Vol. 3 No. 1 (2025)

Spectrum of Engineering Sciences

SPECTRUM OF ENGINEERING SCIENCES

Online ISSN
3007-3138
Print ISSN
3007-312X

Lanthanum-Doped Bismuth Phosphate: Engineering a Next-Generation Antimicrobial Material

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Abstract

Chemical influence of the implant surface creates the bactericidal feature to avoid different infections associated with dental implants. Regardless of the successful use of bismuth against dermal and mucosal infections, the antibacterial efficacy of bismuth is still under consideration. The inhibition zone of fungal pathogens caused by varying $BiPO_4$ nanoparticle concentrations on culture media is measured, as well as by inhibiting spore germination, the antifungal activity was demonstrated. $BiPO_4$ nanoparticles were found to have strong antifungal activity against some fungal pathogen examined in this investigation.

Spectrum of Engineering Sciences
SPECTRUM OF ENGINEERING SCIENCES
Online ISSN
3007-3138
Print ISSN
3007-312X

This study looks into the antifungal and antibacterial properties of bismuth phosphate doped with lanthanum applying the disc diffusion approach to E. Gram-positive S. aureus and gram-negative E.coli. In this study, lanthanum doped bismuth phosphate has been synthesized through sol gel method. Prepared nanoparticles are characterized by Ultraviolet- visible spectroscopy (UV-Vis) and Fourier transform infrared spectroscopy (FTIR). The very low cut off wavelengths and band gap for La^{3+} doped $BiPO_4$ crystals are roughly 290 nm and 0.68 eV respectively based on the UV-Visible spectra. By confirming the existence of functional groups, FTIR results demonstrated that the synthesis of lanthanum-doped bismuth phosphate nanomaterials was successful. Higher antibacterial activity against both S. aureus and E. coli. has been demonstrated by the lanthanum-doped bismuth phosphate nanoparticles.

Keywords: Antimicrobial activity, Antifungal, Sol-gel method, $BiPO_4$ nanoparticles, Ultraviolet-visible, Lanthanum doping.

Introduction

Nanoparticles (NPs) possessed promising qualities compared to conventional particles, boasting a vast array of applications in various sectors of life [1]. Nanoparticles possess a substantially enhanced surface area compared to their larger counterparts, leading to enhanced properties consisting of remarkable strength, a stable structure, high binding ability, enhanced electrical conductivity, and adaptability. [2]. The realm of nanotechnology encompasses the manufacture of nanoscale particles under precise conditions. Because of their distinct characteristics, nanoparticles (NPs) differ from bulk materials with comparable chemical composition in both chemical and physical ways. These differences include biological

Spectrum of Engineering Sciences
SPECTRUM OF ENGINEERING SCIENCES
Online ISSN
3007-3138
Print ISSN
3007-312X

and mechanical properties, melting point, electrical conductivity, and light absorption. [3] It is possible to create new materials with innovative uses by manipulating size and shape at the nano scale [4] NPs have a wide range of applications, including memory systems, chemical sensors, wireless electronic logic, computer transistors, antimicrobial activity, optical activity, biosensing, magnetic properties, mechanical strength, electrical conductivity, and chemical sensors.[5] Additionally, there are numerous uses for these particles in a variety of industries, including drug delivery, filters, medical imaging, tumour hyperthermia, and nanocomposites [6]. Better properties of inorganic nanoparticles have attracted a lot of attention in recent decades. [7] Researchers, particularly in the field of materials science, have recently become interested in them because of their remarkable qualities as rare earth elements. Furthermore, there is curiosity about the potential health effects of these elements, especially lanthanum. [8] Although the effect can be reversed depending on the concentration, lanthanum can increase the capacity of mature osteoclasts to resorb bone. [9] La carbonate, which is used in clinical settings to prevent phosphate formation, is an effective agent to stop the differentiation of osteoclast precursors. [10] As a result, their quantity and bone resorption function are ultimately diminished, which is crucial for the prevention and management of associated disorders. [11]

Bi ions can be released by bismuth (Bi) or its compounds present in biomaterials under physiological conditions. The biological effects of these ions may be detrimental. Bi has the potential to be hazardous even though it is frequently found in pharmaceutical products and is thought to be less toxic than other heavy metals.[12] Due to their antibacterial and anticancer qualities,

Spectrum of Engineering Sciences
SPECTRUM OF ENGINEERING SCIENCES
Online ISSN
3007-3138
Print ISSN
3007-312X

a number of Bi-based compounds are used to treat gastrointestinal infections, syphilis, and hypertension. Bi ion doped hydroxyapatite and bioactive glass are both safe and have excellent antibacterial qualities [13] However, osteoporosis can be brought on by a high concentration of Bi in human bones. The spleen, liver, kidney, and lymph nodes were all toxically affected by Bi ions in mice exposed to concentrations of 25–750 mg/kg (given twice daily) for 4–8 weeks, according to studies. [14]

One of the most frequent causes of both chronic infections and fatalities is bacterial infection. Because of their potent effects and high cost, antibiotics are the recommended treatment for bacterial infections. [15] Chronic infections and fatalities are frequently caused by bacterial infections. Because of their potent effects and affordability, antibiotics are the recommended treatment for bacterial infections. However, as multiple studies have demonstrated, the widespread use of antibiotics is directly associated with the emergence of drug-resistant bacterial strains. As a result of antibiotic abuse, superbugs that are resistant to practically all antibiotics have emerged.NDM-1is a super resistance gene found in these bacteria, according to research. The three bacterial processes that the primary classes of antibiotics currently in use target are DNA replication, translation, and cell wall synthesis [16]. Antibiotics currently in use target three major bacterial processes: DNA replication, translation machinery, and cell wall synthesis. Regrettably, bacterial resistance can negate each of these mechanisms of action. [17]. The expression of enzymes that alter or break down antibiotics is one example of a resistance mechanism. These include aminoglycosides and β-

Spectrum of Engineering Sciences
SPECTRUM OF ENGINEERING SCIENCES
Online ISSN
3007-3138
Print ISSN
3007-312X

lactamases, which alter cell components [18]. Tetracycline resistance is attributed to A-ribosomes, vancomycin resistance to the cell wall, and efflux pump expression, which guarantees concurrent resistance to multiple antibiotics. [19] Although bacterial migration to the surface is reversible, attachment becomes irreversible when EPSs are expressed.

A mature biofilm is created once the bacteria have colonized, multiplying quickly and inhibiting the synthesis of the bacterial flagellum. Systemic chronic infections are caused by the bacteria at this stage adhering to one another and forming a barrier that is resistant to antibiotics [20]. As a result, biofilms are extremely dangerous to human health. Super antigens are another way that bacteria in biofilms can elude the immune system. Thus, bacterial infections remain a major issue even with the extensive use of antimicrobial medications and other contemporary antibacterial agents [21]. Two categories of antimicrobial-coated human implantable devices exist. The first category includes fully implantable devices, like dental implants or heart valves. To prevent thrombosis, the antimicrobial coating on cardiovascular devices, in particular, needs to be compatible with blood. The pore morphology with an enrichment of calcium, silicon, phosphorus, and silver particles determines whether a titanium oxide coating should be applied to implants.[22] Streptococcus epidermis, Streptococcus mutans, and E. Coli is one of the bacteria that the coating prevents from growing and adhering. coli and lessens the possibility of ulceration surrounding the implants. The nanocoating can enhance osteoblast cell lines' adhesion and proliferation, per an initial biological char-

Spectrum of Engineering Sciences
SPECTRUM OF ENGINEERING SCIENCES
Online ISSN
3007-3138
Print ISSN
3007-312X

acterization.[23] Bacteria are highly resistant to foreign chemicals due to the structure of their biofilms.

According to recent research, NPs interact with EPSs to impact biofilm integrity [24]. NPs work against the biofilms of drug-resistant strains of E. coli by blocking the synthesis of EPSs [25]. Additionally, it has been noted that when a biofilm made up of certain amount of subtilis growth, the biofilm's edge occasionally stops expanding, allowing nutrients to enter the biofilm's centre. The bacteria in the centre are able to withstand foreign substances and survive as a result [26].

The antifungal activity of the generated bismuth phosphate nanoparticles against Cladosporium herbarum, Trichothecium roseum, Penicillium chrysogenum, Alternaria alternata, and Aspergillus niger was evaluated both qualitatively and quantitatively using a spore germination test, an agar well diffusion test, and the computation of the minimum inhibitory concentration.[27] This study's fungal species are the most common fungal pathogens that cause the majority of fruit and vegetable spot diseases in storage settings, which cause large losses in horticultural and agricultural crops each year.[28]

Numerous management techniques have been employed, but each has certain drawbacks [29]. In this research project, Sol-gel were used to synthesized nanomaterials and analysed through FTIR and UV-visible spectroscopy, it was established that they had antifungal and antimicrobial properties.

Experimental Section

Spectrum of Engineering Sciences
SPECTRUM OF ENGINEERING SCIENCES
Online ISSN
3007-3138
Print ISSN
3007-312X

The synthesis of La-doped BiPO4 using concentration of 6% nano-particles was accomplished via the chemical sol-gel methodology. he analytical-grade chemicals were utilized without additional purification. To guarantee sterility, a 250 mL beaker was first thoroughly cleaned with distilled water before being covered with foil. The preparation of La-doped BiPO4 nanomaterials required the use of lanthanum chloride heptahydrate, potassium phosphate (KPO_4), and bismuth nitrate pentahydrate (Bi (NO3)3·5H2O). Bismuth nitrate was dissolved in a different beaker with 132 mL of distilled water and 62 mL of ethylene glycol, while potassium phosphate (KPO_4) was dissolved in 200 mL of distilled water. Each solution was subjected to stirring for duration of 60 minutes. Upon completion of the stirring phase, the two individual solutions were amalgamated to facilitate the formation of $BiPO_4$.

The resultant mixture was then placed in a stirrer for an extended period, spanning overnight. On the subsequent day, the solution underwent a rigorous purification process involving washing with distilled water and subjecting it to centrifugal force to effectively eliminate any residual impurities. This purification procedure culminated in the acquisition of $BiPO_4$. The La doped $BiPO_4$ was then transferred to a crucible, where it was subjected to drying for a full 24-hour period. Following the drying phase, the sample was ground into a fine powder and subsequently placed into Falcon tubes to facilitate further analytical processing. Then $BiPO_4$ doped with La was prepared, by concentrations of 6% [30][31][32][33][33].

Spectrum of Engineering Sciences
SPECTRUM OF ENGINEERING SCIENCES
Online ISSN
3007-3138
Print ISSN
3007-312X

Antimicrobial and Antifungal Activity

Both coated and bare silver oxide nanoparticles' antibacterial activity against E. coli was examined using the disk diffusion method. S. aureus, which is Gram-positive, and E. coli. Bacterial cultures were serially diluted to 1106 CFU/ml after being grown overnight for this evaluation. After applying 50 µL of the bacterial suspension to Müller-Hinton agar plates with a sterile swab, the plates were left to dry for half an hour. The 10 µg/ml NP suspension was then loaded onto sterile 5 mm filter paper disks which was then cautiously added to the medium above the plates. As a positive control, ciprofloxacin was taken. The antibacterial potential of nanomaterials was evaluated by measuring the zone of inhibition (ZOI) in millimetres following a 24-hour incubation period at 37 degrees Celsius. The experiments were conducted three times in order to determine the measured values. Utilizing microtiter assays, the zone of inhibition was evaluated. 20µL of bacterial strains and 100 µL of sample were used in 96 flat-bottomed culture plates. the suppression of E. coli and S. aureus. The bacteria S. coli were analyzed.

The negative control was phosphate-buffered saline, and the positive control was ciprofloxacin. The setup underwent aerobically and was kept at a temperature of 37°C for a period of 24 hours. Subsequently, the sample was extracted from each well and cleaned three times using 220 µL of sterile phosphate buffer with a pH of 7.2. The remaining bacteria's stability in each well was assessed using 220 µL of 99% methanol. After the plates had dried, they were stained for 5 minutes with 220 µL of a 7% crystal violet solution. Distilled water was used to get rid of the extra dye. Following air drying of the plates, 220 µL of a 33%

Spectrum of Engineering Sciences
Online ISSN
3007-3138
Print ISSN
3007-312X

glacial acetic acid solution was used to re-dissolve the dye in each well. A microplate reader was used to measure each well's optical density at 630 nm in order to calculate the value.

A human infectious disease called candidiasis is brought on by the Candida species. The antifungal effectiveness of La^{3+}-doped $BiPO_4$ was assessed using the agar well diffusion method. The findings revealed that, in comparison to other Candida species, Candida tropicalis had the largest inhibition zone (3–6 cm), suggesting heightened susceptibility to La^{3+}doped $BiPO_4$. Candida glabrata showed the smallest zone of inhibition (2.4 cm). Every pathogen that was tested was susceptible to La^{3+} doped $BiPO_4$. Candida strains are resistant to antifungal medications in part due to genetic mutations, and C. The species known to be most resistant to these treatments is glabrata. In this investigation, C. Compared to the other strains studied, glabrata was the least sensitive to the inhibitory effects of La^{3+}-doped $BiPO_4$ and the least responsive to traditional antifungal infections. A substance or compound is said to have antifungal activity if it can stop fungi from growing or destroy fungal cells. The human respiratory system, internal organs, skin, and nails are just a few of the body parts that can be impacted by fungal infections. Antifungal medications, whether synthetic or natural, target particular elements of fungal cells, such as their membranes, cell walls, or enzymes that are essential for certain functions. For instance, common antifungals like azoles, polyenes, and echinocandins stop the infection from spreading by interfering with fungal cell function through various mechanisms. Apart from medications, natural compounds with antifungal qualities include tea tree oil, garlic, and specific

Spectrum of Engineering Sciences
SPECTRUM OF ENGINEERING SCIENCES
Online ISSN
3007-3138
Print ISSN
3007-312X

plant extracts. The type of fungus, the location and severity of the infection and the immune system of the patient all affect how well antifungal treatments work. Antifungal resistance, on the other hand, is a developing issue that emphasizes the necessity of ongoing research and the creation of novel antifungal treatments. he term "antifungal activity" describes a substance's capacity to either stop or eradicate fungal growth. They are essential for treating and preventing fungal infections in plants, animals, and people. Fungal infections have grown to be a major global health concern, especially for those with weakened immune systems. They can range from minor skin conditions to serious systemic illnesses. Effective treatments are now more important than ever due to the rising incidence of these infections and the development of antifungal resistance. Antifungal medications function by specifically targeting elements of fungal cells and interfering with essential functions like cell division, membrane integrity, nucleic acid replication, and cell wall synthesis. But growing worries about antifungal resistance make treatment plans more difficult. There are several ways that fungi can develop resistance mechanisms, including: B. changes to the fungus's cell membrane composition to lessen drug binding, mutations in the target enzymes and overexpression of efflux pumps, which eliminate antifungal medications from the cell.

Vol. 3 No. 1 (2025)

Spectrum of Engineering Sciences

SPECTRUM OF ENGINEERING SCIENCES

Online ISSN
3007-3138

Print ISSN
3007-312X

Results and Discussion

Characterization of Nanomaterials

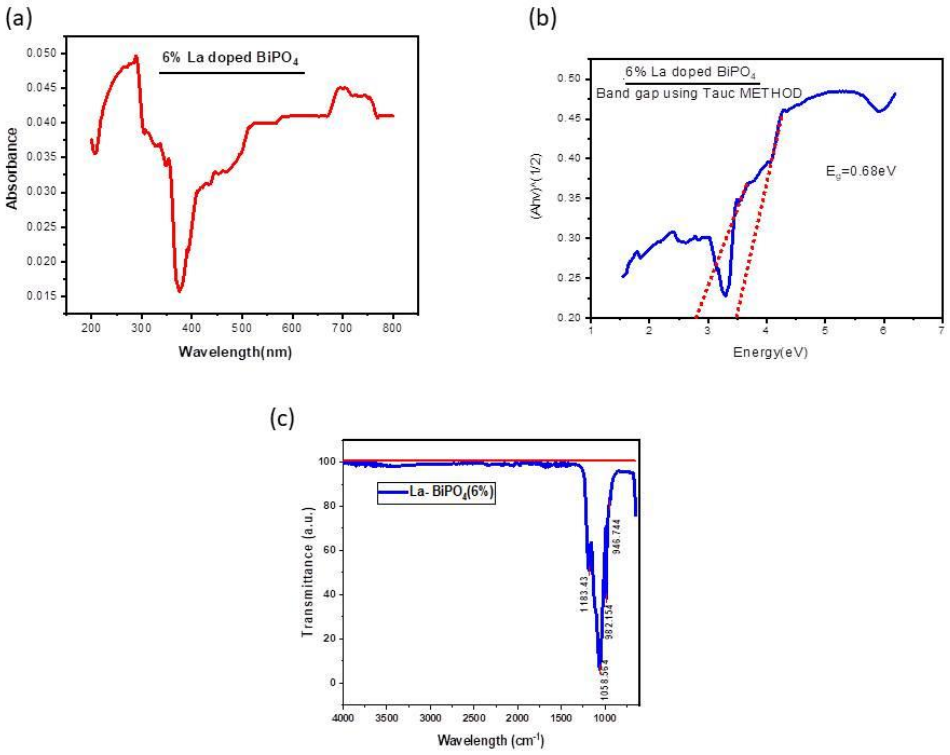

Fig. 1 (a) Optical absorption spectra of 6% La doped $BiPO_4$ (b) Tauc plot Band gap for 6% La doped $BiPO_4$ (c) FTIR spectra of 6% La-doped $BiPO_4$

La^{3+}-doped $BiPO_4$'s UV-visible absorption spectra were measured between 200 and 800 nm. The very low cutoff wavelengths for La^{3+}-doped $BiPO_4$ crystals are approximately 290 nm, based on the spectra. The La3+ ions' energy transfer to the borate matrix may be the cause of the La-doped $BiPO_4$ crystal's low cutoff wavelength. The developed crystals' broad optical transmission window and low cutoff wavelength suggest that they are appropriate for NLO applications. Doped crystals have also been demonstrated to have lower cutoff wavelengths and absorption levels than pure crystals, which probably

Spectrum of Engineering Sciences
SPECTRUM OF ENGINEERING SCIENCES
Online ISSN
3007-3138
Print ISSN
3007-312X

enhances the crystal's NLO characteristic. There are several other factors that can affect absorption, including: B. Particle size, impurity centres, oxygen deficiency, d-d transitions, surface roughness, and lattice distortion ratio. Tauc numbers and absorption data were used to compute the optical band gap energy of La^{3+}-doped $BiPO_4$. Figure 1 depicts a relationship between the energy hν and (αhν)2. The energy gap (E_g) can be obtained by extrapolating the straight-line portion of the curve to (αhν)2=0. The band gaps of La^{3+} doped $BiPO_4$ is 0.68 eV, as the figure illustrates. Introduced impurities or a lower density of localized or defect states are the causes of the band gap reduction. It is possible to correlate presence/absence with the observed variations in band gap values [34].

The optical band gap is a fundamental property of semiconductors that is defined as the energy difference between the top of the unoccupied conduction bad (CBM) and the bottom of the filled valence band (VBM). A distinctive feature of the optical spectrum is the optical absorption edge, which results from the strong optical excitation of electrons across the optical band gap.. Plotting $(Ahv)^{1/\gamma}$ against energy hv allows one to determine the bandgap energy for the samples. The energy band gap value is then determined by fitting the linear segment of the curve along the hν-axis, also known as the energy axis.

The interstitial La doped $BiPO_4$ concentrations between the valence and conduction bands may have contributed to the drop in E_g values. Furthermore, the formation of non-bridging oxygen atoms in the glass network may also be the cause of a drop in E_g values [36]. The molecular fingerprint of the material was determined through FTIR analysis as shown in Figure 1 (c). The production of metal ox-

Spectrum of Engineering Sciences
SPECTRUM OF ENGINEERING SCIENCES
Online ISSN
3007-3138
Print ISSN
3007-312X

ide was verified, and the Fourier transform infrared spectroscopy The synthesised nanostructured compound's integration of multiple functional molecular groups was successfully identified through the use of the FT-IR technique. The material's molecular fingerprint was determined through FTIR analysis. [35]. Fig. 2 (c) displays the obtained FT-IR spectra of La-doped BiPO4 NPs at 6% and pure BiPO4. Every sample's FT-IR spectrum was captured within the 4000 cm-1 range to 400 cm-1. Additionally, we examined the presence of O-H, N-H, C=C, C-O, and C-H functional groups as well as hexagonal crystal symmetry in lanthanum-doped thin films using FTIR spectroscopy. As the dopant concentration rises, the lattice parameter falls. The lattice parameter steadily decreased and was lower than that of lithium niobate. The radius of the ions that make up the crystal also affects its shrinkage.[37] Peaks in the structure of bismuth phosphate were identified at 946.744 cm^{-1} as belonging to the (P-O-P) stretching vibration and 982.154 cm^{-1} as belonging to the C=C stretching bonds of the alkene. Peak and 1058.564cm^{-1} show the symmetry stretching of the CO_3 group and the peaks located at 1183.43 cm^{-1} may be linked to anionic groups. Furthermore, as the concentration of La^{3+}-doped $BiPO_4$ increased, a commensurate rise in the inhibitory effect was noted.

Antimicrobial and Antifungal Response

Two bacterial strains were tested for the antimicrobial activity of sample ID K-19, which contained 6% lanthanum doping in bismuth phosphate at a concentration of 5 mg/ml: the Gram-positive Bacillus spp. and the Escherichia coli gram-negative (E. coli). The inhibition zone diameters measured following sample application were used to calculate the re-

Spectrum of Engineering Sciences
SPECTRUM OF ENGINEERING SCIENCES
Online ISSN
3007-3138
Print ISSN
3007-312X

sults. Escherichia coli (E. coli) showed a distinct inhibition zone of 2–5 cm. coli), suggesting that the K-19 sample exhibited a moderate level of antibacterial activity against bacteria that were Gram-negative. The existence of an inhibition zone indicates that the growth of E is effectively inhibited by the lanthanum-doped bismuth phosphate. coli, perhaps by interfering with its metabolic processes or cell membrane. This finding implies that the sample has a significant, albeit not particularly large, bactericidal or bacteriostatic effect on given the 2.5 cm zone of inhibition E.coli.

The gram-positive Bacillus species, on the other hand. A 2 cm inhibition zone was found to be smaller. Although the K-19 sample exhibited antibacterial activity against Bacillus as well, it was marginally less potent than the E. Coli. The smaller zone of inhibition suggests that the antibacterial properties of the sample may be more effective against gram-negative bacteria, or it could indicate greater resistance of Bacillus to the particular antimicrobial mechanisms exerted by the lanthanum-doped bismuth phosphate. Overall, the findings demonstrate the antibacterial activity of sample K-19, which contains 6% lanthanum doped in bismuth phosphate at a concentration of 5 mg/ml, against both Gram-positive (Bacillus) and Gram-negative (E. bacteria (E. coli).

The action against E. coli is a little more noticeable. The 2–5 cm inhibition zones for E were noted. coli and 2 cm for Bacillus give a first indication of the sample's potential as an antimicrobial agent and call for more research into its stability, efficacy, and mode of action in various settings. Water (D_2H_2O) was used as a control for sample with 0 cm zone of inhibition.

Spectrum of Engineering Sciences
SPECTRUM OF ENGINEERING SCIENCES
Online ISSN
3007-3138
Print ISSN
3007-312X

Figure 2: (a) Antimicrobial results for Bacillus (b) Antimicrobial results for E.coli (c) Antifungal response

At a concentration of 10 mg/mL, the antifungal activity of the 6% lanthanum-doped BiPO4 sample against the common mold Aspergillus, which causes a range of fungal infections in both humans and plants, was assessed. The sample of nanoparticles demonstrated encouraging antifungal activity and stopped Aspergillus species from growing. The sample's nanoparticles have bioactive qualities that influence the fungal strain's growth and development. Aspergillus growth was found to be markedly inhibited upon application of the sample, indicating that the nanoparticles were successful in interfering with essential fungal functions, potentially via mechanisms like fungal metabolism disruption, membrane disruption, or inhibition of cell wall synthesis. Nanoparticles have the special capacity to interact with microbial cells more effectively than bulk materials due to their substantial surface area and compact size. This enables them to pass through the fungal cell wall or membrane and disrupt vital cellular processes. The fact that Aspergillus growth is inhibited implies that the nanoparticles either directly impact the fungal cell's structural integrity or produce reactive oxygen species (ROS), which further degrade the cell's constituent parts and cause cell death. Furthermore, it's well known that nanoparticles can change the permeability of fungal cell membranes,

Spectrum of Engineering Sciences
SPECTRUM OF ENGINEERING SCIENCES
Online ISSN
3007-3138
Print ISSN
3007-312X

which stops growth by obstructing the correct absorption of nutrients and other essential substances.

These outcomes demonstrate the potential of nanoparticles as a potent antifungal agent with a unique mode of action that may be investigated for medical uses. The sample has the potential to develop at a concentration of 10 mg/ml into an effective antifungal treatment, especially for infections related to Aspergillus, according to the encouraging results of the antifungal test. To confirm the precise mechanism of action, ideal concentration, and in vivo efficacy, more research would be necessary. However, considering the growing resistance seen in many fungal strains, the current findings imply that nanoparticle-based treatments may offer a useful substitute or addition to conventional antifungal therapies.

Summary

Fighting infectious diseases and curing patients is getting harder in an era of rising MDR, where bacteria and fungus are becoming resistant to many antibiotics, resulting in significant morbidity and mortality. The issue of bacterial MDR development may be resolved with NPs, which are a good substitute for antibiotics. The recent thorough investigation of antibacterial and antifungal mechanism may add in the creation of antibacterial NPs and to avoid their adverse effects.

References

1. Ezhilarasi, A.A., et al., Green synthesis of NiO nanoparticles using Moringa oleifera extract and their biomedical applications: Cytotoxicity effect of nanoparticles against HT-29 cancer cells. Journal of Photochemistry and Photobiology B: Biology, 2016. **164**: p. 352-360.

Spectrum of Engineering Sciences
SPECTRUM OF ENGINEERING SCIENCES
Online ISSN
3007-3138
Print ISSN
3007-312X

2. Kaviyarasu, K., et al., Elucidation of photocatalysis, photoluminescence and antibacterial studies of ZnO thin films by spin coating method. Journal of Photochemistry and Photobiology B: Biology, 2017. **173**: p. 466-475.
3. Ajmal, S., et al., Effect of Fe and Bi doping on LaCoO3 structural, magnetic, electric and catalytic properties. Journal of Materials Research and Technology, 2019. **8**(5): p. 4831-4842.
4. Hameed, S., et al., Greener synthesis of ZnO and Ag–ZnO nanoparticles using Silybum marianum for diverse biomedical applications. Nanomedicine, 2019. **14**(6): p. 655-673.
5. Arshad, M., et al., Influence of different solvents on portrayal and photocatalytic activity of tin-doped zinc oxide nanoparticles. Journal of Molecular Liquids, 2018. **260**: p. 272-278.
6. Reddy, Y.S., et al., Equilibrium and kinetic studies of the adsorption of acid blue 9 and Safranin O from aqueous solutions by MgO decked FLG coated Fuller's earth. Journal of Physics and Chemistry of Solids, 2018. **123**: p. 43-51.
7. Ezhilarasi, A.A., et al., Green synthesis of NiO nanoparticles using Aegle marmelos leaf extract for the evaluation of in-vitro cytotoxicity, antibacterial and photocatalytic properties. Journal of Photochemistry and Photobiology B: Biology, 2018. **180**: p. 39-50.
8. Jha, A., et al., Rare-earth ion doped TeO2 and GeO2 glasses as laser materials. Progress in Materials Science, 2012. **57**(8): p. 1426-1491.
9. Chen, J., et al., Rare earth nanoparticles prevent retinal degeneration induced by intracellular peroxides, in Nano-Enabled Medical Applications. 2020, Jenny Stanford Publishing. p. 525-546.

Spectrum of Engineering Sciences
SPECTRUM OF ENGINEERING SCIENCES
Online ISSN
3007-3138
Print ISSN
3007-312X

10. Wang, H.Q., et al., Rare-earth ion doped up-conversion materials for photovoltaic applications. Advanced Materials, 2011. **23**(22-23): p. 2675-2680.
11. Zhang, J., et al., Effects of lanthanum on formation and bone-resorbing activity of osteoclast-like cells. Journal of Rare Earths, 2004. **22**(6): p. 891-895.
12. Cai, M., et al., Investigation of a Novel Injectable Chitosan Oligosaccharide—Bovine Hydroxyapatite Hybrid Dental Biocomposite for the Purposes of Conservative Pulp Therapy. Nanomaterials, 2022. **12**(21): p. 3925.
13. Keogan, D.M. and D.M. Griffith, Current and potential applications of bismuth-based drugs. Molecules, 2014. **19**(9): p. 15258-15297.
14. Larsen, A., et al., Gastrointestinal and systemic uptake of bismuth in mice after oral exposure. Pharmacology & toxicology, 2003. **93**(2): p. 82-90.
15. Ansari, A.A., et al., Highly biocompatible, monodispersed and mesoporous La (OH) 3: Eu@ mSiO2 core-shell nanospheres: Synthesis and luminescent properties. Colloids and Surfaces B: Biointerfaces, 2018. **163**: p. 133-139.
16. Hsueh, P.-R., New Delhi metallo-β-lactamase-1 (NDM-1): an emerging threat among Enterobacteriaceae. Journal of the Formosan Medical Association, 2010. **109**(10): p. 685-687.
17. Poole, K., Mechanisms of bacterial biocide and antibiotic resistance. Journal of applied microbiology, 2002. **92**(s1): p. 55S-64S.
18. Jayaraman, R., Antibiotic resistance: an overview of mechanisms and a paradigm shift. Current science, 2009: p. 1475-1484.

Spectrum of Engineering Sciences
SPECTRUM OF ENGINEERING SCIENCES
Online ISSN
3007-3138
Print ISSN
3007-312X

19. Knetsch, M.L. and L.H. Koole, New strategies in the development of antimicrobial coatings: the example of increasing usage of silver and silver nanoparticles. Polymers, 2011. **3**(1): p. 340-366.
20. Huh, A.J. and Y.J. Kwon, "Nanoantibiotics": a new paradigm for treating infectious diseases using nanomaterials in the antibiotics resistant era. Journal of controlled release, 2011. **156**(2): p. 128-145.
21. Hajipour, M.J., et al., Antibacterial properties of nanoparticles. Trends in biotechnology, 2012. **30**(10): p. 499-511.
22. Xia, W., et al., Mesoporous titanium dioxide coating for metallic implants. Journal of Biomedical Materials Research Part B: Applied Biomaterials, 2012. **100**(1): p. 82-93.
23. Della Valle, C., et al., A novel antibacterial modification treatment of titanium capable to improve osseointegration. The International journal of artificial organs, 2012. **35**(10): p. 864-875.
24. Su, H.-L., et al., The disruption of bacterial membrane integrity through ROS generation induced by nanohybrids of silver and clay. Biomaterials, 2009. **30**(30): p. 5979-5987.
25. Ansari, M.A., et al., Synthesis and characterization of the antibacterial potential of ZnO nanoparticles against extended-spectrum β-lactamases-producing Escherichia coli and Klebsiella pneumoniae isolated from a tertiary care hospital of North India. Applied microbiology and biotechnology, 2012. **94**: p. 467-477.
26. Wilking, J.N., et al., Liquid transport facilitated by channels in Bacillus subtilis biofilms. Proceedings of the National Academy of Sciences, 2013. **110**(3): p. 848-852.
27. Kulkarni, N. and U. Muddapur, Biosynthesis of metal nanoparticles: a review. Journal of Nanotechnology, 2014. **2014**(1): p. 510246.

Spectrum of Engineering Sciences
SPECTRUM OF ENGINEERING SCIENCES
Online ISSN
3007-3138
Print ISSN
3007-312X

28. Abdullah, Q., A. Mahmoud, and A. Al-harethi, Isolation and identification of fungal post-harvest rot of some fruits in Yemen. PSM Microbiology, 2016. **1**(1): p. 36-44.
29. Abdelhamid, H.N., et al., A fast and scalable approach for synthesis of hierarchical porous zeolitic imidazolate frameworks and one-pot encapsulation of target molecules. Inorganic chemistry, 2017. **56**(15): p. 9139-9146.
30. Liang, Y., et al., Facile synthesis of ZnO QDs@ GO-CS hydrogel for synergetic antibacterial applications and enhanced wound healing. Chemical Engineering Journal, 2019. **378**: p. 122043.
31. Abdel-Rahman, R.M., et al., Wound dressing based on chitosan/hyaluronan/nonwoven fabrics: Preparation, characterization and medical applications. International journal of biological macromolecules, 2016. **89**: p. 725-736.
32. Niroomand, S., et al., Photochemical and DFT studies on DNA-binding ability and antibacterial activity of lanthanum (III)-phenanthroline complex. Journal of Molecular Structure, 2017. **1130**: p. 940-950.
33. Srivastava, A.K., et al., New insight into curcumin tethered lanthanum carbonate nanospheres and protein corona conferring fluorescence enhancement based sensitive detection of Amyloid-β aggregates. Sensors and Actuators B: Chemical, 2018. **262**: p. 687-695.
34. Prabha, K., et al., Structural, optical, antimicrobial activity and surface analysis of pure and rare earth metal lanthanum (La3+)-doped ammonium pentaborate (APB) single crystals. Chemical Papers, 2024. **78**(4): p. 2287-2299.

Spectrum of Engineering Sciences
SPECTRUM OF ENGINEERING SCIENCES
Online ISSN
3007-3138
Print ISSN
3007-312X

35. Alharshan, G.A., et al., Physical, structural, and optical characteristics of the glasses system based on lanthanum-doped phosphate. Optical and Quantum Electronics, 2024. **56**(7): p. 1179.
36. Abdel-Aziz, A.M., et al., Synthesis, physical, ultrasonic waves, mechanical, FTIR, and dielectric characteristics of B2O3/Li2O/ZnO glasses doped with Y3+ ions. Journal of Materials Science: Materials in Electronics, 2022. **33**(9): p. 6603-6615.
37. Irzaman, H.H. and A. Hardhienata, The effects of lanthanum dopant on the structural and optical properties of ferroelectric thin films. Journal of Rare Earth Element, 2017: p. 139-140.