Antibacterial activity of water soluble dye capped zinc oxide nanoparticles synthesised from waste Zn–C battery

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Abstract

Antibacterial activity of functionalized ZnO nanoparticles synthesized from waste Zn–C battery by microwave method was investigated, water soluble 1-(carboxymethyl)-4-[(E)-2-(3-methoxy-4-methylphenyl)ethenyl] pyridin-1-ium photosensitizer was used as capping agent to control the size of nanoparticle. The characterization of the samples was done with the help of UV–visible spectroscopy, FTIR, SEM–EDS and XRD. The nanoparticles have hexagonal wurtzite structure with a mean diameter of 19.7 nm for 3% dye capped nanoparticle and 30.6 nm for uncapped nanoparticle and are composed by a mixture of small crystallites and disordered ZnO particles. Capped ZnO nanoparticles showed high antibacterial (tested on *E. coli* and *B. subtilis*) activities compared to that of uncapped nanoparticles under the same experimental conditions. This novel water soluble dye capped ZnO nanoparticles emerged as excellent antibacterial agent, the results show minimum inhibitory concentration of 0.39 and 1.56 for *B. subtilis* and *E. coli* and highest zone of inhibition was at concentration of 5 mg/ml. The bioactivity showed dye capped nanoparticle to be new class of antibacterial agent.

Keywords 4-Styrylpyridine · ZnO Nanoparticles · Capping agent · Antibacterial activity · *B. subtilis* · *E. coli*

1 Introduction

In recent years bio-inspired nanoparticles prepared by functionalization of small organic molecules is of increasing interest [1]. Functionalization of NPs allows their possible applications in many fields such as drug delivery, nanomedicine, biosensors, and bionanotechnology [2–4]. The antibacterial activity of nanoparticle depend on various factors such as Particle size of NPs, composition, surface modification, intrinsic properties, and the type of microorganism [5, 6]. For a nanoparticle to be effective antibacterial agent the interaction between bacteria and the Nanoparticle plays important role, for effective interaction nanoparticle should be lyophilic in nature [7]. Inorganic metal oxide nanoparticles are excellent antibacterial agents, the major drawback is their lyophobic nature [8] and large band gap [9], surface modification approaches

aim at improving surface-assisted antibacterial properties by making nanoparticles lyophilic which increases interaction between nanoparticle and bacteria, shifting the wavelength of absorption towards visible region or reducing band gap and by increasing the photoinduced activity of nanoparticles [10, 11]. Organic–inorganic monohybrids functionalized with water soluble photosensitizers could lead to novel antibacterial agents for photoinduced antibacterial applications and lyophilic nature induced in nanoparticle could lead to increased antibacterial activity due to increased interaction between nanoparticle and bacteria [12].

Zinc Oxide is well known metal oxide photocatalyst having many applications such as water treatment process, food packaging materials, dye sensitized solar cells etc. [13, 14]. When a ZnO photocatalyst is irradiated with UV light, it directly excites ZnO by promoting electron

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from valance bond to conduction band which produce electron-hole pairs and generate various active oxygen species, such as hydroxyl radicals, hydrogen peroxide, superoxide radical anions, etc. [15]. ZnO nanoparticles shows inhibitory effect on the growth of *E. coli* and *B. subtilis* strains which was confirmed by previous reports [16, 17]. Hence ZnO nanoparticles can be considered as potent antibacterial compound, but not as much as the established compound such as ampicillin [18]. ZnO being cheap and eco-friendly, the antibacterial properties of ZnO nanoparticles can be further improved by surface modification approaches so that these nanoparticles can be used in various industrial and medical applications [19, 20], the emergence of drug resistance bacteria has instigated researchers to develop novel nanomaterials with antibacterial capacity [21]. Assessing the influence of nanoparticles on microorganisms requires interaction between the microorganisms and the nanoparticles. Bulk metal oxide nanoparticles tend to agglomerate in aqueous, pH-neutral bacterial growth media containing ions and proteins. The aim of this study was to introduce lyophilic property on nanoparticle which stabilizes ZnO nanoparticles in LB medium in order to avoid agglomeration and increase nanoparticles and bacterial interaction.

Waste Zn-C battery is an excellent alternative source of Zinc, synthesis of ZnO nanoparticles from spent Zn-C battery could provide commercially viable, environment friendly, ensure recyclability of spent Zn-C batteries and sustainable benefits [22]. Many methods have been developed for synthesis such as sol-gel, hydrothermal, arc discharge, chemical vapour deposition, microbial route, oxidation process [23–25] etc., low temperature selective chemical precipitation is simple yet efficient technique for preparation of ZnO nanoparticles with organic capping agent [26, 27]. Water soluble organic styrylpyridine photosensitizers was developed as capping agent, these organic photosensitizers has received much attention because of their electron injection properties, which is being exploited in dye sensitized solar cell applications [28], the charge on the capped nanoparticles provide stability and decreases agglomeration, and the water solubility of dye could increase lyophilic nature of nanoparticles and hence interaction between Bacteria and nanoparticle

surface [29]. Organic photosensitizers are also being used in Photodynamic therapy which has emerged as novel method for the treatment of various infectious disease caused by bacteria, fungi, and viruses [30, 31]. In the present work we have synthesised 1-(carboxymethyl)-4-[(E)-2-(3-methoxy-4-methylphenyl)ethenyl]pyridin-1-ium dye functionalized Zinc Oxide nanoparticles from waste Zn-C battery by microwave method and evaluated the antibacterial activity of capped ZnO nanoparticles against *E-Coli* and *B. subtilis* bacteria. To our knowledge we have not seen the reports on synthesis of water soluble photosensitizer capped ZnO nanoparticles from spent Zn-C battery by microwave method.

2 Experimental

2.1 Materials and chemicals

The Chemicals used for the preparation of target ZnO capped with dye 1-(carboxymethyl)-4-[(E)-2-(3-methoxy-4-methylphenyl)ethenyl]pyridin-1-ium were 4-methyl pyridine, Chloroacetic acid, sodium hydroxide, vanillin, acetone and Ethanol. These chemicals were procured from Sigma Aldrich and were used in their pure form without any purification. A mixture of deionised water and methanol was used as solvent for fabrication of the targeted product.

2.2 Synthesis

The synthesis of dye 1-(carboxymethyl)-4-[(E)-2-(3-methoxy-4-methylphenyl)ethenyl]pyridin-1-ium is illustrated in Scheme 1, and was synthesised following the literature procedures [32].

2.3 Synthesis of 1-carboxy-4-methylpyridin-1-ium

A solution of 4-methylpyridine (1.5 g, 16.1 mmol) and 1-chloroacetic acid (1.52 g, 16.1 mmol) in ethyl acetate (25 ml) was stirred for 2 h at room temperature (303 K). The resulting solid was filtered off and washed with ethylacetate to give (1), which was recrystallized from an aqueous ethanol (80%

Scheme 1 Shows the synthesis route of 1-(carboxymethyl)-4-[(E)-2-(3-methoxy-4-methylphenyl)ethenyl]pyridin-1-ium

v/v) solution (0.59 g, 1.78 g yield 73%). ^1H NMR (500 MHz, CD_3OD): δ 2.36 (3H, s), 4.84 (2H, q), 7.22 (2H, d), 8.98 (2H, d).

2.4 Synthesis of 1-(carboxymethyl)-4-[(E)-2-(3-methoxy-4-methylphenyl)ethenyl]pyridin-1-ium

1-carboxy-4-methylpyridin-1-ium (1.5 g, 9.91 mmol), Vanillin (0.95 g, 9.91 mmol), and 15 mL ethylacetate was mixed. Five drops of piperidine was added to the mixture. Then the solution was refluxed at 70 °C for 6 h, cooled the reaction mass, a dark orange-yellow solid was formed and filtered. The solid was washed twice with ethanol. Yellow solid was collected (1.95 g, yield 86%). ^1H NMR (500 MHz, CD_3OD): δ 6.04 (2H, s), 9.01 (2H, d), 8.09 (2H, d), 6.95 (2H, d), 6.99 (1H, d), 7.1 (1H, d), 5.35 (1H, s), 3.83 (3H, s). m/z = 229.38.

2.5 Nanoparticle synthesis

Nanoparticle was synthesised by microwave assisted sol-gel method from spent Zn-C battery [33]. Waste Zn-C battery was manually dismantled to obtain the powdered materials which is positive electrode and contains mainly manganese dioxide and zinc oxide. The powder materials wetted with electrolyte was used as raw material to synthesize ZnO nanoparticles. The obtained powdered material was dried in the oven at 90° C for 2 h to remove moisture and the weight of the dried powder was 6.5 g. The dried powder was crushed in pestle and mortar to obtain fine powder which was suspended in neutral pH distilled water and stirred at 60° C for 30 min to remove KOH and NH_4Cl which are the electrolytes of the battery, the powder was filtered, dried at 90° C for 2 h and the weight of the dried powder was 5.29 g, a loss in the weight of 9.5%v was observed. A quantitative analysis at this stage by SEM-EDX showed the Zn and Mn content of the sample to be 25.2% and 40.8% respectively.

Zinc oxide nanoparticles were prepared by leaching technique using H_2SO_4 as leaching agent, the reactions of leaching are as shown below

Ascorbic acid was used as reducing agent to reduce Mn(IV) to Mn(II), an excess of reducing agent was used in the reaction to achieve reaction, the balanced reaction of reduction is shown below

2 g of spent Zn-C electrode powder was suspended in 15 ml of 2 M sulphuric acid and 5 ml of 0.15 M ascorbic

acid, the suspension was heated on water bath 70–80 °C for 1 h. The resulting solution was filtered to remove carbon, selective precipitation was carried out using 2 M NaOH solution, an initial pH of 14 was set where Zinc hydroxide dissolves as it forms $[\text{Zn}(\text{OH}_4)]^{2-}$ whereas manganese hydroxide remains as precipitate was removed by centrifugation at 5000 rpm. To the above solution 60 mg (3% weight of Zn-C electrode powder) of water soluble dye was added as capping agent and acidified with dilute H_2SO_4 to pH 10 to reprecipitate zinc as $\text{Zn}(\text{OH})_2$. The precipitate was centrifuged at 5000 rpm, washed 3–4 times with water to remove uncapped dye. Finally obtained nanoparticle was vacuum dried at 60 °C for 8 h, similarly uncapped ZnO nanoparticle was synthesised following same procedure as above without using dye. The obtained nanoparticles were subjected for further characterization.

2.6 Antibacterial studies

The antimicrobial activity for pure ZnO and dye capped ZnO nanoparticles were performed, we have chosen 3% dye capped ZnO nanoparticle sample at different concentrations because of its optical absorption in visible region, samples were tested against *Escherichia coli* (ATCC Number 25922) gram negative bacteria and *Bacillus subtilis* (ATCC Number 6633) gram positive bacteria obtained from National Collection of Industrial Microorganisms, NCL, Pune, India for the given studies.

2.7 Determining zone of inhibition

Initially, the stock cultures of bacteria were revived by inoculating in broth media and grown at 37 °C for 18 h. The agar plates of the media (Peptone-10 g, NaCl-10 g and Yeast extract 5 g, Agar 20 g in 1000 ml of distilled water) were prepared and wells were made in the plate. Each plate was inoculated with 18 h old cultures (100 μl , 10^8 cfu/ml) and spread evenly on the plate using sterile cotton swab. After 20 min, the wells were filled with of compound of different concentration (0.0195 to 10 mg/ml). All the plates were incubated at 37 °C for 24 h and the diameter of inhibition zone were noted.

2.8 MIC assay of Nps

Test organism *Escherichia coli* (ATCC Number 25922) gram negative bacteria and *Bacillus Subtilis* (ATCC Number 6633) gram positive bacteria were grown separately in a 50 ml sterilized nutrient broth medium incubated at 37 °C for 14 h. On the subsequent day, test organism cultures were transferred at the rate of 1% in 100 ml nutrient broth. The initial concentration of 5 mg/ml nanoparticle in nutrient broth was diluted using double fold serial dilution, 5 ml of

above stock solution was diluted with 5 ml of sterile nutrient broth to obtain 5 mg/ml concentration. The process was repeated several times to obtain 5 to 0.0195 mg/ml concentrations. To the above of the each medium containing different concentration of ZnO Nps, 0.1 ml of the standard bacterial cell suspension was added and incubated at 37 °C for 24 h. The growth of the inoculums in the broth was assessed by colony count method on solid agar plates and the lowest concentration of the ZnO Nps which inhibited the growth of the test bacteria was taken as the minimum inhibitory concentration (MIC).

2.9 Bacterial growth curves

Bacterial growth curves for functionalized nanoparticles were performed to observe the effect of variation of nanoparticles concentration on growth of bacterial strains of *E. coli* and *B. subtilis*. Bacterial inoculums were prepared in sterile physiological saline (1.5×10^8 bacterial cells/ml) using 24 h fresh bacterial cultures. Each flask was prepared which contained 20 ml of nutrient broth with 0 µg/ml (control), 50 µg/ml, 200 µg/ml, 500 µg/ml and 1000 µg/ml of capped ZnO nanoparticles, respectively. The flasks were inoculated with 100 µl of the bacterial suspension of each strain and incubated at 37 °C under continuous stirring of 150 r.p.m. for 12 h. The Optical Density (OD) of the cultures at 600 nm was measured for every 2 h over a period of 16 h to monitor bacterial growth. The readings obtained were plotted and comparative studies were performed between uncapped ZnO and 3% dye capped ZnO nanoparticles.

3 Results and Discussion

3.1 Characterisation of nanoparticles

The ZnO Nps were synthesized by chemical precipitation and surface modification approach from spent Zn–C battery. The UV–Vis absorption spectra of synthesised NPs were measured in the range of 200 nm to 800 nm. We observed a absorption peak at ~310 nm as shown in Fig. 1a, which corresponds to a band gap of 3.6 eV and is consistent to the previous report [34]. The presence of dye on the surface of ZnO nanoparticles as capping agent was confirmed from FTIR spectroscopy. Multiple peaks corresponding to different functional groups is observed in the spectra. Dye alone showed a spectrum which consists of broad band at 3400 cm^{-1} due to stretching of O–H group of –COOH, the sharp absorption band of C=O of COOH due to vibration occur at 1715 and 1695 cm^{-1} , C–H stretching was at 1495 cm^{-1} , the peak at 1050 cm^{-1} was due to C–O stretching of COOH. The FTIR

Fig. 1 **a** UV–Vis spectra of dye alone, uncapped ZnO, and dye capped ZnO Nps synthesized by the precipitation and microwave method. **b** FTIR spectra of pure dye (Red) and 3% dye capped ZnO Nps (Green)

Fig. 2 (a) XRD pattern of uncapped ZnO Nps formed by precipitation and microwave method. (b) XRD pattern of 3% dye capped ZnO Nps after surface modification

Fig. 3 **a** Characterization of uncapped ZnO Nps synthesized by the precipitation and microwave method using SEM analysis. **b** Capped ZnO Nps by the surface modification method using SEM analysis. **c** EDS spectra of Capped ZnO Nps by the surface modification

Table 1 XRD Data of TiO₂ Nanoparticles

Sample	2θ	θ	Cos θ	Sin θ	FWHM (°)	FWHM radian	β Cos θ	Size (nm)	d-spacing
Uncapped-ZnO	35.8634	17.93	0.951	0.307	0.2732	0.004768	0.00453	30.6	2.50
Capped (5%)-ZnO	35.8634	17.93	0.951	0.307	0.4236	0.007393	0.00703	19.7	

spectra for the ZnO containing dye as capping agent also showed spectrum of multiple bands, the peaks were shifted in comparison to the pure dye. The band with respect to O–H stretching of –COOH was absent while all other bands appear to be present but slightly shifted towards longer wavelength this shows the covalent

bonding of dye with ZnO nanoparticles as shown in the Fig. 1a. Besides these results the FT-IR spectra of functionalized ZnO nanoparticle was compared with the previously reported FT-IR spectra of pure ZnO nanoparticles [35], which appeared to be in good agreement. FT-IR spectrum of ZnO NPs synthesized depends upon

Fig. 4 Optimised structure of dye calculated by using DFT software quantum espresso

Table 2 Zone of inhibition for uncapped ZnO against *E.coli* and *B.subtilis*

Concentration in wells (mg/ml)	Zone of inhibition (mm)			
	Dye uncapped ZnO		Dye capped ZnO	
	<i>E. coli</i>	<i>B. subtilis</i>	<i>E. coli</i>	<i>B. subtilis</i>
5	16	19	21	28
2.5	14	17	18	24
1.25	12	15	16	21
0.625	8	11	12	17
0.312	0	7	8	11
0.156	0	0	0	9
0.078	0	0	0	0
0.039	0	0	0	0
0.0195	0	0	0	0
Control	0	0	0	0

the type of precursor used in the synthesis of nanoparticle. Strong absorption peaks at 432 cm^{-1} attributed to Zn–O stretching band and the oxygen vacancy in ZnO at 503 cm^{-1} was also observed in our case. These discussions are the clear evident that the dye was successfully capped on the surface of the nanoparticles.

From the SEM images of the ZnO NPs (Fig. 3), the morphology was found to be spherical with smooth surface with uniform crystallite and crystallite size structure which is in good agreement with XRD, the effect of capping agent on the surface of nanoparticle can be

clearly seen from the images. The XRD patterns of ZnO samples prepared for capped and uncapped ZnO are shown in Fig. 2. The peaks at 2θ values of 31.67° , 34.31° , 36.14° , 47.40° , 56.52° , 62.73° , 66.28° , 67.91° , 69.03° , and 72.48° were assigned to the planes (100), (002), (101), (102), (110), (103), (200), (112) and (201) and are in good agreement with the hexagonal wurtzite structure of ZnO as confirmed by comparison with the JCPDS card (#36-1451). The crystallite size was estimated from the largest peak by using Debye-Scherrer formula. The d-spacing (inter-planar spacing between atoms) was calculated using Bragg's Law and enumerated in Table 1.

$$D = 0.9\lambda / \beta \cos\theta$$

$$2d \sin\theta = n\lambda$$

where λ is wave length of X-ray (0.1540 nm), β is FWHM (full width at half maximum), θ is diffraction angle, d is d-spacing and D is particle diameter size.

3.2 DFT Calculations

The structures of dye have been optimized using DFT methods using quantum espresso software. Geometry optimization, molecular energy, Mulliken charges, dipole moments, molecular electrostatic potential calculations were performed. The HOMO and LUMO of the dye is shown below with optimized structure. The K-band for HOMO of dye was found to be 51 (Fig. 4).

Fig. 5 Plates showing the antibacterial activity of uncapped ZnO [(a) 5 mg/ml] and different concentrations of dye capped ZnO nanoparticles [(b) 1.25 mg/ml, (c) 2.5 mg/ml, (d) 5 mg/ml] against. **a** *E. coli*, **b** *B. subtilis* against

3.3 Antibacterial activity

The antimicrobial activity were performed by well diffusion method for both uncapped ZnO and 3% dye capped ZnO nanoparticles on a solid agar plates containing different concentration of nanoparticles, each nanoparticle samples ranging from 0.0975 to 5 mg/ml were tested against *Escherichia coli* (ATCC Number 25922) gram negative bacteria and *Bacillus Subtilis* (ATCC Number 6633) gram positive bacteria. In the present work we have selected 3% dye capped ZnO nanoparticles because of their high absorption efficiency.

The result of antibacterial studies have been tabulated in Table 2, which shows the deviation in zone of inhibition with respect to change in concentration of capped nanoparticle, from the table it is observed as the nanoparticle concentration increases the of zone of inhibition also increased. The variation in zone of inhibition with respect to change in concentration of nanoparticles and for different bacterial strains is shown in Fig. 4. Zone of inhibition has been shown for *E. coli* (Fig. 5a) and *B. subtilis* (Fig. 5b) for uncapped [(a) 5 mg/ml] and different concentrations of dye capped ZnO nanoparticles [(b) 1.25 mg/ml; (c) 2.5 mg/ml; (d) 5 mg/ml]. The result with respect to the minimum inhibitory concentration (MIC) antibacterial studies has been shown in Fig. 6. The MIC of uncapped ZnO and capped ZnO is shown in the Table 3, from the table lower MIC was obtained for *B. subtilis* for both capped and uncapped nanoparticles but activity was more against capped nanoparticle.

Evaluation of bacterial growth curves in a liquid medium helped us to evaluate the bacteriostatic effect of these nanoparticles, 4 different concentrations (50, 200, 500 and 1000 µg/ml) were used to study the growth curve of bacteria in solution, significant results were obtained on both strains using uncapped ZnO and capped ZnO, lower growth was observed in *E. coli* than *B. Subtilis* as shown in Fig. 7. The capped ZnO nanoparticles showed higher antibacterial activity when compared to uncapped nanoparticles, capped

Fig. 6 Number of colony forming units of *E. coli* and *B. subtilis* after overnight incubation in the presence of different concentration of dye capped nanoparticle

nanoparticles gave smaller amounts of CFU/ml (colony forming unit per ml).

In the present work the amount of capping agent used during the synthesis of ZnO nanoparticles kept constant (3%), as previous reports suggested that the antibacterial activity varied with quantity of capping agent used, the amount of capping agent influences nanoparticles size. Though in this work we have not studied the effect of different particle size on the antibacterial properties of nanoparticles, instead the effect of functionalization of organic photosensitizer as capping agent on surface of ZnO nanoparticle which also increases lyophilic nature of nanoparticles was studied. Further the results of the work were compared with previously reported works of Zarrindokht et al. [36] and Mohammed azam et al. [37] it was found that antibacterial activity of synthesised uncapped ZnO was in good agreement with the reported works. The mechanism of action of ZnO nanoparticles against bacteria to date is not clear, but however, a few studies

Table 3 Shows the MIC of the ZnO and functionalized ZnO nanoparticles against *B. Subtilis* and *E. coli*

Bacterial species	MIC of the sample (mg/ml)	
	Synthesised pure ZnO	Functionalized ZnO
<i>Bacillus subtilis</i>	1.56	0.38
<i>Escheria coli</i>	3.12	1.56

have suggested that the primary cause of the antibacterial function might be binding interaction of the nanoparticles, ZnO nanoparticles on binding to the outer membrane inhibit active transport and also inhibit RNA, DNA and protein synthesis which leads to death of bacterial cell. Previously reported papers also suggest nanoparticles to react with the thiol group of the proteins in the bacterial cell wall, causing inactivation of transport proteins, reducing cell permeability and causing death of bacteria [38, 39] which is the mechanism of present work. Another possibility could be photoinduced antibacterial activity

Fig. 7 Bacterial growth with different concentrations of dye capped ZnO nanoparticles. **a** *Bacillus subtilis* ATCC Number 6633, **b** *Escherichia coli* ATCC Number 25922 (CFU= colony forming unit)

(UV or sunlight) of ZnO nanoparticles the induction of intercellular reactive oxygen species such as OH radical, H_2O_2 , and O_2^{2-} . The negatively charged hydroxyl radicals and superoxides cannot penetrate into the cell membrane and are likely to remain on the cell surface, whereas H_2O_2 can penetrate into bacterial cells. The reactive oxygen species generated in the process causes oxidative damages to living organism, ROS attack takes place primarily on the cell membrane of bacteria. The damage of cell membrane leads to the leakage of minerals, proteins, and genetic materials which appeared to be the main cause of cell death [40]. The enhanced antibacterial activity of capped nanoparticle is probably attributed to such reasons as, the smaller particle size of capped nanoparticles providing higher surface area to volume ratio, the presence of water soluble organic photosensitizer used in the synthesis of these nanoparticles increases the lyophilic nature of nanoparticles due to functionalization of water soluble organic moieties which leads to easy binding interaction of the nanoparticles to the outer membrane of bacteria.

4 Conclusion

The surface modification of ZnO nanoparticles show increased antimicrobial activity. We witnessed an increase in antimicrobial behaviour of surface dye capped ZnO nanoparticles compared to the uncapped ZnO nanoparticles. The synthesized capped ZnO and uncapped ZnO nanoparticles, the crystallite sizes were measured to be 19.7 and 30.6 nm respectively. The effective binding of organic dye on ZnO nanoparticles is confirmed with FT-IR spectroscopy which showed band at 3400 and 1715 cm^{-1} in pure dye is attributed to $-COOH$ stretching, in the capped nanoparticle the peak at 3400 cm^{-1} is absent and vibration shifted to lower frequency 1625 and 1596 cm^{-1} in indicating covalent bonding via carboxylic centre to the metal oxide nanoparticle. The main reason for increased antimicrobial effect is due to increase in lyophilic nature of ZnO NPs and decrease in particle size, which increased interaction of ZO NPs with bacterial membrane, intracellular proteins, particularly sulphur-containing membrane proteins and phosphorus-containing DNA. The dye capped nanoparticles exhibit excellent antibacterial effect against *B. subtilis* gram positive bacteria with MIC value of 0.39 mg/ml and 1.56 mg/ml against *E. coli* which was much higher than pure ZnO nanoparticles. Capped ZnO nanoparticles exhibit excellent antibacterial effect compared to uncapped ZnO nanoparticles.

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Compliance with ethical standards

Conflict of interest The authors have no conflict of interest.

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