Green synthesis of ZnO nanoparticles using *Cocos nucifera* leaf extract: Characterization, antimicrobial, antioxidant, and photocatalytic activity

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Abstract

Zinc oxide nanoparticles (ZnO NPs) have been successfully prepared using *Cocos nucifera* leaf extract and investigated with their antimicrobial, antioxidant, and photocatalytic activity. The structural, compositional, and morphological properties of the NPs were recorded and studied systematically to confirm the synthesis. The aqueous suspension of NPs showed a UV-Vis. absorption maxima of 370 nm indicating primarily its formation. The XRD analysis identified the NPs with hexagonal wurtzite structure with an average particle size of 16.6 nm. The FTIR analysis identified some biomolecules and functional groups in the leaf extract as responsible for the encapsulation and stabilization of ZnO NPs. The EDX analysis showed the desired elemental compositions in the material. A flower-shaped morphology of ZnO NPs was observed by SEM with a grain size of around 15 nm. The optical properties of the NPs were studied by UV-Vis spectroscopy and the band gap was calculated as 3.37 eV. The prepared ZnO NPs have demonstrated antimicrobial activity against *T. harzianum and S. aureus* with a ZOI (zone of inhibition) of 14 and 10 mm, respectively. The photocatalytic behavior of ZnO NPs showed absorbance degradation at around 640 nm and discolored methylene blue dye after one hour with a degradation

maximum of 84.29 %. Thus, the prepared ZnO NPs could be used potentially in antibiotic development, pharmaceutical industries, and as photocatalysts.

Keywords: ZnO NPs; *Cocos nucifera*; Green approach; antimicrobial; antioxidant; photocatalyst.

1. Introduction

Nanoscience and nanotechnology are the most emerging fields in recent times and moving forward sharply along with physics, chemistry, biology, molecular engineering, and so on. Nanomaterials are in versatile use in pharmaceutical, cosmetic, textile, and even electrical and electronics industries. Nanomaterials are products processed through nanotechnologies that contain nanoparticles (NPs) on a scale ranging from 1 to 100 nm. The NPs of metal and metal oxides are usually used in industries as requirements. Several types of metal and metal oxide NPs such as aluminum, nickel, silver, copper, copper oxide, iron, iron oxide, cerium dioxide, titanium dioxide, and zinc oxide are commonly known [1, 2]. The NPs can be prepared by several methods like physical, chemical, and biological, but physical and chemical methods are associated with high energy demand, sometimes generating poisoned and parlous chemicals, which may lead to consanguineous menaces [3, 4]. To minimize these problems a safe, cost-effective, and less hazardous synthesis procedure is already developed by modern scientists which are called the biological or green method by using plant extract with a little concentration of the chemicals. Among all metal oxides, ZnO NPs have drawn more attention for their safe and inexpensive production and preparation process [5, 6]. ZnO has been enrolled as one of the safest metal oxides by the US FDA (Food and Drug Administration) [7]. There are a lot of applications of ZnO in engineering, biological, and medicinal fields. ZnO NPs have several engineering applications such as in solar cells [8-10], gas sensors [11], chemical sensors [12], biosensors [13], and photodetectors [14], whereas, in biological and medicinal applications, ZnO NPs have cytotoxic activity [15], antimicrobial and fungicidal activities [16], anti-inflammatory activity, capability to quicken wound healing, antidiabetic [17, 18], and chemiluminescent properties [19, 20].

Current studies have supported the synthesis of ZnO NPs in several nanosized from various plant parts like leaf, flower, seed, fruit, root, rhizome, stem, bark, shell, and peel extracts. For example, some researchers utilized the leaf extracts of *Pandanus odorifer* [21], *Eucalyptus globulus* [22], *Aloe barbadensis* [23], *Sechium edule* [24], *Saponaria officinalis*[25], *Annona squamosal*[26], *Artocarpus heterophyllus*[27], *Mangifera indica* [28], *Laurus nobilis* [29], flower extracts of *Trifolium pretense* [30], *Anchusa italic* [31], *Punica granatum* [32], seed extracts of *Cuminum cyminum* [33] *Pongamia pinnata*

[34], fruit extracts of *Emblica Officinalis* [35] *Borassus flabellifer* [36] *Artocarpus gomezianus* [37], root extracts of *Rubus fairholmianus* [38] *Withania somnifera* [39], rhizome extracts of *Zingiber officinale* [40] *Bergenia ciliate* [41], stem extracts of *Phyllanthus embilica* [42], bark extracts of *Cinnamomum verum* [43], *Albizia lebbeck* [44] as well as peel extracts of *Punica granatum* [45], *Musa sapientum* [46], and so on.

Previously, we have reported the green synthesis of Ag NPs for enhanced antibacterial activity using *Cocos nucifera* leaf extract [47]. As a continuation of this work, this study illustrates the green synthesis of ZnO NPs using *Cocos nucifera* leaf extract with profound antimicrobial, antioxidant, and photocatalytic activity. *Cocos nucifera* is a perennial tree that grows in tropical seashore areas, the plant is about ~100 ft long, and its leaf is about ~13 ft [48]. This plant grows best in high rainfall areas and soils with pH (5.5-7) [49] and has various medicinal uses and properties, for example, antidiarrheal, antirheumatic, aphrodisiac, cytotoxic, diuretic, emetic, emollient, hypotensive, kidney treatment, poultice, and vermicide properties [50]. *Cocos nucifera* is a fascinating plant with diverse usages ranging from domestic to therapeutic. In the endosperm (coconut meat), endocarp (coconut hard shell), and leaf extract, the existence of phytochemicals such as tannin, saponin, alkaloid, phenol, flavonoid, and volatile oil was determined. Only in the case of the leaf extract of the plant, alkaloid, tannin, saponin, and flavonoid were identified [51]. Functional groups such as alkaloids are the phytochemicals, that act as capping and reducing agents to prepare ZnO NPs [52, 53] using Zn-salt e.g. $Zn(NO_3)_2.6H_2O$.

Several research works have already been done on *Cocos nucifera*. Roopan et al. [54] studied phytoconstituents, biotechnological applications, and nutritive aspects of Coconut (*Cocos nucifera*). Satheshkumar et al. [55] used curry leaves extracted with coconut water to synthesize ZnO-NPs and observed photocatalytic dye degradation and antibacterial activity. Priyatharesini et al. [56] used *Cocos nucifera* male flower extract to synthesize ZnO NPs and analyzed their antimicrobial activity. Krupa [57] used the endosperm of *Cocos nucifera* (coconut water) to synthesize ZnO NPs and studied tetraethoxysilane (TEOS) sol-gel coatings for combating microfouling. But, still, there is no report on the green synthesis of ZnO NPs using *Cocos nucifera* leaf extract. In this work, we have developed a *Cocos nucifera* leaf extract-mediated facile, cost-effective, and green approach for the preparation of ZnO NPs. The structural, morphological, and optical properties of the NPs are well explored. Finally, the antimicrobial, antioxidant, and photocatalytic activities of the prepared ZnO NPs are studied successfully with potent outcomes.

2. Materials and Methods

2.1. Chemicals and reagents

Cocos nucifera fresh leaves were collected from the local area of Cumilla, Bangladesh. Reagent grade (purity ≥ 98 %) $Zn(NO_3)_2.6H_2O$ and NaOH pellets were purchased from Fluka Analytical, Sigma-Aldrich, Germany. Mueller–Hinton Agar and potato dextrose agar were purchased from HiMedia Laboratories Pvt. Ltd., Mumbai, India. Methylene blue dye, methanol, 2, 2-diphenyl-1-picrylhydrazyl (DPPH), and ascorbic acid were purchased from Merck, Germany. All reagents and chemicals were utilized as received with no further purifications.

2.2. Preparation of leaf extract

The fresh leaves of *Cocos nucifera* were washed several times by using deionized water to dispel dirt particles. After washing the leaves were left to sun dry and grind to fine powder by a mortar. The fine powder leaves (about 5 g) were taken in a 250 mL beaker, mixed with 50 mL of deionized water, and heated at 80 ℃ for 20 minutes. Then, the mixture was filtered in another beaker with Whatman no.1 filter paper and the extract was formed in this stage according to literature [47, 58-60]. The extract was then cooled down and stored in the refrigerator (4 ℃) for utilization in the synthesis of ZnO NPs, as demonstrated in Fig. 1.

2.3. Preparation of ZnO Nps

For the preparation of ZnO NPs, 25 mL of 0.05 M aqueous solution of $Zn(NO_3)_2.6H_2O$ was mixed with 4 mL of the prepared aqueous leaf extract of *Cocos nucifera* in a 250 mL beaker as demonstrated in Fig. 1 [47, 58-60]. Then, the pH of the mixture was adjusted to 12 by the drop-wise addition of 0.02 M aqueous NaOH solution. The total solution, known as the mother solution, was stirred for almost three hours with a magnetic stirrer at ambient temperature and then centrifuged by a high-speed Benchtop centrifuge machine (model no. H3-18K, Kecheng, China) at 8000 rpm for 20 minutes. This results a solid product with light-orange color which was then dried overnight in an oven (model no. LDO-060E, Labtech, Korea) at 60 ℃. After that, the solid product was collected. Finally, the light-orange colored product turns into white powder when it was calcined in a muffle furnace (model no. FTMF-703, SCI FINETECH, Korea) at 550 ℃ for 30 minutes. The white powder was collected in a small sample vial after cooling and stored in a desiccator for further use.

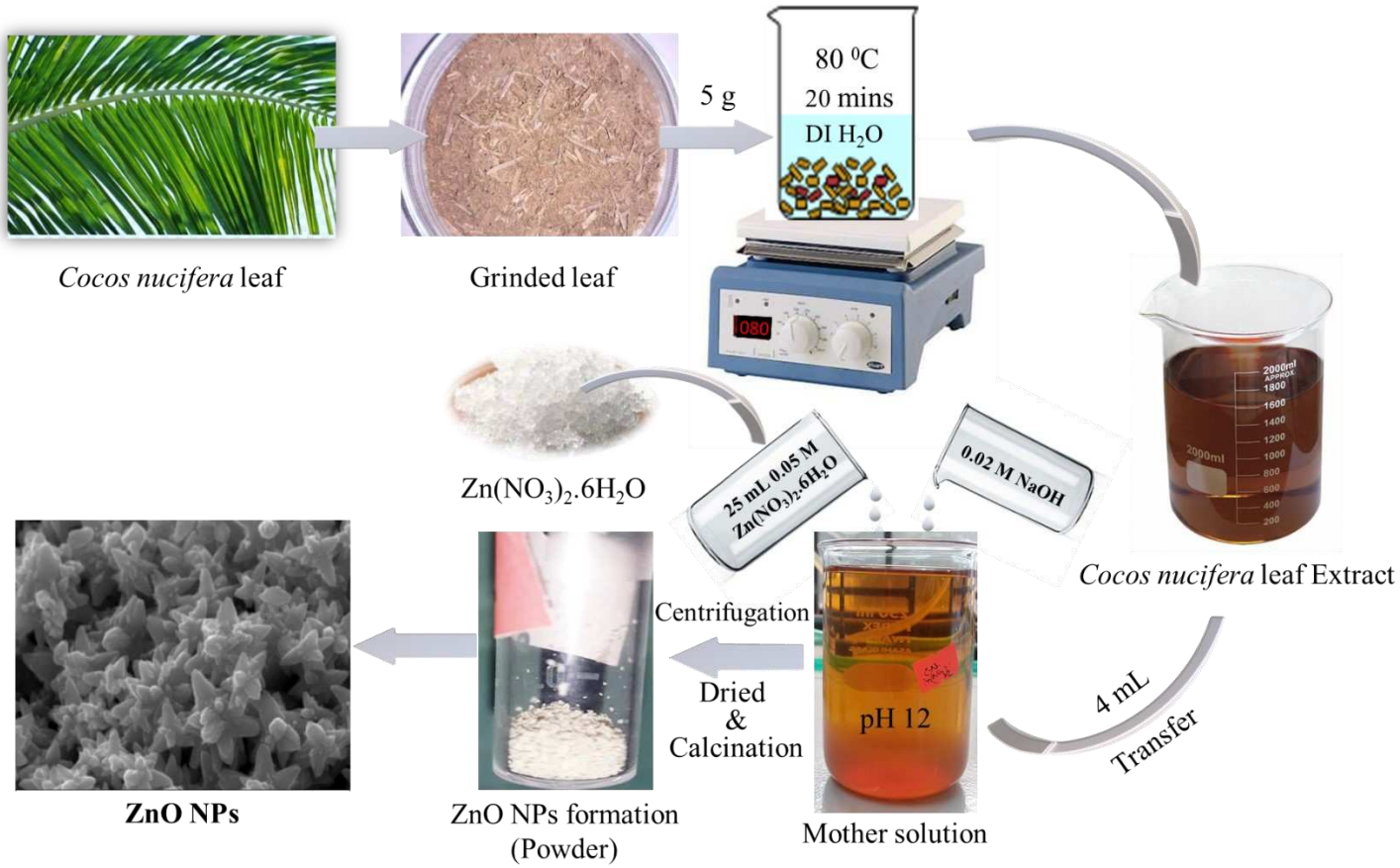


Fig. 1 Preparation of ZnO NPs using *Cocos nucifera* leaf extract

2.4. Characterization techniques of the prepared ZnO NPs

To characterize the prepared ZnO NPs, we have utilized diverse analytical tools such as Ultraviolet-Visible **(**UV-Vis**)** spectroscopy, X-Ray Diffraction (XRD) analysis, Fourier Transform Infrared (FTIR) spectroscopy, Energy Dispersive X-Ray (EDX) spectroscopy, and Scanning Electron Microscopy (SEM). UV-Vis spectrophotometer (UV prove 1800, Shimadzu, Japan) was used primarily to confirm the formation of ZnO NPs, and the spectrum was recorded in the range of 300-500 nm by utilizing deionized water as a reference. The XRD was used to identify the phase and information of unit cell dimensions of the prepared materials [61]. The XRD of the powdered ZnO NPs was conducted by Explorer GNR, using monochromatic Cu Ka radiation (1.5419 Å) operated at a voltage of 40 kV and current of 30 mA with 2θ angle (30^0 - 80^0) pattern and scan seed of 2^0/minutes. All possible diffractions are determined by scanning the sample from 2θ angles due to the casual orientations of the powder sample. These diffraction peaks are converted to d-spacings which allow the identification of materials which is specific for each material [62]. The estimation of crystalline size (D) of the prepared ZnO NPs was calculated by Debye–Scherrer formula [63] shown below.

$D = k\lambda/\beta \cos\theta$ ------- (1)

Where k (value 0.9) is the shape factor (dimensionless), λ is the X-ray wavelength of 1.5419 Å, β is the Full Width at Half Maximum (FWHM) in radian, and θ is the Bragg's angle in radian.

The FTIR spectrophotometer (IRAffinity-1S, Shimadzu, Japan) was employed to identify the presence of the characteristics of functional groups coming from the conjugation between nanomaterial and the adsorbed biomolecules [64]. The FTIR spectrum of the prepared powdered sample was recorded in a wide range of wavenumbers (400-4000 cm^{-1}) with 20 no. of scans and 2 cm^{-1} resolution which utilized the Happ-Genzel apodization function and KBr pellet method. The surface morphology and elemental composition of the prepared material were studied by SEM equipped with EDX (Model: EVO18, Carl Zeiss Microscopy, USA). A high-quality surface image of the sample was obtained by scanning the material surface with a focused beam of electrons from an electron gun applying an acceleration voltage of 15 kV.

2.5. Antimicrobial screening of the prepared ZnO NPs

Antimicrobial screening is an important method of analysis of the inhibitory effects of compounds against microorganisms [65]. There are a few laboratory methods available to evaluate the antimicrobial activity of a compound. The agar dilution or disc diffusion method is the most common of all methods [66]. Antimicrobial screening of ZnO NPs (50 µL dose used & concentration was 150 µg $disc^{-1}$) was assessed against various bacterial and fungal strains. Three gram (+ve) bacterial strains such as *Staphylococcus aureus* (cars-2), *Bacillus megaterium* (*BTCC-18*), and *Bacillus cereus* (carsgp-1) as well as two fungal strains, for instance, *Aspergillus niger (carsm-3)* and *Trichoderma harzianum (carsm-2)*) were used in agar well diffusion method alike to our previous report [67]. Mueller–Hinton Agar (HiMedia, India) was used to form agar medium to culture bacteria and potato dextrose agar medium (HiMedia, India) was used to culture fungal strains. *Ceftriaxone* (10 µL) for bacterial strains and *amphotericin-B* (10 µL dose and 50 µg $disc^{-1}$) for fungal strains were used as standards [67]. After placing the sample in a culture medium, the discs were incubated for 24 h at 37 °C for bacteria and 48 h at 26 °C for fungi in the incubator. Measuring the zone of inhibition (ZOI), the antimicrobial activity was determined.

2.6. Photocatalytic behavior of ZnO NPs

The ZnO NPs can act as photocatalysts because they exhibit photocatalytic activity under irradiation of sunlight [5, 24]. For this experiment, we used a 50 mg/L aqueous solution of methylene blue

(MB) dye with a 5 mg/20 mL catalytic load of ZnO Nps. After mixing both solutions (dye and catalyst), the blue color of the dye solution turns into a colorless solution within 1 hour. The UV absorption was taken after 0, 10, 15, 30, and 60 minutes. The percentage of degradation was calculated by the following equation.

% of degradation = $(C_i - C_f / C_i) \times 100$ ……..(2)

Where C_i and C_f are the initial and final concentrations of dye that degrade with time.

2.7. DPPH radical scavenging activity assay

2, 2-diphenyl-1-picrylhydrazyl (DPPH) radical scavenging assay was done to determine the ability of the prepared ZnO NPs to scavenge free radicals. The ability of NPs to inhibit oxidation was tested by decolorizing a methanol solution of DPPH. In methanol solution, DPPH creates a violet/purple color, which fades to shades of yellow in the presence of antioxidants. A 0.1 mM DPPH in methanol solution was prepared and 2.4 mL of it was combined with 1.6 mL of extract in methanol at varying concentrations (6.25-1200 µg/mL). The reaction mixture was vortexed completely and kept at room temperature for 30 minutes in the dark. At 517 nm, the absorbance of the mixture was determined spectrophotometrically. Ascorbic acid was utilized as a standard. The following equation was used to compute the percentage of DPPH radical scavenging activity.

% DPPH radical scavenging activity = $[(A_0-A_1)/A_0] \times 100$ ……..(3)

where, the absorbance of the control is A_0, and the absorbance of the sample is A_1.

The percent of inhibition was then plotted against concentration, and the IC_{50} was derived from the graph. At each concentration, the experiment was performed three times [68].

3. Results and discussions

3.1. Mechanism of ZnO NPs formation

There are several proposed mechanisms for the formation of ZnO NPs in the green synthesis approach [21-46, 69, 70]. In the present work, we have used the aqueous extract of *Cocos nucifera* leaf as the stabilizing as well as the natural reducing agent for ZnO NPs preparation. The phytochemical screening of this leaf demonstrated the existence of various phytochemicals such as alkaloids, resins, steroids, glycosides, terpenoids, flavonoids, polyphenols, and aromatic hydrocarbons [52, 53]. The presence of these phytochemicals in *Cocos nucifera* leaf plays an important role in the NPs preparation

acting as a reducing and capping agent. **Fig. 2** showed the probable reaction mechanism for the formation of ZnO NPs in which aromatic hydroxyl groups present in the phytochemicals and polyphenols are attached with the Zn^{2+} ions from $Zn(NO_3)_2.6H_2O$ to form a stable complex system. This complex system release ZnO NPs after centrifugation and calcination [71-73].

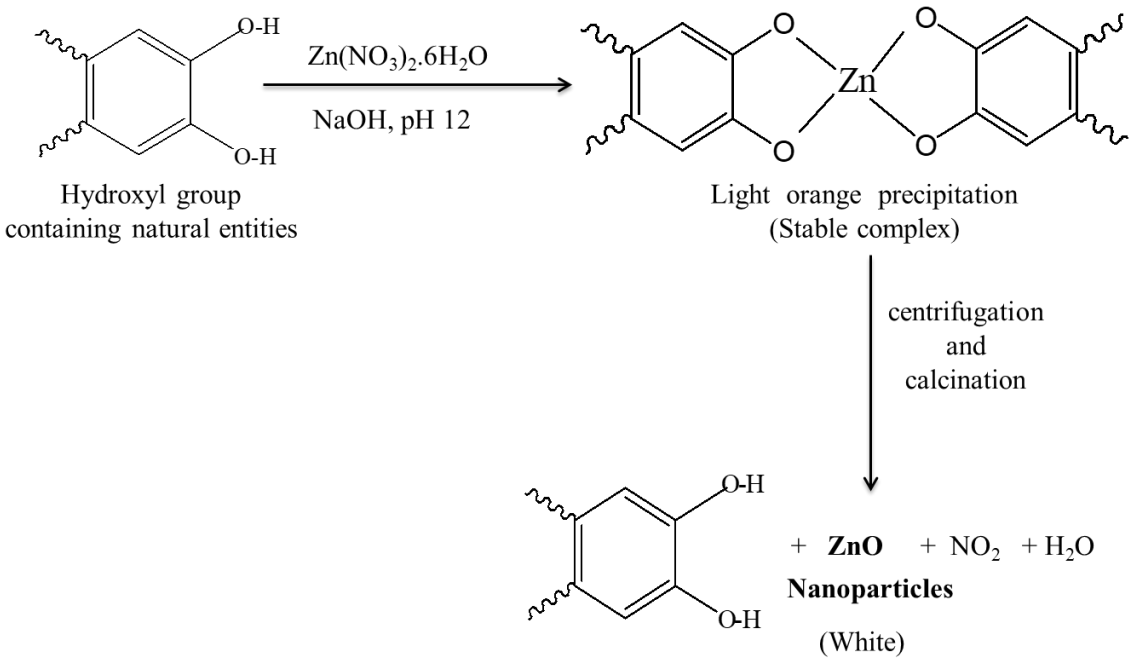


Fig. 2 Proposed mechanism of ZnO NPs formation.

3.2. Ultraviolet-Visible (UV-Vis) spectroscopy analysis

ZnO NPs generally show UV absorption bands in the λ_{max} ranges from 355 to 380 nm [74, 75]. **Fig. 3** shows the absorption intensity of the prepared ZnO NPs measured in the wavelength range from 300 to 500 nm. The prepared ZnO NPs using *Cocos nucifera* leaf extract showed λ_{max} at 370 nm which is supported by the literature [66-68]. The bandgap energy of ZnO NPs was found to be 3.37 eV as calculated by using Tauc's plot, which is alike to the reported bandgap energy of ZnO (wide band gap 3.10 - 3.39 eV) [31, 33, 76, 77]. These findings primarily confirm the formation of ZnO NPs following our approaches.

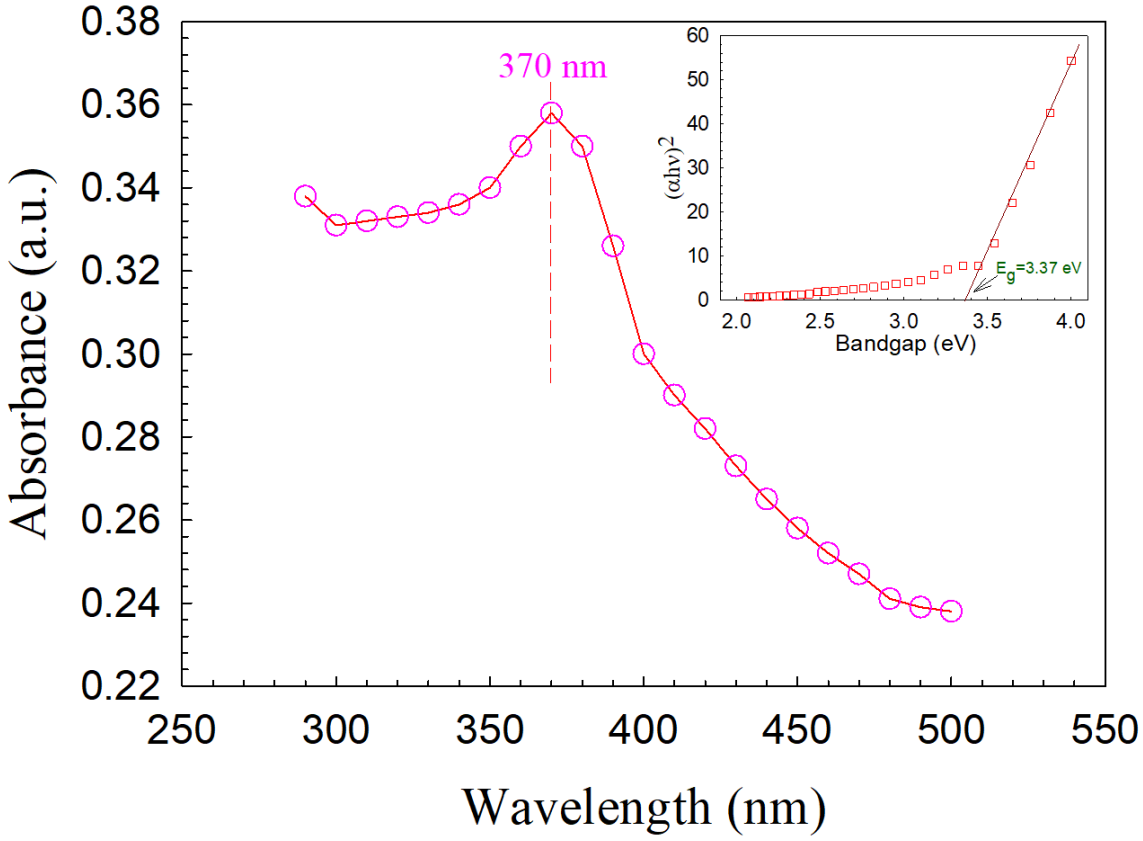


Fig. 3 UV–Vis spectrum of ZnO NPs prepared using *Cocos nucifera* leaf extract.

3.3. X-ray diffraction analysis

The white powder obtained from the preparation step of the material was subjected to the XRD analysis and the corresponding XRD patterns are shown in **Fig. 4.** The XRD patterns revealed 9 diffraction peaks appearing at 2θ angles of 31.83°, 34.46°, 36.28°, 47.58°, 56.62°, 62.91°, 66.46°, 68.06°, and 69.10° corresponding to the miller indices of 100, 002, 101, 102, 110, 103, 112, 200, and 201, respectively. According to JCPDS card no: 36-1451, the obtained patterns identified our prepared material as ZnO with hexagonal wurtzite structure, space group: P63mc, unit cell volume: 47.62, unit cell parameters: a = b = 3.25 Å and c = 5.21 Å, and α = β = 90° and γ = 120°. The obtained XRD patterns are quite comparable with the previous report [31, 75]. The average crystal size of the prepared ZnO NPs was calculated by using Debye Scherrer's equation (section 2.4, equation 1) and is found to be 16.6 nm (range:11.9-24.1 nm).

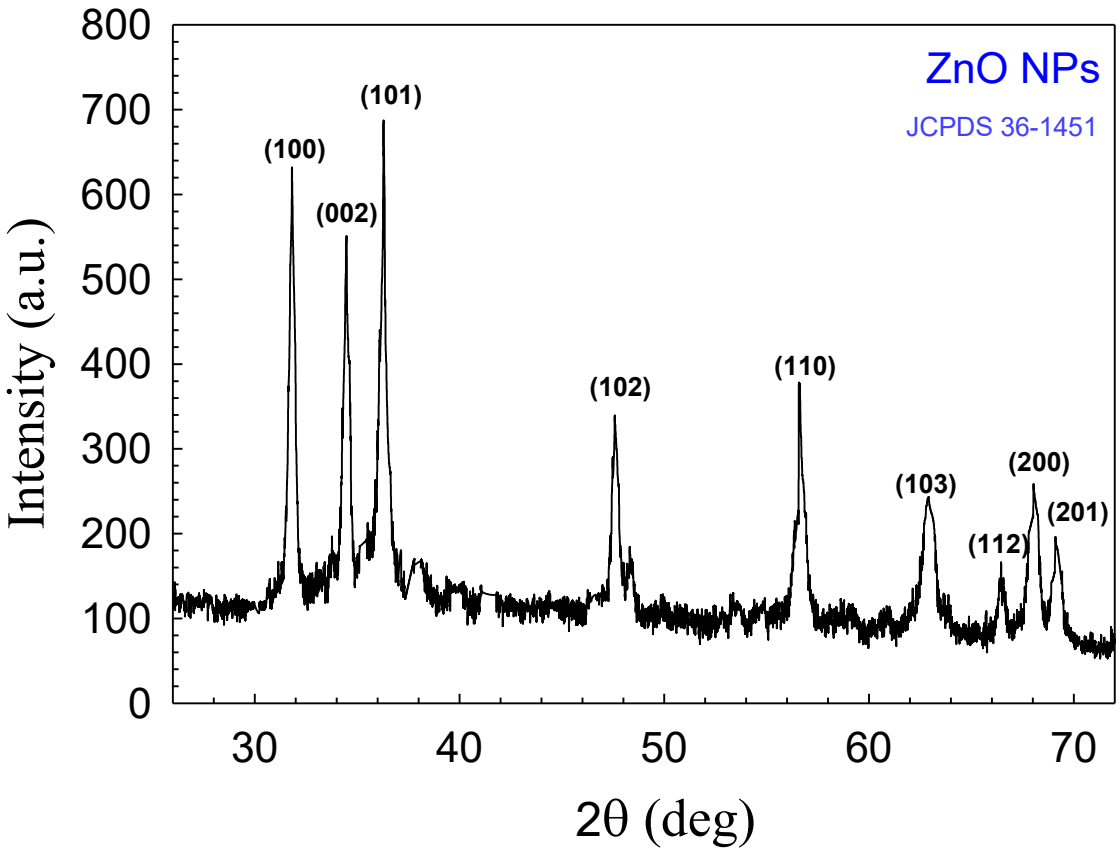


Fig. 4 XRD pattern of ZnO Nps prepared using *Cocos nucifera* leaf extract

3.4. FTIR spectroscopy analysis

The FTIR spectrum of the prepared ZnO NPs using *Cocos nucifera* leaf extract is illustrated in **Fig. 5.** The inset of Fig. 5 shows the FTIR spectrum of *Cocos nucifera* leaf extract. This spectroscopic measurement was carried out to identify the functional groups of the possible biomolecules responsible for the capping and efficient stabilization of the ZnO NPs. According to the literature [78], the peaks that appeared at (3200-3600) cm^{-1} in the FTIR spectrum can be corroborated by the O-H stretching alcohols, stretching vibrations of the primary and secondary amines, and C−H stretching of alkanes. The peaks observed at 1568, 1411, and 1100 cm^{-1} originated due to the C=C stretching in the aromatic ring in polyphenols and aliphatic amines, while 2300 cm^{-1} originated from di-substituted alkynes, and 550 cm^{-1} from the hexagonal phase of ZnO [78, 79]. As mentioned previously, the *Cocos nucifera* leaf contains alkaloids, steroids, terpenoids, flavonoids, polyphenols, and aromatic hydrocarbons. In this consequence, the results of the FTIR analysis indicate that the functional groups present in the biomolecules of leaf extract as well as phytocompounds such as alkaloids, steroids, terpenoids, flavones, polyphenols, and

aromatic hydrocarbons may also act as reducing and capping agent for ZnO NPs formation and prevent agglomeration of the NPs in the aqueous extract medium [47, 80].

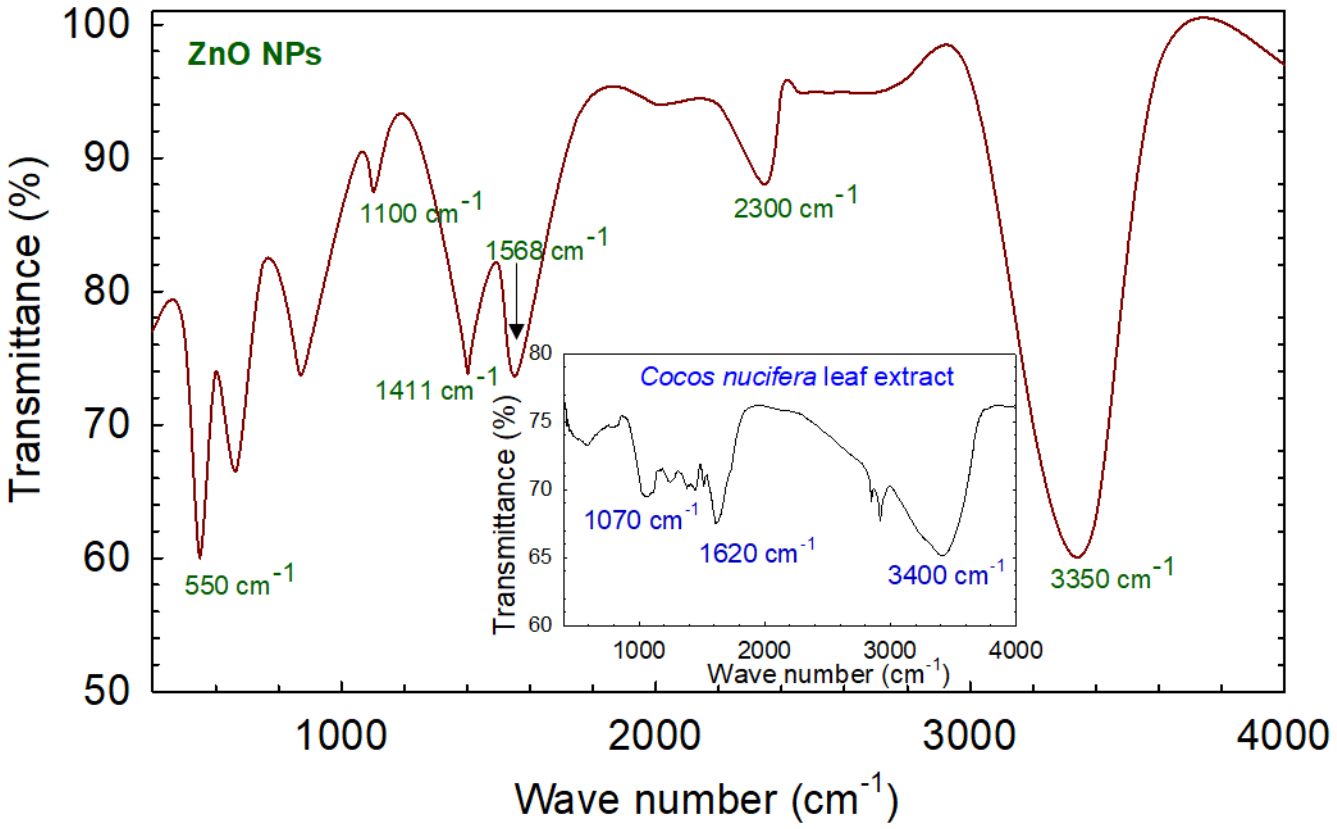
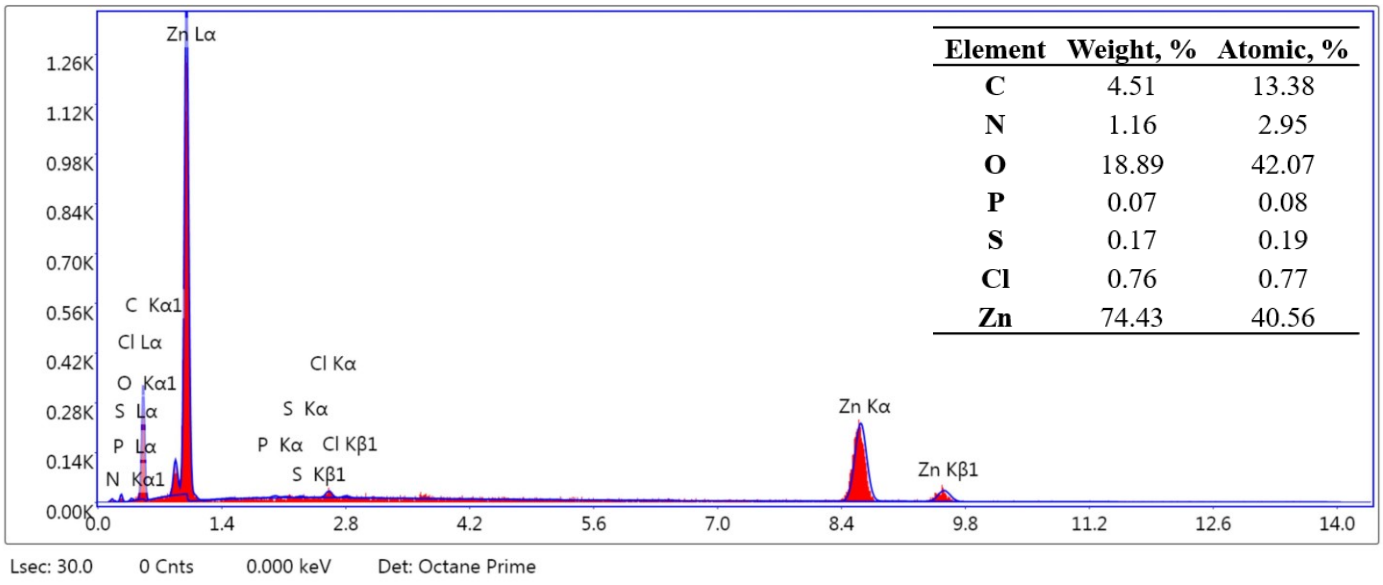


Fig. 5 FTIR spectrum of ZnO NPs prepared using *Cocos nucifera* leaf extract. The inset shows the FTIR spectrum of *Cocos nucifera* leaf extract.

3.5. Energy dispersive X-ray (EDX) analysis



Element	Weight, %	Atomic, %
C	4.51	13.38
N	1.16	2.95
O	18.89	42.07
P	0.07	0.08
S	0.17	0.19
Cl	0.76	0.77
Zn	74.43	40.56

Fig. 6 EDX spectrum and elemental composition of ZnO NPs prepared using *Cocos nucifera* leaf extract.

The elemental composition of ZnO NPs was obtained from EDX analysis. **Fig. 6** shows the existence of chemical elements and their composition in the prepared ZnO NPs. The presence of a large percentage of Zn and O is indicative of ZnO formation. As expected, the atomic percentage of Zn and O are almost equal (ZnO in 1:1 ratio) and then the highest percentage of C along with some other elements such as N, P, S, and Cl originated from the biomolecules of *Cocos nucifera* leaf. The presence of Zn at a high percentage whereas C and other elements in a lower percentage indicate that plant phytochemical groups were involved in reducing and capping the ZnO NPs.

3.6. Scanning electron microscopy (SEM) analysis

The surface morphology of the prepared ZnO NPs was studied by SEM analysis. The SEM image of ZnO NPs is depicted in **Fig. 7,** which shows a uniform distribution of flower-shaped ZnO molecules. The calculation of particle size of ZnO NPs from the SEM image using ImageJ software gives the size of NPs as about 15 nm which is agreed with the calculated particle size (16.6 nm) from XRD data. The hydrogen bonding and electrostatic interaction between bioorganic capping molecules and NPs have accumulated them to stay together [81]. Moreover, the SEM image showing ZnO NPs revealed that the NPs are not in direct contact with each other which signifies the stabilization of the NPs by capping agents [82].

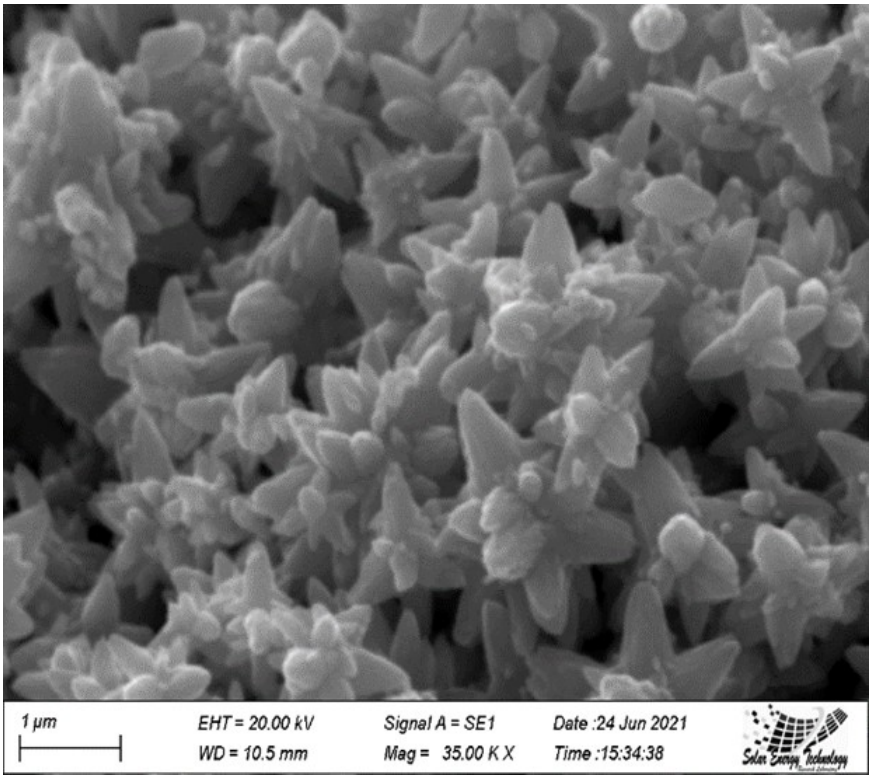


Fig. 7 SEM image of ZnO NPs prepared using *Cocos nucifera* leaf extract.

3.7. Antimicrobial screening analysis

3.7.1. Mode of action

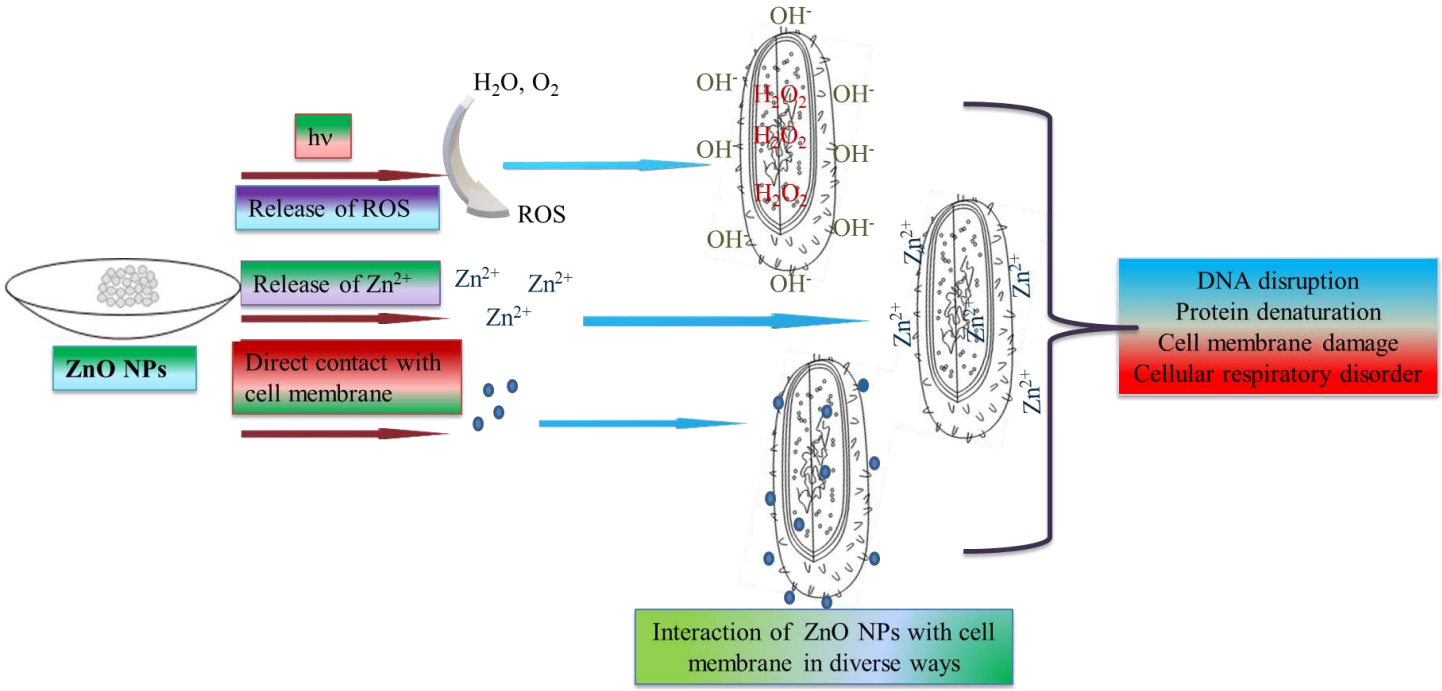


Fig. 8 Mode of action of ZnO NPs against microbes (In the figure, ROS means reactive oxygen species).

The ZnO NPs showed good antimicrobial activity against a wide variety of microbes including bacteria and fungi. The prepared NPs interact with the cell membrane of microbes in different pathways such as through the release of ROS (reactive oxygen species), the release of Zn^{2+}, and direct contact with the cell membrane. This process damages the cell through DNA disruption, protein denaturation, cellular respiratory disorder, cell membrane damage, and so on. **Fig. 8** illustrates the discussed mechanism which is also proposed in the literature [83, 84].

3.7.2. Antimicrobial activity of ZnO NPs

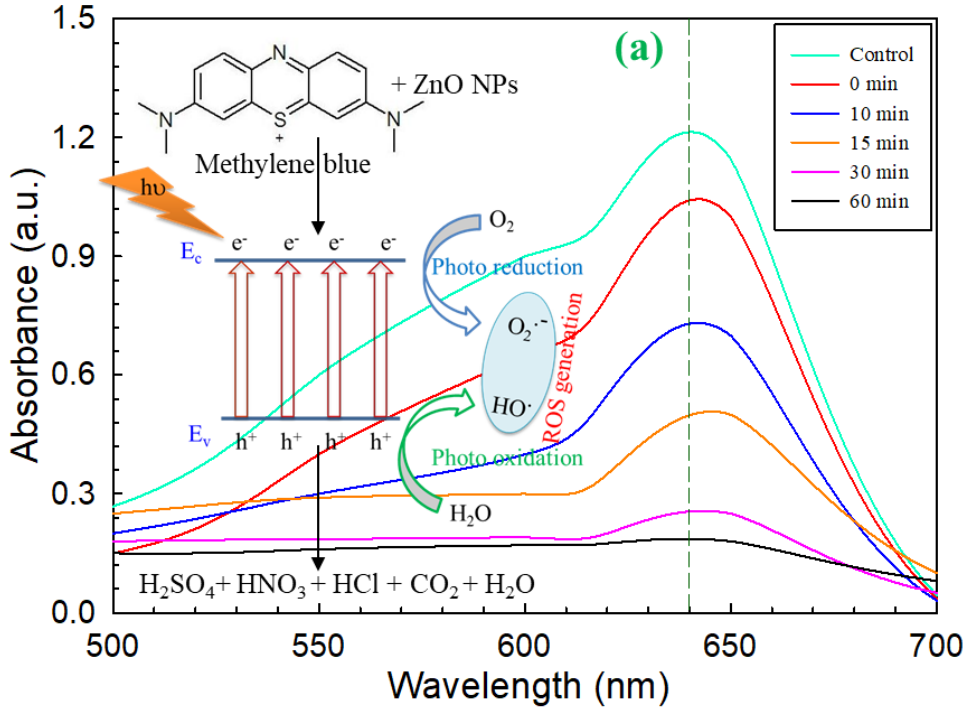
Antimicrobial activity was studied against three bacterial and two fungal pathogenic strains as shown in **Table 1**. The highest ZOI of ZnO NPs was found to be 14 mm for fungal pathogenic strains of *T. harzianum* which causes infection in renal transplant recipients in humans [85]. Synthesized ZnO nanoparticles show moderate antimicrobial activity (≥10 mm) with gram (+ve) bacteria *S. aureus* (10 mm) and fungus *A. niger* (10 mm) and slight antimicrobial activity (8 - 9 mm) against *B. megaterium* and *S. aureus*.

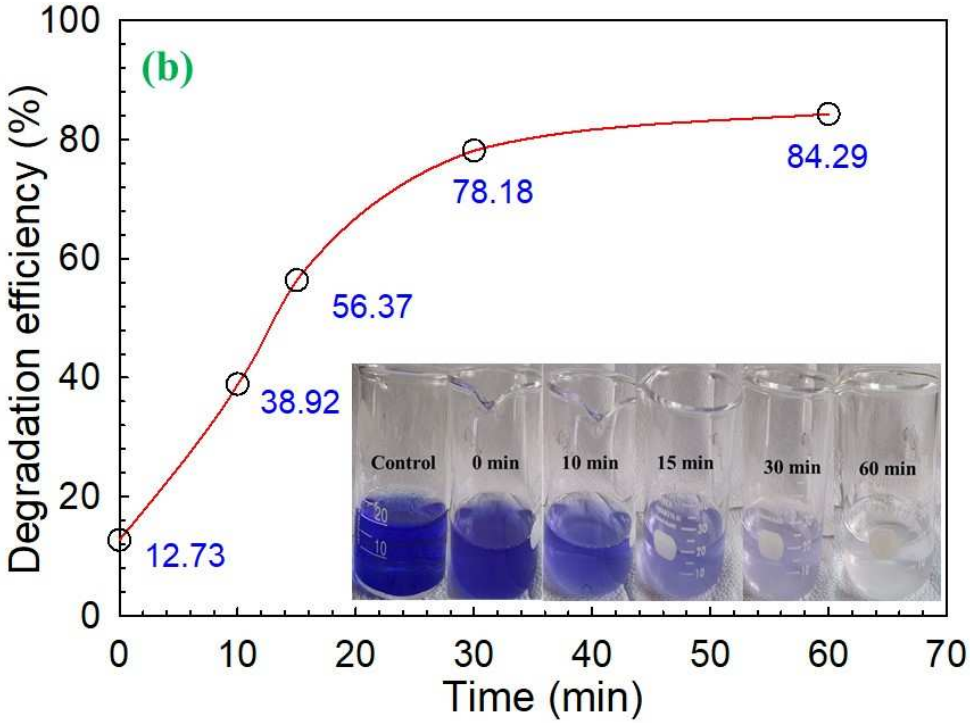
Table 1 ZOI diameters (mm) of ZnO NPs, ceftriaxone, and amphotericin-B against tested bacterial and fungal strains.

Material	Gram (+ve) Bacteria			Fungi	
	B. megaterium	*S. aureus*	*B. cereus*	*A. niger*	*T. harzianum*
ZnO NPs	08	10	08	10	14
Ceftriaxone	50	40	20	-	-
Amphotericin-B	-	-	-	08	17

3.7.3. Photocatalytic behavior of ZnO NPs

Fig. 9 (a) demonstrates the photocatalytic behavior of the prepared ZnO NPs which represents the degradation of dye concentration at different time intervals, whereas **9** (b) represents the percentage of dye degradation with respect to time with a clear view (inset) of the color change during the reaction. The initial absorbance of the dye was compared with the final absorption after mixing the prepared ZnO NPs with the dye. It was shown that the absorbance degrades graphically at 640 nm. The mixed solution was discolored after 1 hour and methylene blue dye degraded a maximum of 84.29 % by the ZnO NPs. A possible mechanism is proposed [86, 87] for this degradation process, like the production of ROS (reactive oxygen species) by photo-oxidation (hydroxyl radical generation) and photo-reduction (peroxide radical generation) process [88]. The reaction rate can be calculated using the first-order kinetic equation $\ln(C_0/C_t) = kt$, where C_0 and C_t are the initial and final concentration of ZnO NPs and k is the rate constant which is equal to 0.0219 min^{-1}, and t is the degradation time showed in **Fig. 9(c)**. Finally, this ROS degraded the dye into mineral acids, CO_2, and water. The probable mechanism is embedded in the inset of **Fig. 9** (a).





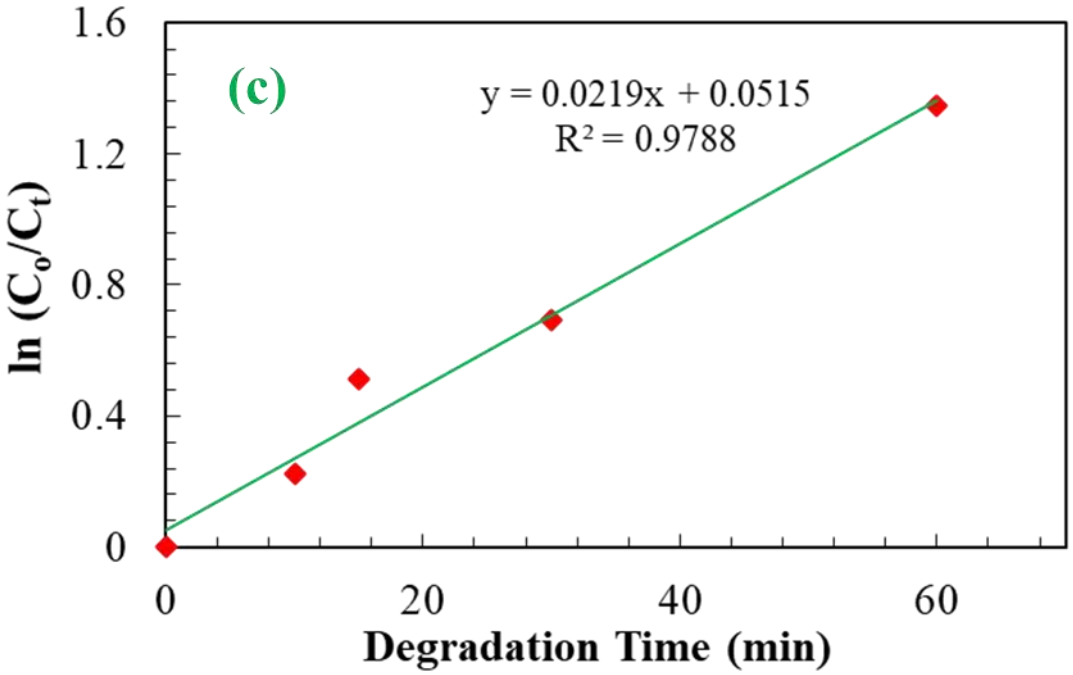


Fig. 9 (a) UV–Vis spectra showing the degradation of methylene blue dye through the photocatalysis activity of the prepared ZnO NPs. (b) percentage of degradation of methylene blue dye with respect to a time where the inset figure illustrates the color change with time during the degradation of methyl blue dye with ZnO NPs. (c) shows the reaction kinetics.

3.7.4. Antioxidant activity assay

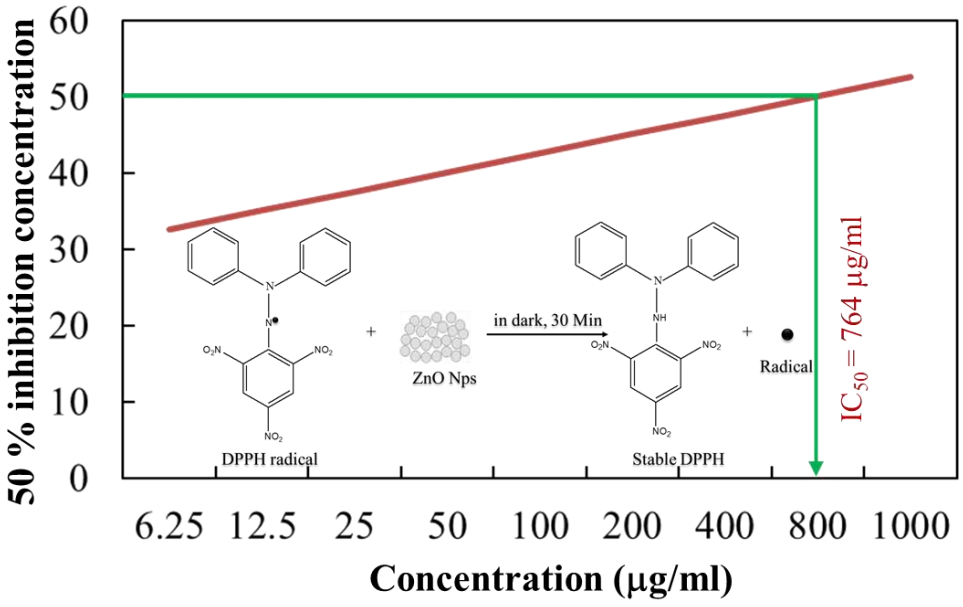


Fig. 10 DPPH (2, 2-diphenyl-1-picrylhydrazyl) free radical scavenging activity of the prepared ZnO NPs showing IC_{50} value. Inset shows the mechanism for DPPH free radical scavenging activity of ZnO NPs.

Fig. 10 demonstrates the DPPH (2, 2-diphenyl-1-picrylhydrazyl) free radical scavenging activity of the prepared ZnO NPs showing IC_{50} value. The inset of the same figure illustrates the mechanism for DPPH free radical scavenging activity of ZnO NPs following that of Murali et al. [89]. At 517 nm, the absorbance of DPPH decreased with the increase of the concentration of ZnO NPs. This result indicates that the prepared ZnO NPs can inhibit oxidation due to transferring of electron density located at the oxygen atom to the nitrogen atom in DPPH free radical which contains odd electron by $n \rightarrow \pi^*$ transition [90, 91]. The required concentration of the prepared ZnO NPs to show 50 % inhibition (IC_{50}) of DPPH was found to be 764 μg/mL.

4. Conclusions

In this attempt, we have successfully prepared ZnO NPs with an average size of 16.6 nm, using *Cocos nucifera* leaf extract by a facile, inexpensive, and green approach. The prepared NPs were identified and characterized by different techniques such as UV-Vis spectroscopy, XRD, FTIR, EDX, and SEM analyses. The aqueous solution of the prepared ZnO NPs showed absorption maxima, λ_{max} at 370 nm in UV-Vis spectroscopic measurement. The XRD analysis identified the formed ZnO NPs with hexagonal wurtzite structure. The FTIR analysis indicates the presence of some reducing biomolecules associated with some organic functional groups responsible for the encapsulation and stabilization of the NPs. The obtained elemental composition from EDX analysis supports the formation of the desired ZnO NPs. The antimicrobial study of the prepared ZnO NPs showed that the material is very active against various pathogenic bacteria and fungi. The prepared NPs showed high photocatalytic activity while moderate antioxidant activity. Thus, we can conclude that the prepared ZnO NPs could be used in biomedical, medicinal, and pharmaceutical applications; and also, as photocatalysts in the dye degradation process.

Acknowledgment

The authors highly acknowledge the Organic Chemistry Research Laboratory, Department of Chemistry, Comilla University, Cumilla for the laboratory and instrumental facilities. We also acknowledge the Bangladesh Council of Scientific and Industrial Research (BCSIR) and Bangladesh Atomic Energy Commission for SEM-EDX and XRD analysis. The authors are thankful to the Department of Pharmacy, Comilla University, and the Department of Chemistry, Jagannath University, Dhaka for allowing us to experiment on the antioxidant and antimicrobial study.

Funding

The research work is funded by GARE (Grant for advanced research in education), Ministry of Education, Dhaka, Bangladesh bearing Project ID (PS 20191023).

Ethical Statements:

The study was conducted according to the guidelines of the planning and development (P&D) committee of the Department of Chemistry, Comilla University (Ref: Chem/P&D/100/10-15;14/09/2020). *Cocos nucifera* leaves were used in this study which was kindly provided by Dr. Mohammad Anowar Hossain Bhuyan, Joint Director, Bangladesh Academy for Rural Development (BARD), Cumilla 3503, Bangladesh, in September 2020, and were authenticated by Professor Dr. Shaikh Bokhtear Uddin, Department of Botany, University of Chittagong, Chattogram-4331, Bangladesh. A voucher specimen of this species was deposited to the Chittagong University Herbarium with Accession number (SBU 210222-32660 CUH).

Competing interests

We have no competing interests.

Availability of Data

Our data are deposited at Dryad as (DOI): https://doi.org/10.5061/dryad.tht76hf27.

Author Contribution

Farjana Rahman: Experiment, Investigation, Methodology, Data curation, Formal analysis, Writing - original draft.

Md Abdul Majed Patwary: Supervision, Funding acquisition, Experiment, Investigation, Methodology, Data curation, Formal analysis, Writing - original draft, review & editing.

Md. Abu Bakar Siddique: Experiment, Formal analysis, Writing - review & editing.

Muhammad Shahriar Bashar: Experiment, Formal analysis, Writing - review & editing.

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