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ÇEVENTAM

ANTIMICROBIAL AND ANTIFUNGAL BOROPHENE

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Abstract

This paper addresses the critical problem of antibiotic resistance and the need for alternative antibacterial strategies. It focuses on the application of nanomaterials with different dimensionalities (0-D, 1-D, 2-D, and 3-D) in antibacterial contexts. The article explores the unique properties and mechanisms of low-dimensional nanomaterials like silver nanoparticles (AgNPs) and graphene quantum dots (GQDs) in fighting bacterial infections. These nanomaterials offer promise in wound dressings, medical implants, and food packaging, delivering clinical benefits while minimizing side effects. This research explores the potential of β-rhombohedral crystalline structured borophene nanosheets as multifunctional antibacterial and antifungal agents. Prepared via physical exfoliation, these nanosheets exhibit significant inhibitory activity against pathogenic microorganisms, including *Staphylococcus aureus*, *Pseudomonas aeruginosa*, *Escherichia coli*, *Candida albicans* and *Aspergillus brasiliensis*. The study suggests that borophene nanosheets, with their unique physicochemical properties, hold promise as effective antimicrobial coatings in biomedical and packaging applications, offering a novel solution to combat bacterial and fungal infections.

Keywords: antimicrobial, antifungal, borophene, microorganisms, nanosheets

Introduction

Antimicrobial agents play a crucial role in preventing public health issues caused by ubiquitous bacteria (Dey et al. 2022, Hajipour et al. 2012). The history of antibiotics; development (Miller et al. 2014, Jijie et al. 2017) and the concerning rise of drug-resistant bacteria (Yarlagadda et al. 2016, Stephans et al. 2020) have spurred intense interest in carbonbased nanomaterials (Wu et al. 2014, Bourquin et al. 2018). These materials, with at least one dimension less than 100 nm, hold great promise across various biology-based applications, including drug delivery systems (DDSs), photodynamic/photothermal therapy (PDT/PTT), and theranostics. (Li et al. 2016, Xiong et al. 2017) Nanomaterials, including silver (Ag), copper (Cu), titanium dioxide (TiO2), zinc oxide (ZnO) nanostructures, graphene, carbon nanotubes, and composite materials, have gained attention as effective antimicrobial agents due to their high surface area and biocompatibility (DíezPascual et al. 2014, Wang et al. 2020). Inorganic antimicrobial agents, such as graphene, are preferred for their heat resistance and durability (Mousavi Khaneghah et al. 2018). Graphene, a two-dimensional nanomaterial, exhibits strong antimicrobial properties attributed to its high surface area, mechanical strength, and biocompatibility (Krishnamoorthy et al. 2014, Zou et al. 2016). Hexagonal boron nitride (h-BN) nanosheets have also shown promise as antimicrobial agents, but limited research has been conducted on their antimicrobial properties (Deshmukh et al. 2020, Wang et al. 2014).

Nanomaterials

3-D nanomaterials combine elements of 0-D, 1-D, or 2-D structures, offering versatile applications in wound dressings, medical implants, and drug delivery (Liu et al. 2016, Yan et al. 2015). For instance, 3-D-layered double nanohybrids have demonstrated enhanced antibacterial efficacy by inducing oxidative stress and protein degradation (Liu et al 2016, Komarala et al. 2016). A vertical heterostructure of MoS2-coated reduced graphene oxide (rGO) exhibited in situ bacterial binding and ROS generation, effectively targeting E. coli and S. aureus (Wang et al. 2020). Furthermore, 3-D-printed polylactic acid (PLA) scaffolds, functionalized with polydopamine and loaded with antibacterial agents, displayed long-term antibacterial activity (Li et al. 2018) Composite materials like p-BC/AgNPs exhibited excellent antibacterial efficiency against E. coli and S. aureus, showcasing their potential in wound dressings, medical implants, and drug delivery applications (Yan et al. 2015). Functional nanomaterials, spanning dimensions from 0-D to 3-D, offer diverse and promising avenues for antibacterial applications. They harness properties like photothermal conversion efficiency, controlled drug release, and catalytic activity to combat bacterial infections (Horn et al. 2013, Wang et al. 2019). These materials hold great promise in addressing the critical challenge of multidrug-resistant bacterial infections. While challenges such as stability, biocompatibility, and in vivo toxicity persist, ongoing research, including biomolecule functionalization and materials science advancements, paves the way for enhanced biocompatibility and tissue friendly targeting. As this field continues to advance, nanomaterials offer promising solutions to combat bacterial infections, especially against multidrug-resistant "superbugs" (Zhou et al. 2020). The best of our knowledge, a summary of antibacterial nanomaterials in terms of their dimensionality has not been published (Figure.1).

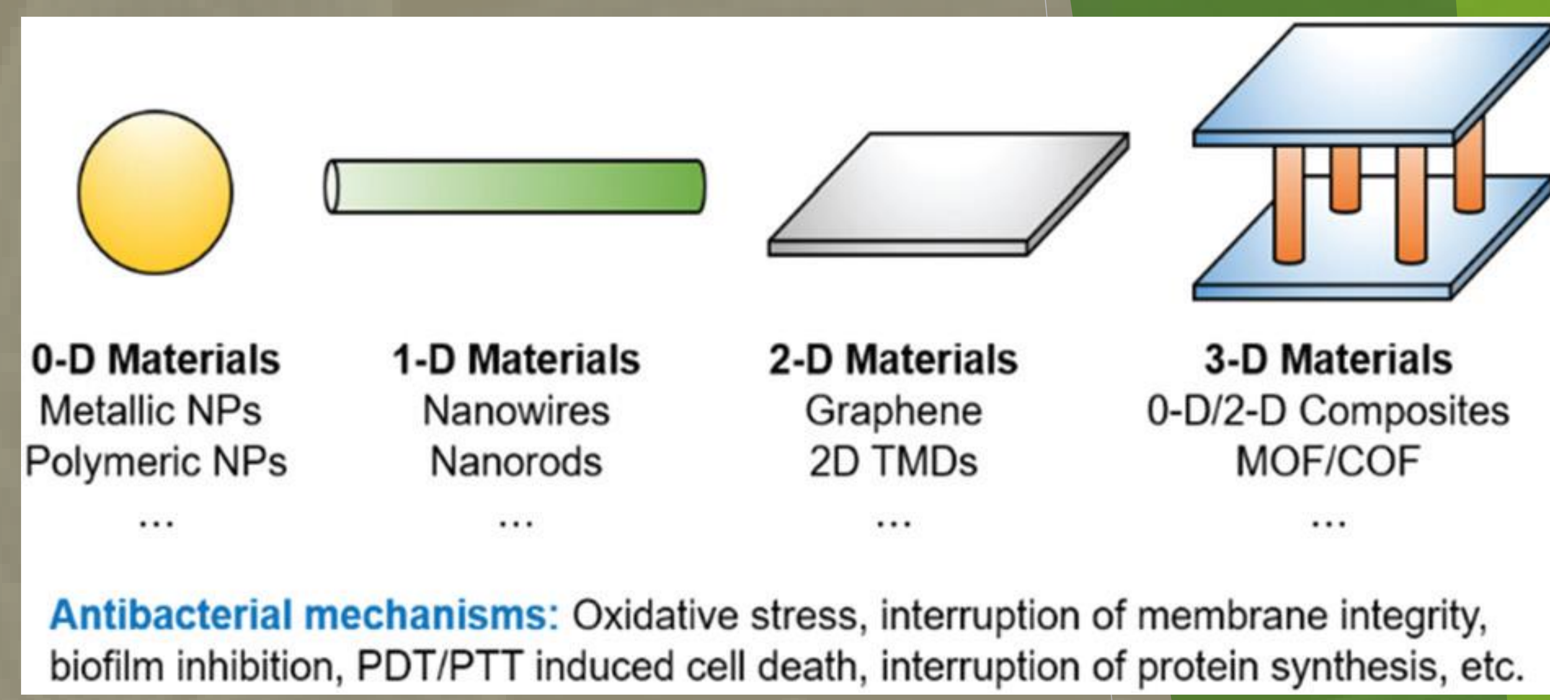

Figure.1. Schematic illustration of the low-dimensional materials, including their antibacterial mechanisms, covered in this review.

Methods

In this study, we successfully prepared 2D borophene nanosheets via physical exfoliation (Taşaltın et al. 2021). The structural and chemical properties were characterized using high resolution transmission electron microscopy (HRTEM), scanning electron microscopy (SEM), X-ray diffraction (XRD), and Fourier-transform infrared spectroscopy (FTIR). The antimicrobial activity was evaluated against Staphylococcus aureus, Pseudomonas aeruginosa, Escherichia coli, Candida albicans, and Aspergillus brasiliensis following NF EN ISO 11930:2012 guidelines (Fatima et al. 2021, Wang et al. 2014). The schematic diagram of experimental process of the prepared β borophene was given in Figure.2.

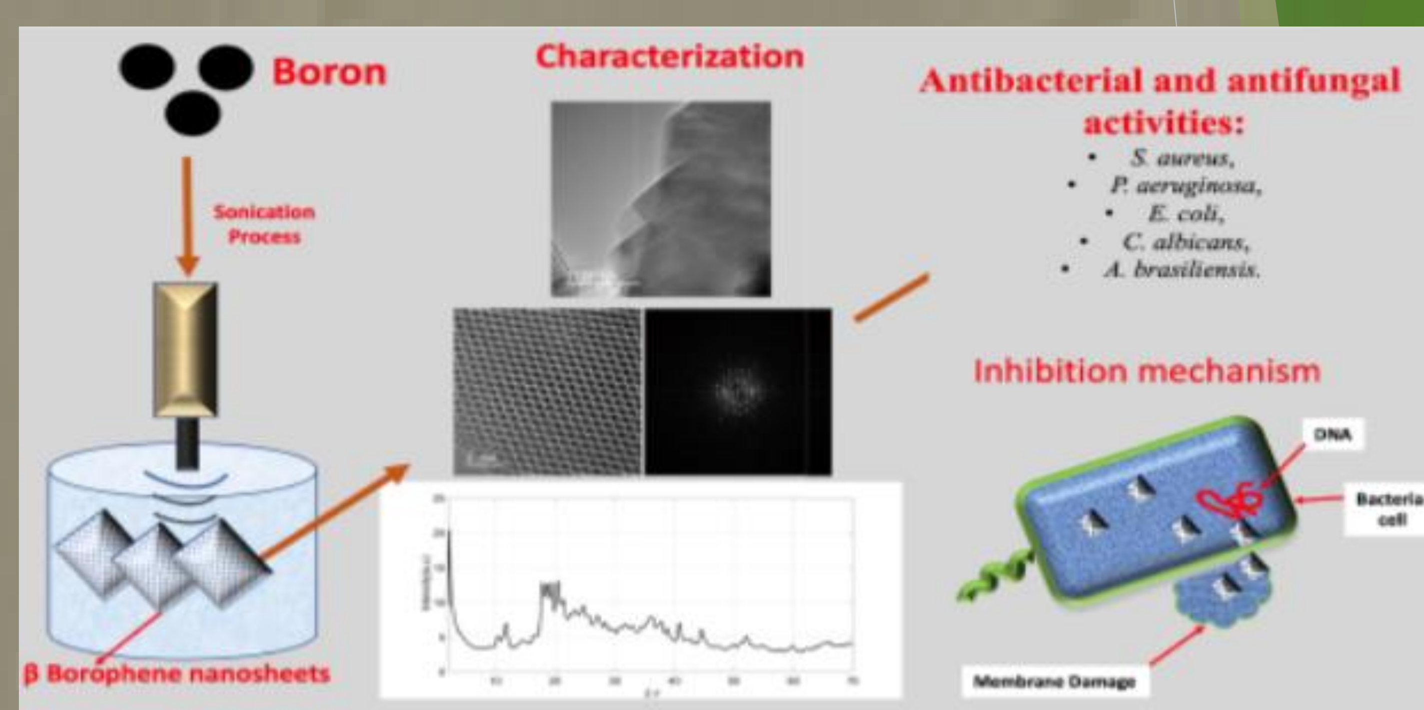

Figure.2 The schematic diagram of experimental process of the prepared β borophene

Results and Discussion

The HRTEM analysis revealed the β-rhombohedral crystalline structure of borophene nanosheets (Fundamentals and Applications 2021, Uno et al. 2021). SEM images showed few-layered borophene nanosheets with diameters ranging from 333.9 nm to 1 µm and thicknesses of 3 to 10 nm. FTIR spectra confirmed the presence of borophene functional groups (James et al. 2017, Das et al. 2015). XRD analysis confirmed the β-rhombohedral phase of borophene (Sachdeva et al. 2021). Antimicrobial tests demonstrated that borophene nanosheets exhibited significant reductions in microbial growth, with log reductions ranging from 3.64 to 5.52 against various pathogens (Sham Shihabudeen et al. 2010, Kumar et al. 2006). The zone inhibition assay revealed inhibition zones ranging from 18.0 to 25.3 mm, indicating strong antimicrobial activity (Boyanova et al. 2005). The exact mechanism of action remains under investigation but may involve disruption of microbial cell membranes, formation of reactive oxygen species (ROS), and oxidative damage (Duan et al. 2022, Ayub et al. 2021).

Conclusion

This study presents the successful preparation of β-rhombohedral borophene nanosheets and their potent antimicrobial activity against various pathogens. Borophene nanosheets show promise as effective antimicrobial agents for biomedical applications, including coatings, paints, and packaging materials. Further research is needed to elucidate the precise antimicrobial mechanism and explore additional biomedical applications.

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