Synthesis, characterization and bioactivity of thio-acetamide modified ZnO nanoparticles embedded in zinc acetate matrix

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Abstract
ZnO nanoparticles embedded in zinc acetate matrix were synthesized by chemical route. The effect of thio-acetamide concentration during its synthesis was probed by structural, morphological, optical and bioactivity studies. XRD characterization indicated the formation of dominant phase of zinc acetate along with the low intensity peak of wurtzite ZnO. Morphological transition from bulky-like feature to flower-like feature via flake-like feature, is evidenced with increasing thio-acetamide molar concentrations. The optical band gap of samples decreased from ~3.29 to 3.24 eV whereas the emitted color shifted from near green to blue region with increasing of molar concentration of thio-acetamide from 0 to 30% in the sample. The nanoparticles exhibited antimicrobial activity against seven (7) common human pathogenic bacteria including drug resistant varieties K. pneumoniae and S. aureus. The nanoparticles formed pores in the biological model membranes made from egg-phosphatidyl choline. Our study reveals that the thio-acetamide modified ZnO nanoparticles embedded in zinc acetate matrix could be used as potential drug lead to fight drug resistance against K. pneumoniae and S. aureus.

1. Introduction

Research on the synthesis of nanomaterials have shown growing interest among the material scientists due to the emergence of diverse functionality of the nanomaterial with high surface-to-volume ratio [1, 2]. In addition, the nanomaterials also exhibited highly controllable physical, biological and chemical properties in the atomic and sub-atomic levels. Hence, the nanoparticles with tunable properties have found applications in different sectors such as agriculture [3], optoelectronic [4], communications [2], electronics [5] and biomedicine [6].

Among the several nanomaterials, zinc oxide (ZnO) has been considered as one of the versatile nanomaterial due to its outstanding properties such as high photo stability [7], high chemical stability [8], significant electrochemical coupling coefficient [9], wide range of radiation absorption [2] etc ZnO has proven as the potential candidate for optoelectronic and electronics devices [10, 11] due to its n-type conductivity with band gap (3.37 eV) [12] and larger exciton binding energy 60 meV [10]. The interaction between ZnO nanoparticles and bacteria are more prominent and toxic bacteria mostly die [13]. However, ZnO is non-toxic and biocompatible with human cells [14]. Due to this tremendous properties, ZnO nanoparticles could be used as antibacterial agents [15–17]. The size of ZnO nanoparticles and hence their properties can be influenced by several means like synthesis method, precursor materials, temperature etc.

Haque et al [2] synthesized ZnO nanoparticles by using zinc acetate and neem leaf extract. These authors reported that the antibacterial and photocatalytic properties of ZnO are improved in biosynthesized method due to the organic chemicals (terpenoids) present in the neem leaf extract. Mayekar et al [18] reported the synthesis of different shape ZnO nanoparticles with crystallite size ~38 nm using different salts such as zinc nitrate, zinc chloride and zinc acetate. These authors also reported that the antibacterial activity of ZnO nanoparticles is more

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significant obtained from zinc acetate precursors. Raghupathi et al [19] reported that the antibacterial activity of ZnO nanoparticles in S. aureus is inversely proportional to the size of ZnO nanoparticles. In another work, Kaur and Kalia [20] also reported that ZnO nanoparticles shows highest microbial activity synthesized from zinc acetate and zinc sulphate precursors. Sanjay et al [21] reported the membrane protective activity of ZnO nanoparticles synthesized by co-precipitation method. The authors also pointed out that ZnO nanoparticles showed maximum inhibition of lipid peroxidation in liver tissue at concentration 600 μg ml⁻¹. Oves et al [22] reported that graphene based ZnO nanocrystal shows moderate antibacterial activity against both resistant as well as sensitive S. aureus strains. However, the antibiofilm potential of this nanocrystal is shown to be enhanced dramatically when the same is supplemented with Curcumin. Rauf et al [23] also reported the anticancer activity against the breast cancer cell line (MCF-7) of 40 nm sized ZnO nanoparticle synthesized using Bougainvillea flower extract. Their study also indicated that the ZnO nanoparticles with minimum inhibitory concentration of 15 μg ml⁻¹ exhibited good response against MCF-7 cell line whereas the same with minimum inhibitory concentration of 16 μg ml⁻¹ showed excellent antimicrobial activity against P. aeruginosa, E. coli and S. aureus. Similarly, Hussain et al [24] synthesized ZnO nanoparticles synthesized using Pandanus odorifer leaf extract and they suggested that the ZnO nanoparticles could not only be used as a potential anticancer and antimicrobial agent but also be useful for the development of innovative products of drugs and skin cares. Promising antimicrobial activities of ZnO has also been reported against K. pneumoniae with minimum inhibitory concentration (MIC) 40 μg ml⁻¹ [25]. Studies revealed that ZnO nanoparticles targeted membrane components such as outer membrane protein and lipopolysaccharides leading to release of cytosolic proteins and DNA. MIC of ZnO nanoparticles was found to be 1.33 mM on S. aureus [26]. The mechanism of ZnO-mediated cell death was found to be interaction with plasma membrane, followed by cell lysis [26]. However, their interaction with membrane lipids remains to be investigated.

In this present work, we study the structural, morphological, optical and bioactivity the thio-acetamide modified ZnO nanoparticles embedded zinc acetate matrix. Our study indicated that the synthesized new nanoparticles could be useful for cost effective blue LEDs, plasma membrane lysis and potential drug lead against drug resistant human pathogens such K. pneumoniae and S. aureus those exhibit resistances to most potent antimicrobials.

2. Experimental

Stoichiometric amount of zinc acetate (Zn(CH₃COOH)₂·2H₂O) and thio-acetamide (C₅H₃NS) were dissolved in 100 ml of water. The resultant solution was homogenized under constant stirring for 1h with the help of magnetic stirrer. The as-prepared solutions were kept at 90 °C for 8 h and then cooled to room temperature. After this the dried samples were washed with distilled water and ethanol. Finally, the as-prepared samples were dried at 70 °C for 8 h. Based on C₅H₃NS molar doping concentrations, we have named our samples as ZS0 (0 M C₅H₃NS), ZS1 (10 M C₅H₃NS), ZS2 (20 M C₅H₃NS) and ZS3 (30 M C₅H₃NS).

The samples were characterized XRD (Panalytical Empyrean) to identify the structural information. The morphological features of the samples were probed through field emission scanning electron microscope (FESEM) (SUPRA 55 FESEM). FTIR (Shimadzu, IRAffinity-1) spectrophotometer was used to study the functional group present in the samples. The energy band gap of the samples was calculated using diffuse reflectance spectroscopy by a double-beam UV–Visible spectrometer (Shimadzu, UV-2450). The Raman characterization of samples was done by using Raman spectrometer (Renishaw inVia, UK). Photoluminescence (PL) spectra of the samples were recorded using a Cary Eclipse PL spectrometer under the excitation wavelength of 320 nm.

2.1. Leakage assay

Leakage assay was performed by a time-dependent NBD–fluorescence quenching approach [27]. Briefly, giant unilamellar vesicles (GUVs) (~10 nmol PO4) containing 0.3 mol% NBD-PE were incubated with 1 mg ml⁻¹ nanoparticles in 200 μl assay mix (10 HEPES, pH 7.5 and 100 mM NaCl) and incubated at 25 °C for 5 min. The stabilized fluorescence (F₀) was recorded using a JASCO FP-6500 spectrophluorimeter (Japan) and a time-dependent fluorescence measurement was performed for 3 min. At 1 min, 10 μl of freshly prepared 1 M sodium dithionite in 1 M Tris-base was added to quench the NBD–fluorescence coming from outer membrane leaflet and monitored for 2 min. At 3 min, 20 μl 1% Triton-X100 was added to lyse the GUVs that resulted in ~100% NBD–quenching. Percentage leakage activity induced by nanoparticles was calculated from the percentage NBD–fluorescence reduction (FR) after dithionite addition using the following formula:
where, $F_0$ and $F_f$ represent the fluorescence intensity before and after addition of dithionite respectively. Data were analyzed using GraphPad Prism (version 6).

2.2. Antimicrobial assay
Antimicrobial activity of nanoparticles was determined on seven human pathogenic strains using agar well diffusion method (table 5) [28]. All cells used in the experiment were grown in Luria Bertani (LB) medium to mid-log phase at 25 °C and 180 rpm., after which cells were collected at 5000 g and washed with nutrient broth NB. Cells were resuspended at 10^5 colony forming units (CFU)/ml and immediately used for determination of antimicrobial activity assay. Briefly, 5 mm wells were bored on nutrient broth agar (NBA) plates were homogeneously spread with 10^6 CFUs of the bacteria. 100 μg of nanoparticles suspended in sterile distilled water at 1 mg ml\(^{-1}\) was placed in the well and incubated at 37 °C for 12 h. The zones of inhibition were determined from triplicate experiments and average diameter was determined. 1 mg ml\(^{-1}\) azithromycin and sterile distilled water were used as positive and negative controls respectively.

$$FR = \left(\frac{F_0 - F_f}{F_0}\right) \times 100$$ (1)
3. Results and discussion

3.1. Structural, morphological and optical characterization

The XRD pattern of ZS0, ZS1, ZS2 and ZS3 samples (Figure 1) indicated the presence of dominant phase corresponds to the crystalline phase of Zn(CH₃COO)₂·2H₂O (JCPDS, card No: 14-0902) along with the low intensity peak of wurtzite ZnO (JCPDS, card No. 05-0664) at 31.42°. This confirms the synthesis of ZnO nanoparticles embedded in zinc acetate matrix. The intensity of XRD peaks in fact decreased with increasing the C₂H₅NS molar concentration.

Figure 2 represents the Raman spectra of the samples recorded at room temperature. The Raman mode centered at ∼344 cm⁻¹ and ∼402 cm⁻¹ in different samples are attributed to the A₁(TO) and E₁(TO) mode of ZnO respectively [29, 30]. The observation of peak centered at ∼818 cm⁻¹ for all samples is attributed to combination of longitudinal acoustic and optical phonon mode (LA + LO) of ZnO [29]. The high intensity peak at ∼937 cm⁻¹ in all samples corresponds to second order multi phonon scattering mode and assigned as 2E₂H + E₂L [31]. The peaks at ∼1348 cm⁻¹ and ∼1442 cm⁻¹ for all samples represent three phonon Raman scattering processes assigned as A₁(TO) + A₁(LO) + E₂(high) [32] and A₁(long) + E₁(transv) + E₂ [31] mode of ZnO respectively. The exact positions of above modes along with other modes present in the respective sample are reflected in the table 1 along with their reported values. Majority of the peaks (table 1) are resembled with the characteristic features of ZnO. Since major phase of the sample corresponds to Zn(CH₃COO)₂·2H₂O and no literature available on Raman spectra of Zn(CH₃COO)₂·2H₂O, we therefore anticipate that the peak at ∼1215 cm⁻¹ in all samples could be associated with the Zn(CH₃COO)₂·2H₂O phase.

Figure 3 represents the FTIR spectra representing information about presence of different functional group in the synthesized samples. The appearance of Zn-O stretching vibrations bonds at 484, 622 and 695 cm⁻¹.
demonstrate the presence of ZnO phase in our samples which is in accordance with the XRD and Raman studies. In ZS3 samples the band at 1342 cm$^{-1}$ corresponds to gaseous SO$_2$ [33] mode which is due to increasing of molar concentration of C$_2$H$_5$NS. The observations of other different bands present in the samples are summarized in Table 2 along with corresponding reported values.

Figure 4 shows the FESEM image depicting the morphological feature of the samples. The ZS0 sample (figure 4(a)) showed a featureless molten bulk with irregular masses trying to aggregate at the edges. These features form the boundaries of flakes/flowers appearing in subsequent micrographs. With increasing the concentration of the C$_2$H$_5$NS, the otherwise featureless mass becomes aggregated. Clear boundaries

| Assigned vibrational band                                      | Band (cm$^{-1}$) observed for different samples | Reported value of band |
|---------------------------------------------------------------|-----------------------------------------------|------------------------|
| Stretching vibration of Zn–O                                  | 484 484 484 482                              | 482 [34]               |
| Zn–O stretching band                                         | 622 622 622 620                              | 622 [35]               |
| Stretching and bending vibrations of the intercalated C–O species | 669 669 669 669                              | 669 [36, 37]           |
| Zn–O stretching                                              | 695 695 695 695                              | 695 [38]               |
| Bending mode of carbonate                                    | 843 843 843 843                              | 815, 883, 914 [34]     |
| O–H liberation mode                                          | 952 952 952 952                              | 950 [39]               |
| Stretching vibration of C–O                                  | 1017 1017 1017 1017                         | 1020 [34]              |
| C–O stretching vibration                                     | 1055 1055 1055 1051                         | 1051 [40]              |
| Gaseous SO$_2$                                                | 1342 1342 1342 1342                         | 1342–1495 [34]         |
| Carboxylate group                                            | 1443 1443 1445 1445                         | 1424–1495 [34]         |
| C=O band                                                     | 1551 1553 1555 1555                         | 1542 [34]              |
| Carboxyl group                                               | 1699 1699 1699 1699                         | 1707 [34]              |
| overtones of out-of-plane C–H deformation                    | 1967 1967 1967 1967                         | 1967 [41]              |
| Existence of CO$_2$                                          | 2342 2340 2340 2340                         | 2342 [42]              |
| Existence of CO$_2$                                          | 2356 2357 2354 2359                         | 2357 [46]              |
| vibration modes of aromatic C–H bonds                        | 3081 3081 3081 3081                         | 3080 [43, 44]          |
demarcating various flakes and stunted rods appeared. These flakes or rods are \( \sim 200 \) nm thick. Further addition of the \( \text{C}_2\text{H}_5\text{NS} \), tends to give a hexagonal geometry to the features resulting in floral arrangement. It is clear from the figure (figure 4(d)) that the flower-like structures are composed of layers of a few nm thickness. Therefore, a clear morphological transition from bulky-like feature to flake-like feature and finally the flower-like feature is evidenced with increasing \( \text{C}_2\text{H}_5\text{NS} \) molar concentrations.

In order to study the effect of \( \text{C}_2\text{H}_5\text{NS} \) molar concentrations on the band gap of the sample, UV-Visible spectroscopic characterization was undertaken. The band gap \( (E_g) \) of the samples was extracted by Tauc's

![Figure 5](image-url) - Variation of \((\alpha h\nu)^2\) versus photon energy \((h\nu)\) for (a) ZS0 (b) ZS1 (c) ZS2 (d) ZS3 nanosamples.

![Figure 6](image-url) - The variation of \(\ln \alpha\) vs \(h\nu\) for ZS0, ZS10, ZS20 and ZS30 samples.
Table 3. The values of $E_g$, $n$, $\alpha'_{\text{classical}}$, $\alpha'$ and $E_u$ of the samples extracted from UV-Visible characterization.

| Sample | $E_g$ (eV) | $n$ | $\alpha'_{\text{classical}}$ ($\times 10^{-24}$ cm$^3$) | $\alpha'$ ($\times 10^{-24}$ cm$^3$) | $E_u$ (meV) |
|--------|------------|-----|------------------------------------------------|---------------------------------|------------|
| ZS0    | 3.29       | 2.296 | 3.362                                           | 3.361                           | 45.13      |
| ZS1    | 3.28       | 2.297 | 3.367                                           | 3.367                           | 60.15      |
| ZS2    | 3.26       | 3.301 | 3.373                                           | 3.374                           | 63.69      |
| ZS3    | 3.24       | 3.304 | 3.378                                           | 3.381                           | 81.79      |

Figure 7. PL Spectra of ZS0, ZS1, ZS2 and ZS3 samples recorded at 300 K.

Figure 8. CIE chromaticity diagram of samples ZS0, ZS1, ZS2 and ZS3 samples.
relation [36] represented as:

$$\alpha = B \frac{(h\nu - E_g)^p}{h\nu}$$

(2)

where $h\nu$ is the photon energy and B is a material dependent constant parameter. The parameter p can take different values depending up on the direct or indirect transition. From the plot of $(\alpha h\nu)^2 \sim h\nu$ (figure 5), the direct band gap value of the samples was extracted. The Urbach energy ($E_u$) of samples can be calculated from the slope of the ln $\alpha$ versus $h\nu$ plot (figure 6). These two parameters give important information about the sample. In our case, the $E_g$ decreased from $\sim$3.29 to 3.24 eV and $E_u$ increased from 45.13 to 81.79 meV with increasing C$_2$H$_5$NS molar concentration from 0 to 30% (table 3). The increase of $E_u$ value of the sample is an indication on the increase of structural disorder [45, 46]. The decrease of $E_g$ along with increase of $E_u$ with increasing C$_2$H$_5$NS molar concentration in the sample indicated the C$_2$H$_5$NS induces more structural disorder in the sample. This confirms the observation from XRD analysis. In addition, we calculated refractive index ($n$), classical electron polarizability ($\alpha'_{\text{classical}}$) and electron polarizability ($\alpha'$) of the samples using following relation [36, 46]:

$$n = KE_g^{0.5}$$

(3)

$$\alpha'_{\text{classical}} = \frac{n^2 - 1}{n^2 + 2} \frac{M}{\rho} \times 0.395 \times 10^{-24} \text{ cm}^3$$

(4)

$$\alpha' = \left[ \frac{12.41 - 3.4(E_g - 0.365)}{12.41} \right] \frac{M}{\rho} \times 0.395 \times 10^{-24} \text{ cm}^3$$

(5)
where $K = 3.3668$ and $C = -0.32234$. The $M$ and $\rho$ are the molecular weight (g/mol) and density of required material (g/cm$^3$). The calculated values of $n$, $\alpha'$ classical and $\alpha'$ are reflected in table 3. These values are nicely matched with reported values for ZnO nanoparticles [46].

Since the absorption characteristics of the samples were influenced by C$_2$H$_5$NS concentration, we therefore study the emission characteristics of the samples in terms of photoluminescence (PL) characterization. It is evident from the PL spectra (figure 7) that the luminescence intensity of the sample influenced significantly with increasing C$_2$H$_5$NS concentration. The presence of different emission bands in our samples are reflected in table 4. The emission features of the samples mostly coincide with that of ZnO. However, sharp peaks are not observed due to the poor crystallinity of ZnO present in the sample. The appearance of major peak at ∼360 nm and weak peak at ∼378 nm corresponds to near band edge emission peaks of ZnO which arises due to combination of electron hole pairs [47]. Due to the presence of different intrinsic defects (Zn and O vacancies, Zn and O interstitials), the violet emission bands appeared in our samples [48, 49]. The presence of blue emission at 459 and 494 nm in our samples could possibly be due to the electron transitions from the Zn level to the top of the valence band [50, 51]. The presence of green emission bands in our samples are related to O vacancies [52, 53] and this emission band diminished at high molar concentrations of C$_2$H$_5$NS. In order to have more information on the emission behavior, the CIE chromaticity diagram (figure 8) and CIE co–ordinate (table 4) of the samples were extracted from PL spectra using the software [http://www.geocities.com/krjustin/gocie.html]. As indicated from CIE chromaticity diagram (figure 8), the colour emission shifted from near green to blue region with increasing C$_2$H$_5$NS molar concentration in the sample. This is an indication on the applicability of the samples for blue LED application [54].

3.2. Biological activity

3.2.1. Antimicrobial activity of nanoparticles

We observed that all common human pathogenic bacteria showed sensitivity towards the nanoparticles tested (figure 9 and table 5). All nanoparticles exhibited antimicrobial activity against all seven common pathogenic bacterial strains to different extent. ZS0, ZS1, ZS2 and ZS3 nanoparticles exhibited highest antimicrobial activity against K. pneumoniae, P. aeruginosa, E. coli, whereas S. sonei was resistant to ZS1. The ZS2 and ZS3 nanoparticles exhibited potential cytotoxicity against B. licheniformis whereas ZS0 and ZS1 showed moderate activity. In addition, all the nanoparticles exhibited moderate antimicrobial activity against S. flexineri and S. aureus (table 5).

The nanoparticles exhibit differential antimicrobial activity on the bacterial strains used that might have originated from their differential interaction with their plasma membrane. As the membrane composition of the bacteria differ from each other leading to different membrane properties such as membrane charge, fluidity, permeability etc. that might influence the interaction of nanoparticles in their plasma membrane. Graphene decorated ZnO nanoparticles have exhibited anti-microbial activity against methicillin resistant S. aureus with an MIC of 31.25 µg ml$^{-1}$ [22]. Our study shows that the thio-acetamide modified ZnO nanoparticles embedded in zinc acetate matrix is a potent anti-microbial that could be further developed into therapeutics against drug resistant S. aureus. In a similar study, bio-functionalized nanoparticles of ZnO modified with aqueous Pandanus odorifer leaf extract exhibited an MIC of 85 µg ml$^{-1}$ against two common human pathogens B. subtilis and S. aureus [24].

3.2.2. Lysis of GUVs by nanoparticle

In order to gain further insight into the mechanism of action of nanoparticles on bacterial plasma membrane, we investigated the membranolytic activity of these nanoparticles on giant unilamellar vesicles (GUVs). GUVs prepared from egg-PC are in vitro biomimetic membranes those are used for investigating membrane-mediated events such as membrane-lysis. GUVs were prepared by electro-formation method using copper electrodes from 100 µg (130 nmol) egg-PC yielded 100 to 2000 number of GUVs/ml. The unilamellar

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### Table 5. Zone of inhibition showing by nanoparticles against common human pathogens.

| Strain         | ZS0   | ZS1   | ZS2   | ZS3   | +ve control | −ve control |
|----------------|-------|-------|-------|-------|-------------|-------------|
| P. aeruginosa (MTCC-1035) | 1.7 ± 0.06 | 1.5 ± 0.15 | 1.9 ± 0.12 | 1.9 ± 0.06 | 1.6 ± 0.2 | 0           |
| E. coli (MTCC-118)    | 1.6 ± 0.2 | 1.7 ± 0.1 | 1.1 ± 0.1 | 1.0 ± 0.1 | 0           | 0           |
| S. aureus (MTCC-212)  | 1.2 ± 0.1 | 1.4 ± 0.1 | 1.1 ± 0.6 | 1 ± 0.1  | 0           | 0           |
| B. licheniformis (MTCC-2617) | 1.2 ± 0.1 | 1.3 ± 0.1 | 1.6 ± 0.06 | 1.5 ± 0.05 | 1.5 ± 0.055 | 0           |
| S. sonei (MTCC-586)   | 1.3 ± 0.06 | 0      | 1.3 ± 0.15 | 1.2 ± 0.05 | 1.5 ± 0.1 | 0           |
| S. flexineri (MTCC-1185) | 0.8 ± 0.1 | 0.9 ± 0.05 | 0.9 ± 0.05 | 0.9 ± 0.05 | 1.3 ± 0.06 | 0           |
| K. pneumonia (MTCC-618) | 1.9 ± 0.05 | 1.6 ± 0.15 | 1.6 ± 0.05 | 1.4 ± 0.05 | 1.7 ± 0.1 | 0           |

*−ve control- double distilled H$_2$O, +ve control- azithromycin.*

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characteristics of the vesicles with unilamellarity index (I_U) of (49 ± 1.3)% reflected that the fraction of NBD-PE remains hidden from the membrane-impermeable quenching agent sodium dithionite. This is an indication on the preservation of integrity of the membrane in the absence of nanoparticles. A schematic diagram of the leakage assay is given in figure 10. GUVs containing 0.3 mol% NBD-PE incubated in the absence or presence of the nanoparticles (marked as GUV and nanoparticles-GUV respectively (figure 10) exhibited a normalized stable fluorescence of 100% (F₀).

Treatment with sodium dithionite led to instantaneous quenching of NBD-PEs in the outer membrane leaflet, while leaving the NBD-PE localized to the inner leaflet unaffected. This dithionite quenching of NBD-fluorescence decreased the initial fluorescence by about 50%. However, treatment of GUVs with ZS0, ZS1, ZS2 and ZS3 (indicated as the nanoparticles-GUVs) observed ~70% reduction of NBD-PE fluorescence upon dithionite addition due to lysis of GUVs (table 6). These results indicate that incubation of the nanoparticles compromised the GUVs membrane integrity, leading to pore formation that allowed the water soluble dithionite to quench the inner fluorescent NBD-PE. Further, addition of Triton-X-100 leads to complete membrane lysis by quenching of all fluorescent lipids.

Our results showed that all the nanoparticles led to lysis of GUVs. However, highest membranolytic activity was observed in the order ZS3 > ZS2 > ZS1 > ZS0. This differential membranolytic activity might have originated from their differential interaction with GUVs. Hence, this differential interaction of nanoparticles with GUVs might account for their differential antimicrobial activity against the bacteria used in the experiment. Our study reveals that these thio-acetamide modified ZnO nanoparticles embedded zinc acetate matrix will be useful in treating human pathogenic bacteria those exhibit resistance against conventional antimicrobial drugs.

4. Conclusion

We report the effect of C₂H₅NS on the structural, morphological, optical as well as bioactivity of ZnO nanoparticles embedded in zinc acetate matrix. Our study indicated the band gap of nanoparticle samples decreased with increasing C₂H₅NS concentration. The emission band of the samples corresponding to the feature of ZnO and the emitted color shifted from near green region to blue region with increasing C₂H₅NS concentration. Lysis of GUVs study revealed that increase of C₂H₅NS concentration in the nanoparticles
Table 6. Lysis of GUVs by different nanoparticle.

| Sample         | Initial Fluorescence (in %) \((F_0 = F_D + F_I)\) | After dithionite addition \([F_0(P_1 + P_2)]\) | After Triton X-100 addition \((F_U)\) | % Fluorescence reduction after dithionite treatment \((P_1 + P_2)\) | % Fluorescence leakage \([P_2/F_0] \times 100\) |
|----------------|-----------------------------------------------|-----------------------------------------------|-----------------------------------------------|-------------------------------------------------|-----------------------------------------------|
| GUVs (control) | 100 ± 0.82                                     | 49.6 ± 0.98                                   | 0.32 ± 0.28                                   | 49.7 ± 1.3                                      | 0                                             |
| ZS0-GUVs       | 100 ± 0.70                                     | 30.2 ± 0.50                                   | 1.067 ± 1.07                                  | 68.8 ± 1.02                                     | 38.7                                          |
| ZS1-GUVs       | 100 ± 0.27                                     | 26.9 ± 0.15                                   | 0.2 ± 0.25                                    | 74.04 ± 0.97                                   | 48.9                                          |
| ZS2-GUVs       | 100 ± 0.25                                     | 26.1 ± 0.11                                   | 0.76 ± 0.67                                   | 74.06 ± 0.9                                    | 49                                            |
| ZS3-GUVs       | 100 ± 0.25                                     | 12.8 ± 0.22                                   | 0.1 ± 0.12                                    | 87.88 ± 1.11                                   | 76.8                                          |

*\(F_O\): outside Fluorescence, \(F_I\): inside Fluorescence and \(F_U\): unquench Fluorescence.
induces % of reduction of NBD-PE fluorescence through lysis. Our study indicated that the synthesized samples could be useful for cost effective blue, deep-blue LEDs. These nanoparticles and its bio-functionalized forms could be used as antimicrobial agents against the drug-resistant human pathogenic bacteria such as K. pneumoniae and S. aureus those are difficult to be eliminated through conventional antimicrobial agents. In addition, the membranolytic activity of the nanoparticles indicates that these nanoparticles could be used as drug leads as anticancer agents.

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Data availability

The raw/processed data required to reproduce these findings cannot be shared at this time as the data also forms part of an ongoing study.

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