and 92.0 per cent, respectively. It was discovered that Zn doping significantly increased the photocatalytic activity of CeO₂ NPs toward the breakdown of methylene blue under UV light irradiation. Produced G-CeO₂ NPs had more antibacterial action against *K. pneumonia* than the other bacteria under investigation, and Zn: CeO₂ NPs are also more effective against *B. subtilis*, *S. aureus*, and *K. pneumonia* while being only moderately effective against *E. coli*. *In vitro* cytotoxicity was discovered on the cultured L929 Normal Fibroblast cell line and HCT116 Colon cancer cell line. Cerium oxide and Zn: CeO₂ had IC₅₀ values of 11.25 g/ml and 12.2 g/ml and 79.71 g/ml and 80.86 g/ml, respectively, against L929 Normal Fibroblast and HCT116 cell lines. The antibacterial and anticancer properties of cerium

oxide and Zn doped cerium oxide NPs have been investigated. Cerium oxide and Zn doped cerium oxide nanoparticles have been studied for their antibacterial and anticancer capabilities to discover new methods for creating the next generation of medications to control bacterial infections and cytotoxic effects. As a consequence, the aqueous leaf extract of *Psidium guajava* (guava leaves) was used to create cerium oxide and Zn: CeO₂ nanoparticles, which may have use in both environmental and medical research.

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