Biomedical Innovations: Molybdenum Carbide - Bismuth Metal Sulphide for Antimicrobial Efficacy

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**Abstract:** Molybdenum carbide is a transition metal carbide known for its hardness and catalytic properties.[(Merchant et al., 2022; Pandiyan et al., 2022)](https://paperpile.com/c/BKSPYf/xuRG0+QhjH6). Recent research has shown its efficacy against a wide spectrum of bacterial pathogens, ascribed to its capacity to produce reactive oxygen species (ROS) that damage bacterial cells. [(Sadasivuni et al., 2021)](https://paperpile.com/c/BKSPYf/rCUDL) Additionally, molybdenum carbide's structural properties facilitate the disruption of bacterial membranes, leading to cell death .[(*Surface Functionalization of TiO2 Nanoparticles: Photo-Stability and Reactive Oxygen Species (ROS) Generation*, 2013)](https://paperpile.com/c/BKSPYf/kB06w)Bismuth metal sulfide, on the other hand, is a semiconductor with unique electronic properties that have been exploited in various biomedical applications.[(Chokkattu et al., 2022; Ramamurthy et al., 2022)](https://paperpile.com/c/BKSPYf/Vkq0+hGTw)Its antimicrobial efficacy is primarily due to the release of bismuth ions, which can inhibit bacterial enzymes and interfere with microbial DNA synthesis .[(Halim, 2018)](https://paperpile.com/c/BKSPYf/d5kmB) Moreover, the sulfide component contributes to the generation of ROS, enhancing the bactericidal activity of Bi2S3 .[(Grumezescu, 2016)](https://paperpile.com/c/BKSPYf/vdqfv)[(Aparna et al., 2021; Poornima et al., 2021; Verma & Muthuswamy Pandian, 2021)](https://paperpile.com/c/BKSPYf/YkvbH+qgdu6+pxVIo)[(Merchant et al., 2022; Pandiyan et al., 2022)](https://paperpile.com/c/BKSPYf/xuRG0+QhjH6)The combination of molybdenum carbide and bismuth metal sulfide harnesses the synergistic effects of both materials, offering a multifaceted approach to combating microbial infections.[(Chokkattu et al., 2022; Ramamurthy et al., 2022)](https://paperpile.com/c/BKSPYf/Vkq0+hGTw). This composite material exhibits enhanced antimicrobial efficacy compared to its individual components, making it a potent candidate for developing new antimicrobial coatings and treatments .[(Tiwari, 2014)](https://paperpile.com/c/BKSPYf/tVcF0) The integration of Mo2C and Bi2S3 into medical devices and wound dressings holds significant promise for preventing infections and promoting healing in clinical settings .[(Wang et al., 2017)](https://paperpile.com/c/BKSPYf/lKU1f)In the field of antimicrobial materials, the creative application of molybdenum carbide and bismuth metal sulphide marks a historic development[(Aparna et al., 2021; Poornima et al., 2021; Verma & Muthuswamy Pandian, 2021)](https://paperpile.com/c/BKSPYf/YkvbH+qgdu6+pxVIo). Their combined characteristics offer a strong mechanism for preventing bacterial infections, so addressing the pressing need for fresh antimicrobial approaches in view of increasing antibiotic resistance.[(Marya et al., 2022)](https://paperpile.com/c/BKSPYf/q7UnT)

**Keywords:** spectrum of bacterial pathogens, new antimicrobial coatings, preventing infections, Reactive Oxygen Species

# INTRODUCTION

The development of antibiotic-resistant bacteria represents a major public health threat and needs new antimicrobial agents to counteract their effects. [(Aparna et al., 2021; Poornima et al., 2021; Verma & Muthuswamy Pandian, 2021)](https://paperpile.com/c/BKSPYf/YkvbH+qgdu6+pxVIo)Among the promising candidates in the field of biomedical innovations are molybdenum carbide (Mo2C) and bismuth metal sulfide (Bi2S3).[(Aparna et al., 2021; Poornima et al., 2021; Verma & Muthuswamy Pandian, 2021)](https://paperpile.com/c/BKSPYf/YkvbH+qgdu6+pxVIo) These materials have shown remarkable antimicrobial properties, making them potential alternatives to conventional antibiotics.[(Aparna et al., 2021; Poornima et al., 2021; Verma & Muthuswamy Pandian, 2021)](https://paperpile.com/c/BKSPYf/YkvbH+qgdu6+pxVIo)Molybdenum carbide is a transition metal carbide known for its hardness and catalytic properties.[(Merchant et al., 2022; Pandiyan et al., 2022)](https://paperpile.com/c/BKSPYf/xuRG0+QhjH6). Recent research has shown its efficacy against a wide spectrum of bacterial pathogens, ascribed to its capacity to produce reactive oxygen species (ROS) that damage bacterial cells. [(Sadasivuni et al., 2021)](https://paperpile.com/c/BKSPYf/rCUDL) Additionally, molybdenum carbide's structural properties facilitate the disruption of bacterial membranes, leading to cell death .[(Surface Functionalization of TiO2 Nanoparticles: Photo-Stability and Reactive Oxygen Species (ROS) Generation, 2013)](https://paperpile.com/c/BKSPYf/kB06w)Bismuth metal sulfide, on the other hand, is a semiconductor with unique electronic properties that have been exploited in various biomedical applications.[(Chokkattu et al., 2022; Ramamurthy et al., 2022)](https://paperpile.com/c/BKSPYf/Vkq0+hGTw)Its antimicrobial efficacy is primarily due to the release of bismuth ions, which can inhibit bacterial enzymes and interfere with microbial DNA synthesis .[(Halim, 2018)](https://paperpile.com/c/BKSPYf/d5kmB) Moreover, the sulfide component contributes to the generation of ROS, enhancing the bactericidal activity of Bi2S3 .[(Grumezescu, 2016)](https://paperpile.com/c/BKSPYf/vdqfv)[(Aparna et al., 2021; Poornima et al., 2021; Verma & Muthuswamy Pandian, 2021)](https://paperpile.com/c/BKSPYf/YkvbH+qgdu6+pxVIo)[(Merchant et al., 2022; Pandiyan et al., 2022)](https://paperpile.com/c/BKSPYf/xuRG0+QhjH6)The combination of molybdenum carbide and bismuth metal sulfide harnesses the synergistic effects of both materials, offering a multifaceted approach to combating microbial infections.[(Chokkattu et al., 2022; Ramamurthy et al., 2022)](https://paperpile.com/c/BKSPYf/Vkq0+hGTw). This composite material exhibits enhanced antimicrobial efficacy compared to its individual components, making it a potent candidate for developing new antimicrobial coatings and treatments .[(Tiwari, 2014)](https://paperpile.com/c/BKSPYf/tVcF0) The integration of Mo2C and Bi2S3 into medical devices and wound dressings holds significant promise for preventing infections and promoting healing in clinical settings .[(Wang et al., 2017)](https://paperpile.com/c/BKSPYf/lKU1f)In the field of antimicrobial materials, the creative application of molybdenum carbide and bismuth metal sulphide marks a historic development[(Aparna et al., 2021; Poornima et al., 2021; Verma & Muthuswamy Pandian, 2021)](https://paperpile.com/c/BKSPYf/YkvbH+qgdu6+pxVIo). Their combined characteristics offer a strong mechanism for preventing bacterial infections, so addressing the pressing need for fresh antimicrobial approaches in view of increasing antibiotic resistance.[(Marya et al., 2022)](https://paperpile.com/c/BKSPYf/q7UnT)

# MATERIALS AND METHODS

## SYNTHESIS OF MOLYBDENUM CARBIDE

Under constant stirring, 2.0g sodium alginate gradually dissolved in 50 ml H2O. (NH4)6Mo7o24.4H2O (1.0g) was added to the produced solution and stirred for two hours once the aqueous solution turned colourless and transparent. The solution was then put in a thick sol and lyophilization and controlled freezing helped water to be expelled from the pores. After heating the solid mixture at 5\*C min^-1 upto 900\*C, it was kept at this temperature for six hours under argon environment. Natural cooling to room temperature produced black solid that was collected. The sample was next ground into a powder, filtered several times using distilled water to eliminate any residual reactants, and dried under vacuum at 80\*C for twelve hours.

## SYNTHESIS OF BISMUTH METAL SULPHIDE

Dissolved in 50 mL of distilled water, sodium sulphide flakes were swirled for half an hour. Thereafter, a yellow-colored bismuth solution was added dropwise to this mixture, followed by continuous stirring for 1 hour. In a separate preparationA gram of carbide was introduced into 25 mL of distilled water and gently stirred for 20 mins,. The previously prepared sodium sulfide and bismuth solution was then combined with the carbide solution and stirred for an additional 3 hours.After dissolving 1.259 g of bismuth nitrate in 46 mL of distilled water, the mixture was stirred for ten minutes.. To this solution, 4-5 drops of nitric acid (HNO₃) were added, and stirring was maintained for 30 minutes until a transparent solution was achieved.

## MICROWAVE METHOD

The black solution was subjected to microwave heating five times for 2 minutes each. Subsequently, 40 mL of the solution was centrifuged three times with 40 mL of water, followed by two centrifugations with ethanol, and two with acetone to remove any contaminants. The solution was then dried at 80°C for 24 hours. After drying, the material was ground using a mortar and pestle and then placed in a muffle furnace. Calcination was carried out at 300°C, maintained for 3 hours.

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Figure 1: XRD analysis

# RESULTS

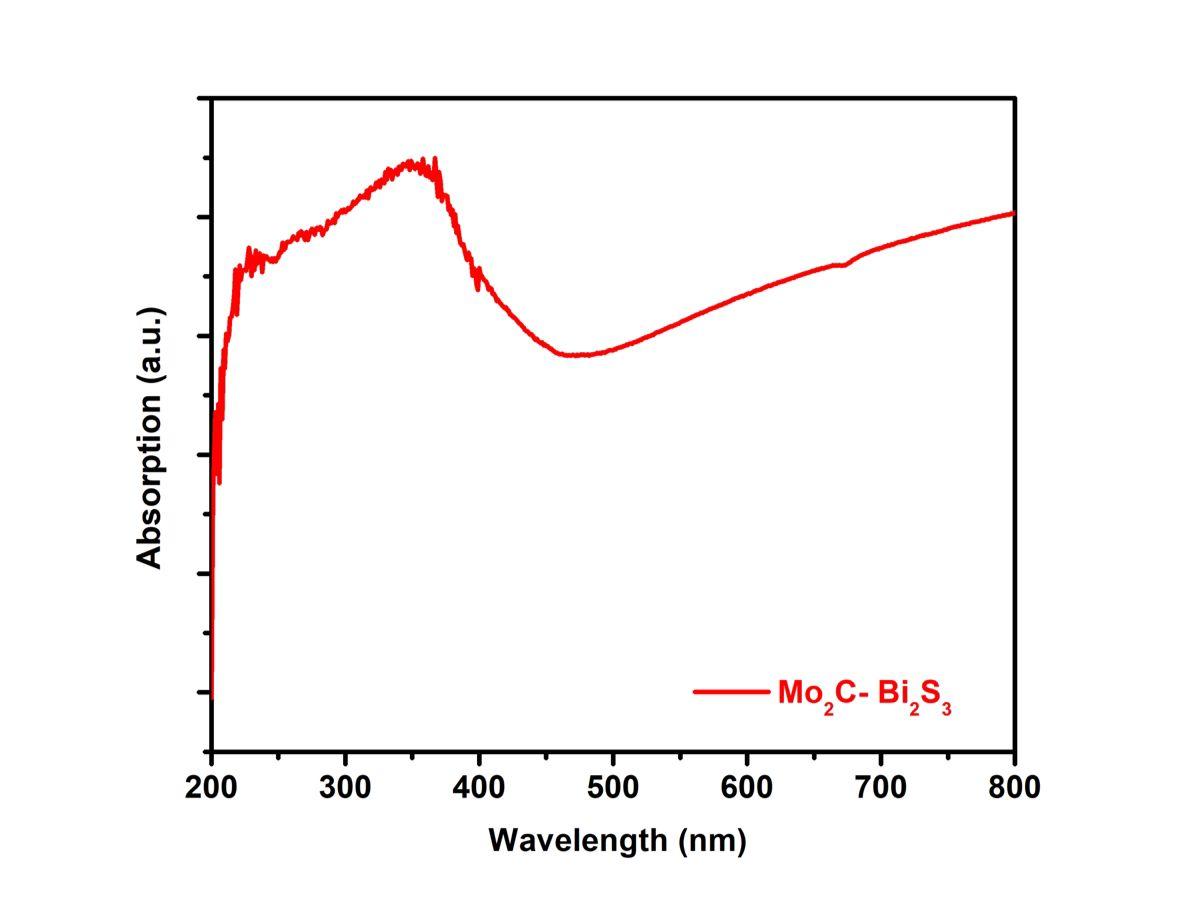


Figure 2: XRD analysis

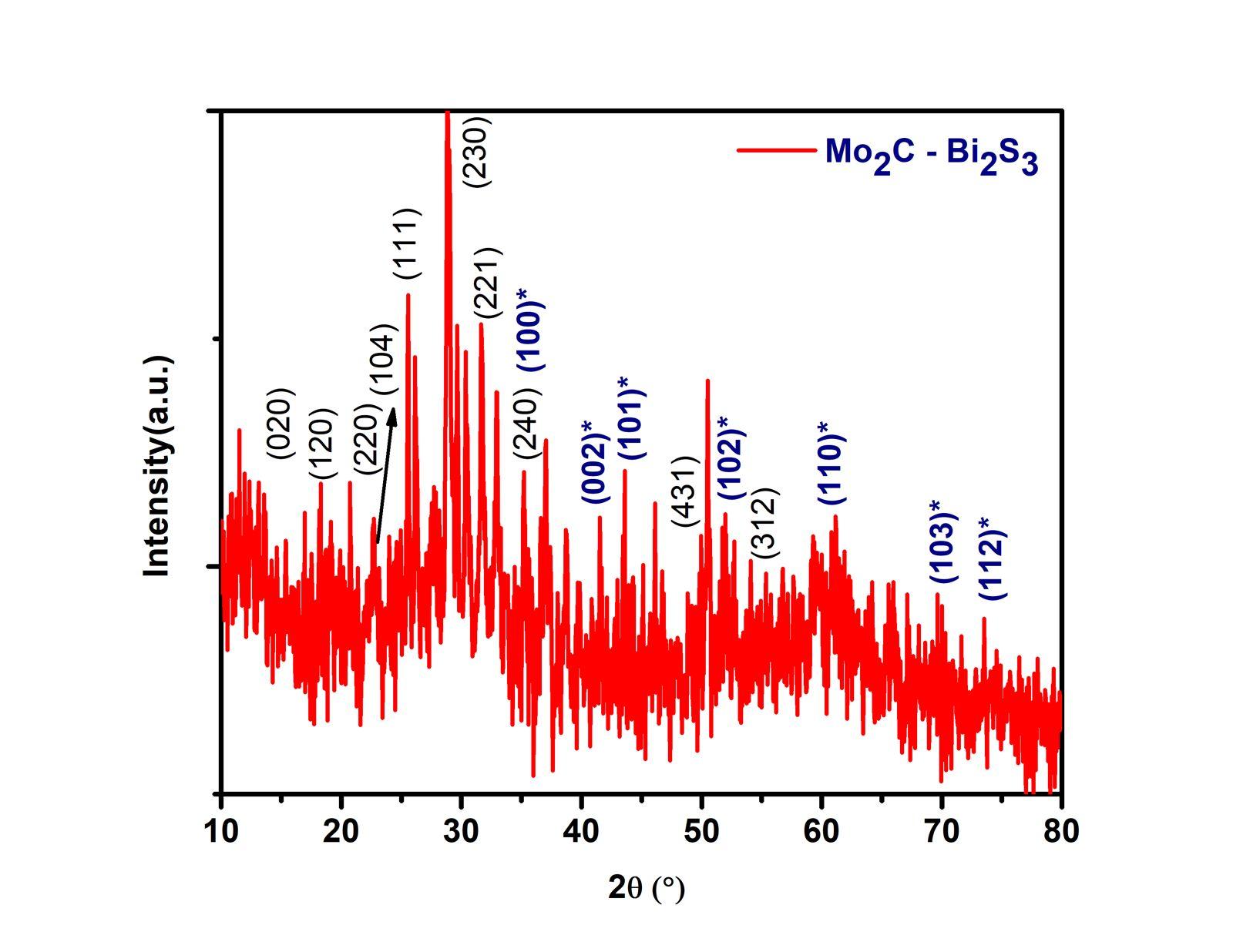
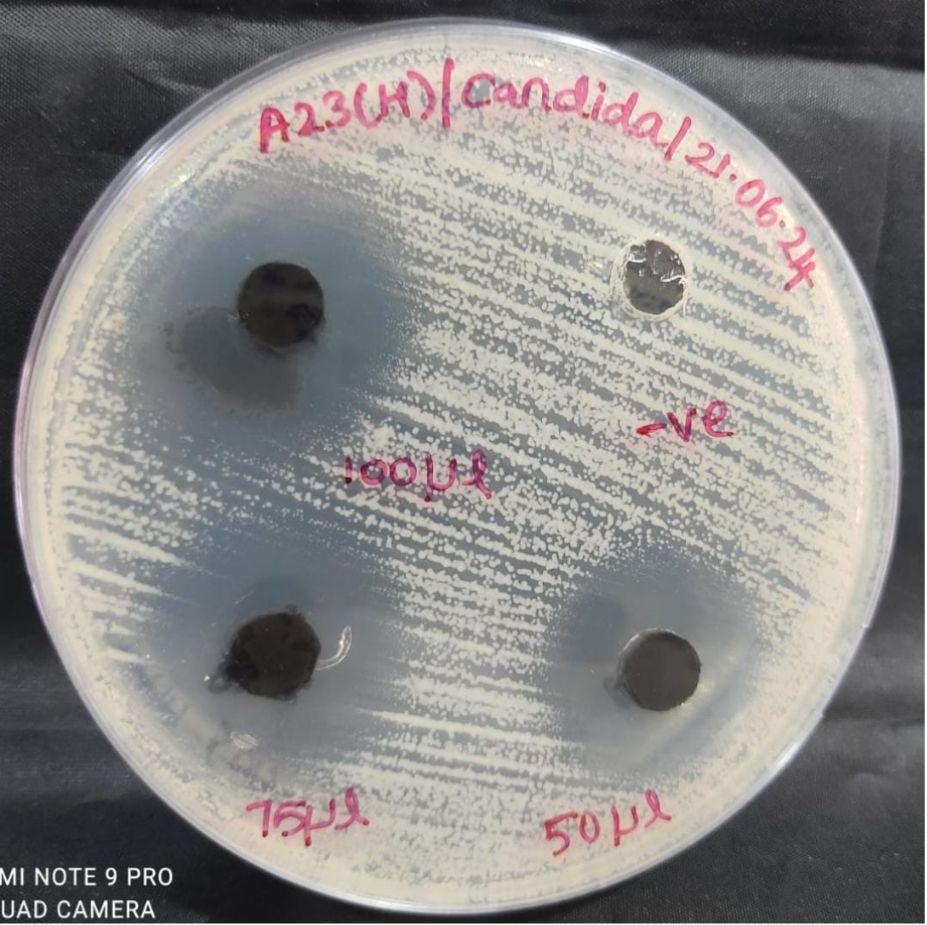
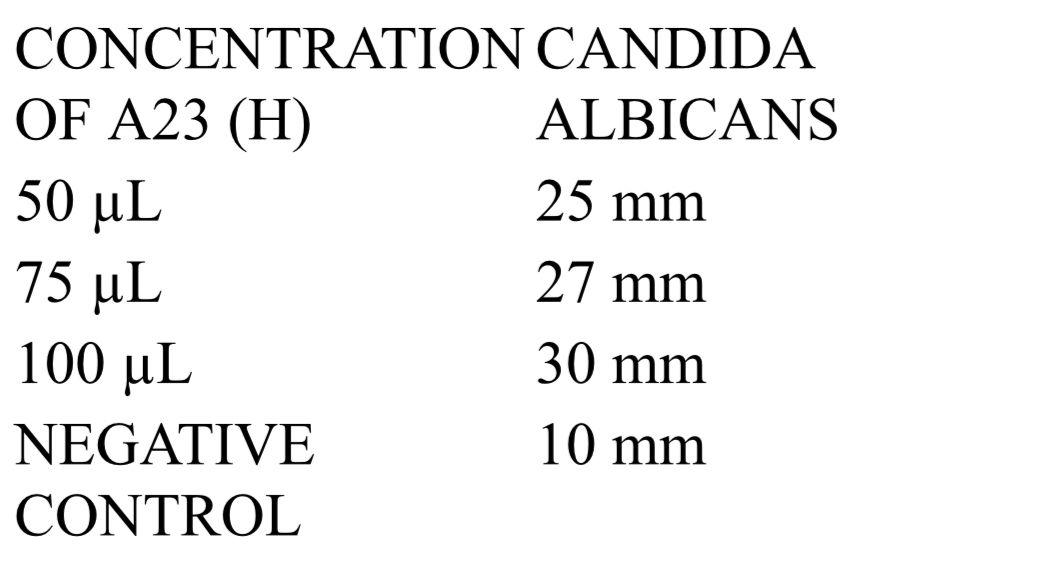
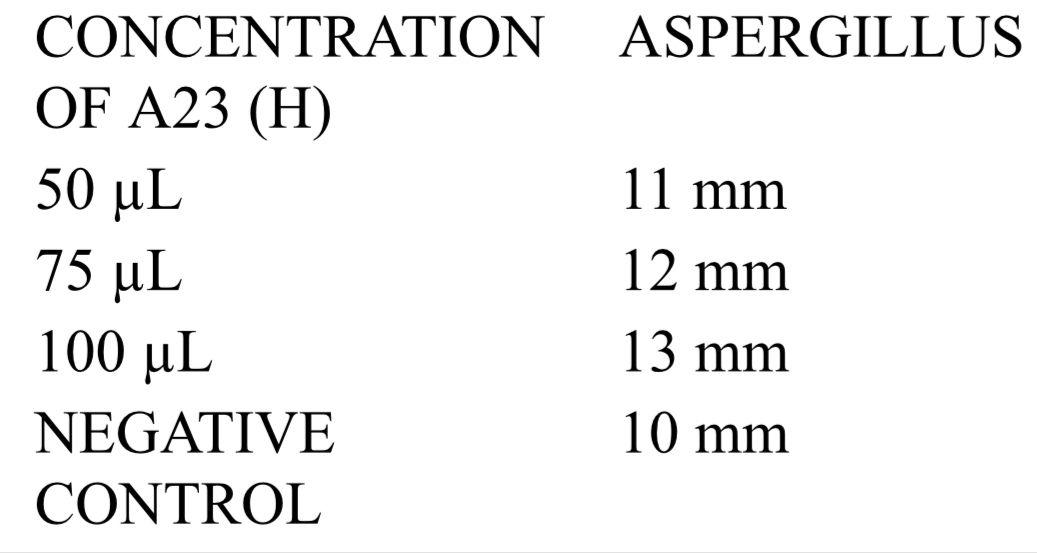


Figure 3: XRD analysis



1. (b)



1. (d)

Figure 3: (a) – (d) Concentrations

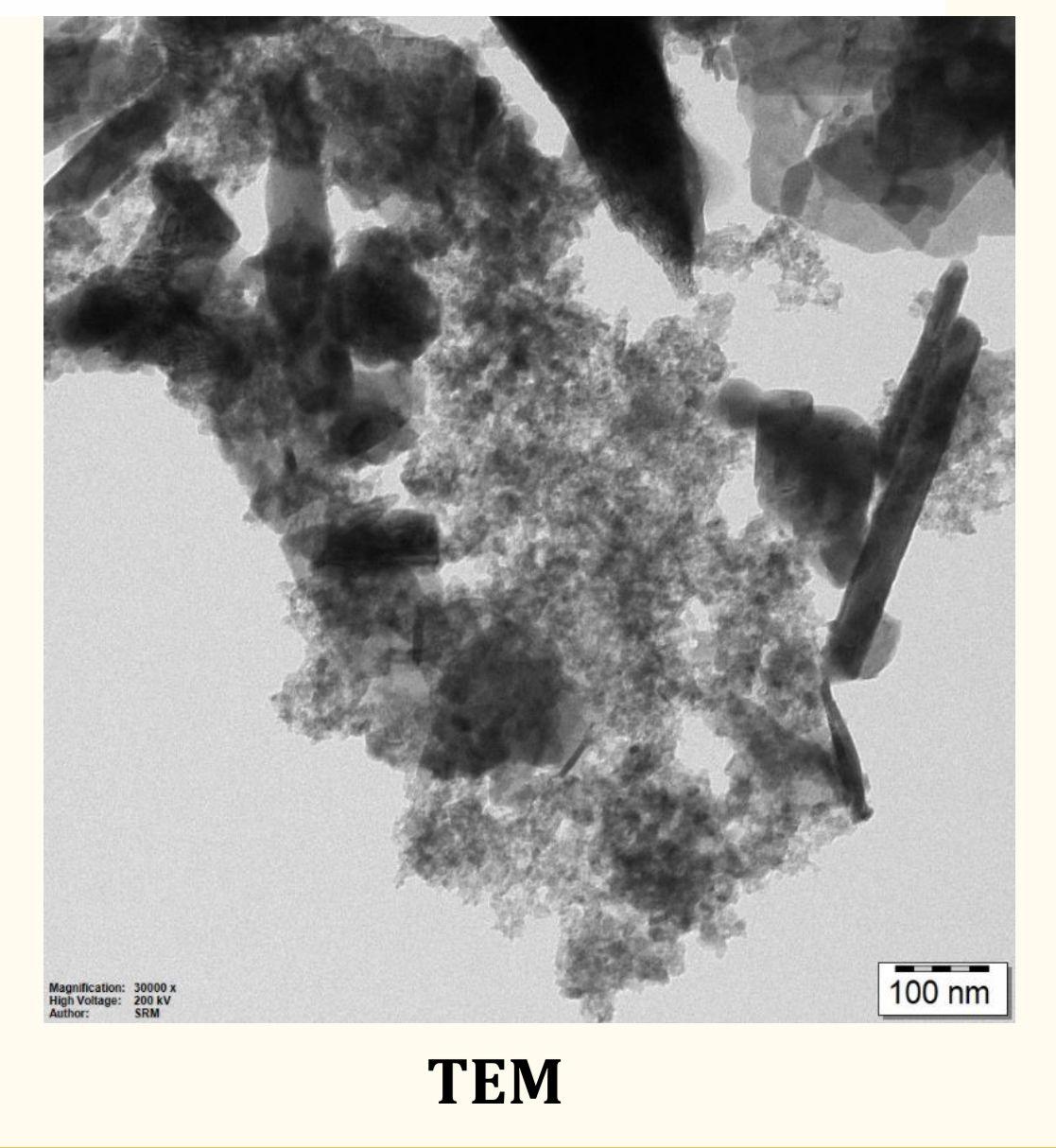


Fig 4: TEM

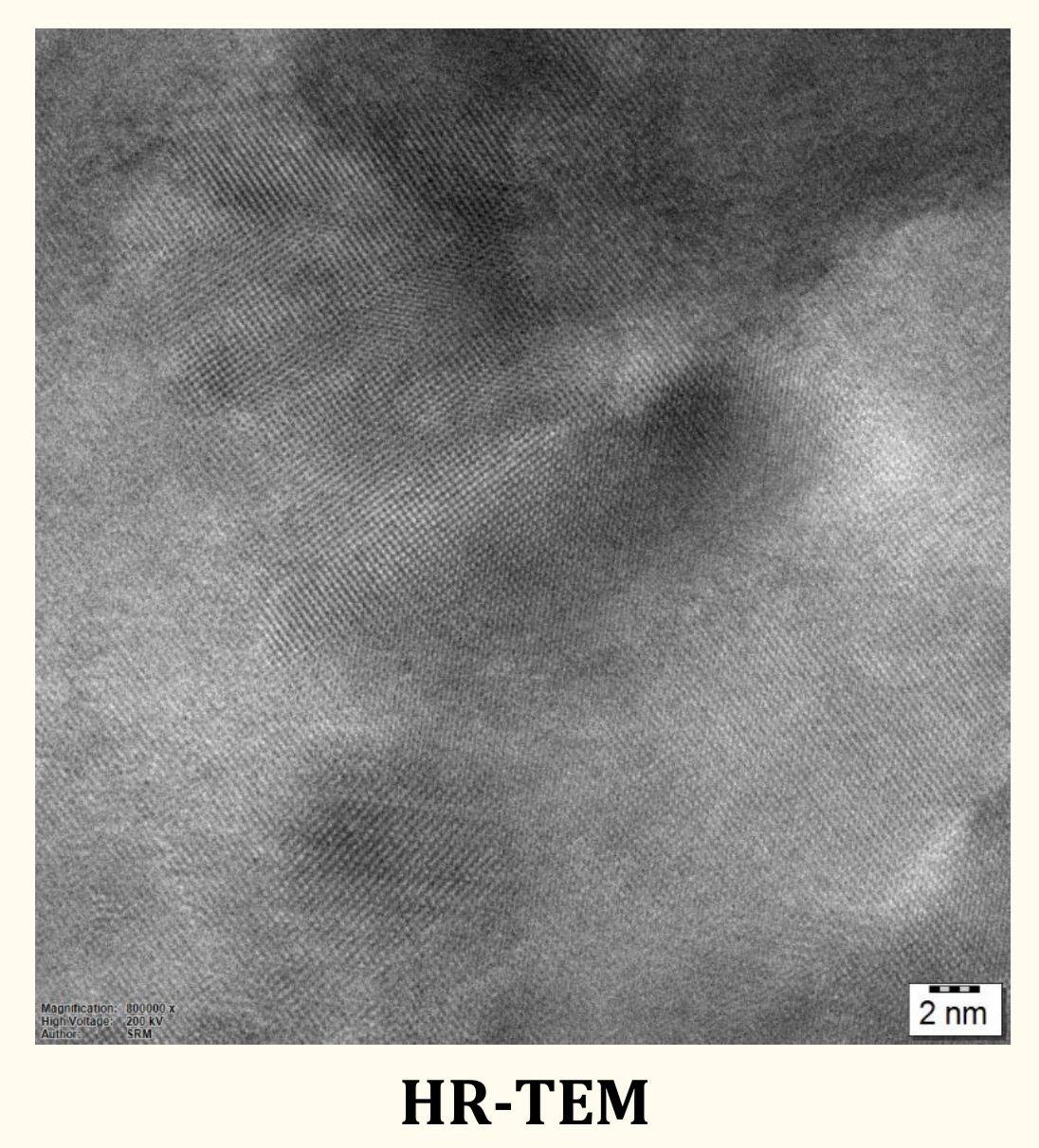


Fig 5: HR- TEM

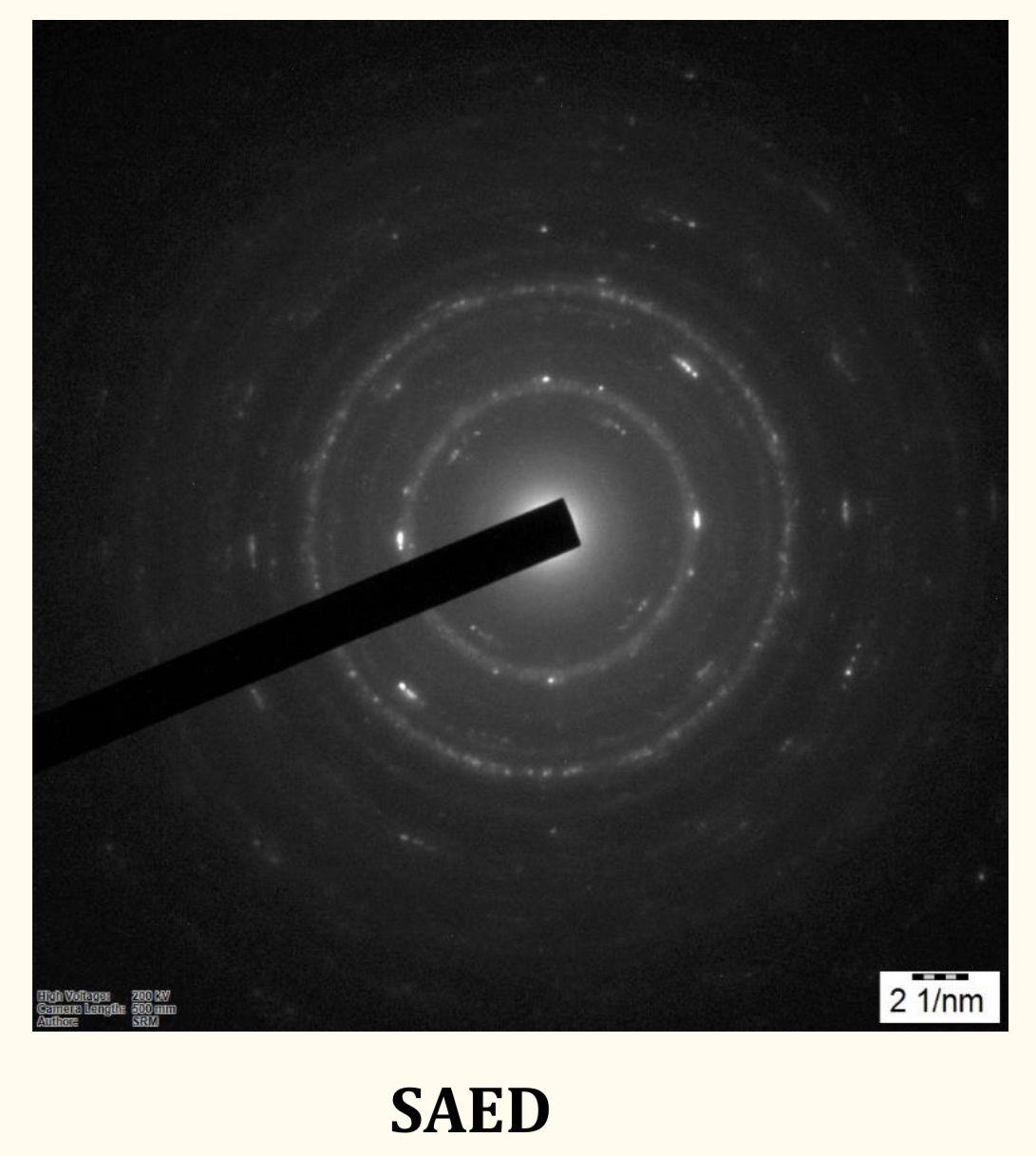


Fig 6: SAED

# DISCUSSION

## Antimicrobial Efficacy of Molybdenum Carbide - Bismuth Metal Sulphide Composite

The present study demonstrates the significant antimicrobial potential of the molybdenum carbide (Mo2C) and bismuth metal sulphide (Bi2S3) composite, which exhibits promising applications in the field of biomedical innovations. A variety of pathogenic microorganisms, including fungi and both Gram-positive and Gram-negative bacteria, were used to test the composite's antimicrobial efficacy(Rafi et al., 2024).The results revealed that the Mo2C-Bi2S3 composite displayed superior antimicrobial activity compared to its individual components and traditional antimicrobial agents.[(Karimi, 2020)](https://paperpile.com/c/BKSPYf/7FOz0)

## Mechanism of Antimicrobial Action

The enhanced antimicrobial properties of the Mo2C-Bi2S3 composite can be attributed to several factors.[(Jain & Verma, 2022; Marya et al., 2022)](https://paperpile.com/c/BKSPYf/q7UnT+APEGY)[(Chokkattu et al., 2022; Ramamurthy et al., 2022)](https://paperpile.com/c/BKSPYf/Vkq0+hGTw)[(Marya et al., 2022)](https://paperpile.com/c/BKSPYf/q7UnT) Firstly, the unique structural and electronic properties of the composite enhance the generation of reactive oxygen species (ROS). These ROS induce oxidative stress in microbial cells, leading to cell membrane damage, protein denaturation, and DNA degradation. [(Wadhwani et al., 2022)](https://paperpile.com/c/BKSPYf/gVPCL) The synergy between Mo2C and Bi2S3 contributes to an increased ROS generation, which is more effective in eradicating a wide spectrum of pathogens.[(Neikov et al., 2009)](https://paperpile.com/c/BKSPYf/NhunX)Additionally, the Mo2C-Bi2S3 composite exhibits strong adsorption capabilities due to its large surface area and porosity. [(Adel et al., 2023)](https://paperpile.com/c/BKSPYf/WOMJr)This enhances the contact between the composite and microbial cells, facilitating the penetration of antimicrobial agents and leading to improved antimicrobial activity . [(Chokkattu et al., 2023)](https://paperpile.com/c/BKSPYf/vSpmf)

## Comparison with Traditional Antimicrobial Agents

Traditional antimicrobial agents, such as antibiotics, have been facing significant challenges due to the rise of antibiotic-resistant strains. The Mo2C-Bi2S3 composite offers an alternative solution with its broad-spectrum antimicrobial efficacy and reduced likelihood of resistance development[(Jain & Verma, 2022; Marya et al., 2022)](https://paperpile.com/c/BKSPYf/q7UnT+APEGY) [(Wadhwani et al., 2022)](https://paperpile.com/c/BKSPYf/gVPCL)[(Muthuswamy Pandian et al., 2022; Ramakrishnan et al., 2023)](https://paperpile.com/c/BKSPYf/Y1CHf+N3LIs). Unlike conventional antibiotics that target specific cellular functions, the composite induces multifaceted damage to microbial cells, making it difficult for microorganisms to develop resistance .[(Raneesh & Visakh, 2021)](https://paperpile.com/c/BKSPYf/ToAVs)

## Biocompatibility and Safety Profile

An essential aspect of developing new antimicrobial agents is ensuring their biocompatibility and safety for human applications.[(Sreevarun et al., 2023)](https://paperpile.com/c/BKSPYf/tekXu) Preliminary cytotoxicity studies indicated that the Mo2C-Bi2S3 composite exhibits minimal toxicity towards mammalian cells at concentrations effective against microbial pathogens.[(Zhou et al., 2014)](https://paperpile.com/c/BKSPYf/XOPG8) This suggests that the composite can be safely used in biomedical applications, such as coatings for medical devices and wound dressings .[(Weerarathna et al., 2023)](https://paperpile.com/c/BKSPYf/4rJAo)

## Future Directions and Applications

The results of this study open up new avenues for investigation into the Mo2C-Bi2S3 composite's potential uses in biomedicine (Tuluwengjiang et al., 2024).Future studies could focus on optimizing the synthesis process to enhance the composite's antimicrobial properties and exploring its efficacy in in vivo models. Additionally, investigating the potential of this composite in treating biofilm-associated infections, which are notoriously difficult to eradicate with conventional treatments, could yield valuable insights.[(Chadwick & Goode, 2008)](https://paperpile.com/c/BKSPYf/g5mol)The Mo2C-Bi2S3 composite demonstrates a promising antimicrobial efficacy with a broad spectrum of action, minimal toxicity, and a reduced potential for resistance development. These attributes position it as a valuable candidate for next-generation antimicrobial agents in biomedical applications.

# CONCLUSION

The molybdenum carbide (Mo2C) - bismuth metal sulphide (Bi2S3) composite represents a significant advancement in antimicrobial technology with its demonstrated broad-spectrum efficacy against various pathogenic microorganisms. The superior antimicrobial activity of this composite is attributed to its enhanced generation of reactive oxygen species (ROS) and effective adsorption properties, which collectively contribute to the destruction of microbial cells through multifaceted mechanisms.

Unlike traditional antimicrobial agents, which face challenges related to resistance development, the Mo2C-Bi2S3 composite offers a robust alternative due to its unique mode of action that mitigates the risk of resistance. Additionally, the composite shows minimal cytotoxicity towards mammalian cells, highlighting its potential for safe and effective use in biomedical applications.

# FUTURE SCOPE

To fully investigate the Mo2C-Bi2S3 composite's potential in practical applications, future studies should concentrate on improving its synthesis and scaling up.Investigating its efficacy in vivo and its performance against biofilm-associated infections will be crucial in establishing its viability as a next-generation antimicrobial agent. Overall, the Mo2C-Bi2S3 composite holds great promise for advancing antimicrobial technology and improving infection control in various biomedical contexts.

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