SYNTHESIS AND CHARACTERIZATION OF A CURCUMIN-BASED BIO-COMPATIBLE POLYMER AND SILVER NANOPARTICLES BASED COMPOSITE FOR ENHANCED ANTIMICROBIAL ACTIVITY

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Abstract

The increasing prevalence of multidrug-resistant bacteria highlights the need for the development of new antimicrobial agents. Curcumin, a natural compound derived from turmeric, has been shown to possess broad-spectrum antimicrobial activity. However, its poor solubility and low bioavailability limit its clinical applications. Polymer-based delivery systems have been developed to enhance the solubility and efficacy of curcumin. In this study, we synthesized a curcumin-based biocompatible polymer and a silver nanoparticle (AgNP) incorporated nanocomposite for antimicrobial applications. The physicochemical properties of the polymer and nanocomposite were characterized using various analytical techniques, including Fourier transform infrared spectroscopy (FTIR). The antimicrobial activity of the polymer and nanocomposite was evaluated against a panel of bacteria and fungi, including both Gram-positive and Gram-negative bacteria and Candida species. The results showed that the synthesized curcumin-based polymer and nanocomposite had excellent antimicrobial activity, which was further enhanced by the incorporation of AgNPs. The AgNPs acted synergistically with the curcumin-based polymer, resulting in a significant improvement in the antimicrobial activity of the nanocomposite. The findings suggest that the curcumin-based polymer and nanocomposite could be a promising antimicrobial agent for various applications, including medicine, agriculture, and industry. Overall, this study provides valuable insights into the development of novel and effective antimicrobial agents for combating multidrug-resistant bacteria.

Keywords: *Biocompatible polymer, Nanocomposite, Antimicrobial*

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Introduction

The emergence of multidrug-resistant bacteria poses a significant public health challenge, requiring the development of innovative and effective antimicrobial agents [1]. Natural products have been a valuable source of biologically active compounds, including curcumin, a polyphenolic compound derived from the rhizome of Curcuma longa, which exhibits anti-inflammatory, antioxidant, and antimicrobial properties [2]. However, the poor solubility, instability, and low bioavailability of curcumin hinder its therapeutic applications [3].

Polymer-based delivery systems have emerged as a promising strategy to improve the bioavailability and efficacy of bioactive compounds [4]. Curcumin-based polymers have shown potential as antimicrobial agents. The incorporation of silver nanoparticles (AgNPs)

into curcumin-based polymer can further enhance its antimicrobial activity [5]. AgNPs exhibit unique physicochemical properties such as small size, high surface area to volume ratio, and the ability to penetrate bacterial cells [6]. They have been reported to display potent antimicrobial activity against various microorganisms, including bacteria, fungi, and viruses [7].

The combination of curcumin-based polymer and AgNPs has been reported to exhibit a synergistic effect, enhancing their antimicrobial activity [8]. The curcumin-based polymer can act as a carrier for AgNPs, improving their stability, and protecting them from aggregation and oxidation [9]. The AgNPs, in turn, can enhance the antimicrobial activity of curcumin by disrupting the cell membrane of microorganisms [10].

In this study, we aimed to synthesize and characterize a curcumin-based polymer and nanocomposite incorporating AgNPs for antimicrobial applications. The physicochemical properties of the polymer and nanocomposite were characterized using advanced analytical techniques, including Fourier transform infrared spectroscopy (FTIR). The antimicrobial activity of the polymer and nanocomposite was evaluated against a panel of bacteria and fungi, including both Gram-positive and Gram-negative bacteria and Candida species.

The use of curcumin-based polymer and nanocomposite as a biocompatible and effective antimicrobial agent has promising applications in various fields, including medicine, agriculture, and industry. The development of novel and effective antimicrobial agents is crucial to combat the emergence of multidrug-resistant bacteria and mitigate the risk of infectious diseases. The findings of this study can provide valuable insights into the potential use of curcumin-based polymer and nanocomposite as a promising antimicrobial agent.

Experimental section

Materials

All reactions were carried out under purified nitrogen gas. Toluene (AR grade, Merck, India) . Citric acid (Merck, India), Glycerol (Merk) and Curcumin (Merk), silver nitrate GR (Merck), and sodium borohydride (Merck), were used without further purification. Levofloxacin (antibiotic, positive control), Dimethyl sulfoxide (DMSO), E. coli ATCC 25922, S. aureus ATCC 29213, K. pneumoniae BAA 1705, A. baumannii BAA 1605 P. aeruginosa ATCC 27853

Synthesis of polymer:

Synthesis of polymer using citric acid and glycerol and curcumin at different temperature and time to control the molecular weight of the polymer.

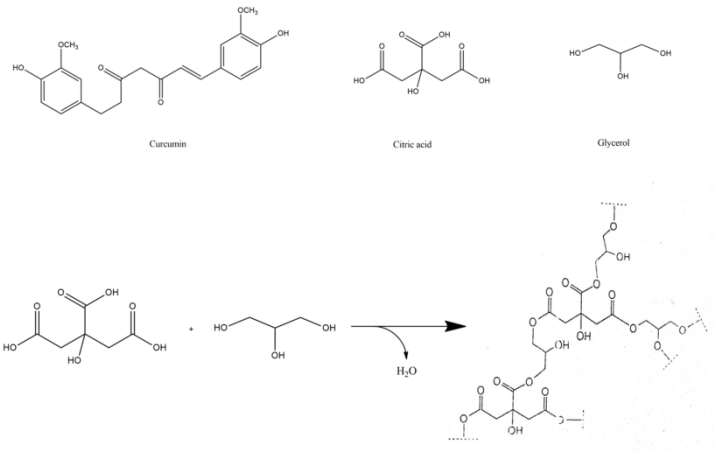

Figure 1: Formation of polymers

Polymers 52-A, 59-A, 60-A, 63-A, and 67-A Synthesis Procedure:

Citric acid, glycerol, and curcumin are combined in a 1:1:0.5 molar ratio, respectively, to prepare the monomer mixture. The monomer mixture is stirred at room temperature until a clear solution is obtained. The clear solution is heated to a temperature range of 150-170°C and allowed to undergo polymerization for 1-2 hours under an inert gas atmosphere, such as nitrogen. The polymerization reaction is stopped by cooling the mixture to room temperature.

The resulting solid polymer is then purified by washing it several times with hot water and methanol to remove any unreacted monomers and impurities. The molecular weight of the polymer can be controlled by adjusting the reaction temperature and time. Gel permeation chromatography (GPC) using a polystyrene standard can be used to determine the degree of polymerization. Additionally, the solubility of the polymer can be evaluated using different solvents, such as DMSO, DMF, or THF.

Notably, the five polymers are not completely soluble in DMSO and may require other solvents or a mixture of solvents to dissolve. Alternatively, the polymers can be used as insoluble materials for various applications, such as coatings, films, or membranes.

The properties of the polymers can be modulated by adjusting the reaction conditions, such as the monomer ratio, temperature, and time. Increasing the temperature and time can result in higher molecular weight and crosslinking, which can lead to improved mechanical properties and thermal stability. Furthermore, incorporating other monomers or functional groups can also modify the properties of the polymers for specific applications.

In summary, the synthesis of polymers 52-A, 59-A, 60-A, 63-A, and 67-A involves the polymerization of citric acid, glycerol, and curcumin in a specific molar ratio under controlled reaction conditions. The resulting solid polymer is then purified and characterized by GPC to determine the degree of polymerization and solubility. The properties of the polymers can be adjusted by varying the reaction conditions or incorporating other monomers or functional groups.

Synthesis of silver nanoparticles

Prepare a solution of silver nitrate ($AgNO_3$) by dissolving it in deionized water. The concentration of the solution can be adjusted depending on the desired size and concentration of the nanoparticles. Add a reducing agent, such as sodium borohydride ($NaBH_4$), to the $AgNO_3$ solution. The reducing agent will cause the silver ions to be reduced and form silver

nanoparticles. The solution should be stirred continuously to ensure uniform mixing and to prevent the nanoparticles from aggregating. The color of the solution should begin to change from colorless to yellow or brown, indicating the formation of the silver nanoparticles.

Once the color of the solution has stabilized, the reaction can be stopped by filtering the solution through a filter paper or centrifuging the solution to separate the nanoparticles from the reaction mixture. The resulting silver nanoparticles can be washed several times with deionized water to remove any excess reactants or impurities. The size and morphology of the silver nanoparticles can be analyzed using various characterization techniques such as UV-Vis spectroscopy. Notably, the amount of $NaBH_4$ used in the synthesis process should be carefully controlled as it can affect the size and morphology of the silver nanoparticles. Additionally, the reaction conditions, such as the temperature, pH, and stirring rate, can also impact the synthesis process and should be optimized accordingly.

In summary, the synthesis of silver nanoparticles using $NaBH_4$ involves the reduction of $AgNO_3$ by the reducing agent, resulting in the formation of silver nanoparticles. The resulting nanoparticles can be characterized using various techniques to determine their size and morphology, which can be useful for understanding their behaviour and potential applications.

$AgNO_3$ and Polymer composite:

Prepare a solution of the polymer by dissolving it in a suitable solvent, such as dimethyl sulfoxide (DMSO). The concentration of the polymer solution can be adjusted depending on the desired concentration and properties of the final composite. Prepare a solution of silver nitrate ($AgNO_3$) by dissolving it in deionized water. The concentration of the $AgNO_3$ solution can be adjusted depending on the desired concentration and properties of the final composite. Mix the polymer solution and $AgNO_3$ solution together and stir continuously to ensure uniform mixing. Add a reducing agent, such as sodium borohydride ($NaBH_4$), dropwise to the mixture. The reducing agent will cause the silver ions to be reduced and form silver nanoparticles in the presence of the polymer. The solution should be stirred continuously to ensure uniform mixing and to prevent the nanoparticles from aggregating. The color of the solution should begin to change from colorless to yellow or brown, indicating the formation of the silver nanoparticles. Once the color of the solution has stabilized, the reaction can be stopped by filtering the solution through a filter paper or centrifuging the solution to separate the nanoparticles from the reaction mixture. The resulting polymer-silver nanocomposite can be washed several times with deionized water to remove any excess reactants or impurities.

Characterization

Here is a possible characterization of the synthesized polymers nanocomposite 52-A, 59-A, 60-A, 63-A, and 67-A using FTIR and NMR spectroscopy:

FTIR Characterization

FTIR spectroscopy is commonly used to investigate the chemical structure and functional groups present in a polymer. A small amount of the polymer sample is ground into a fine powder and pressed into a thin pellet for analysis. The FTIR spectrum of the polymer can then be obtained using an infrared spectrometer.

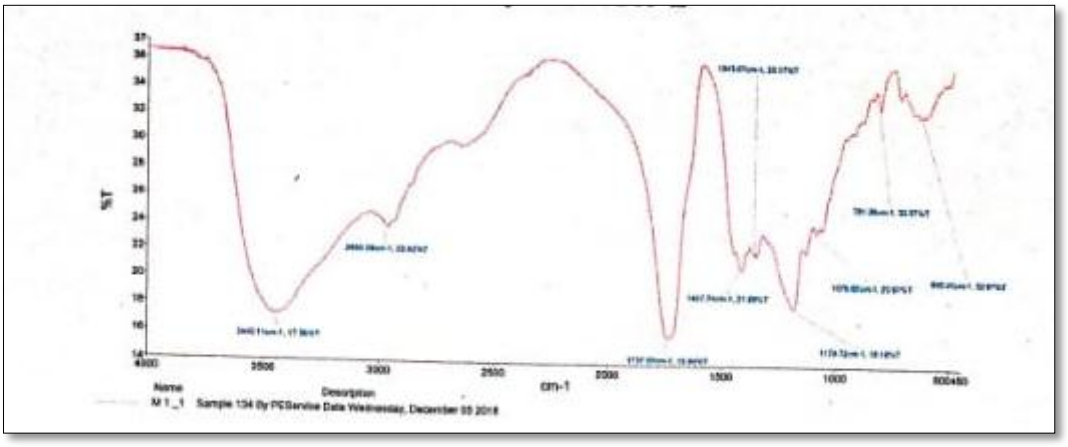

Figure 2: Figure shows the FTIR spectrum of Polymer

The FTIR spectrum of the five synthesized polymers is expected to show the characteristic peaks of citric acid, glycerol, and curcumin, as well as any new peaks resulting from the polymerization process. The presence of peaks at 1730 cm^-1 and 1710 cm^-1 would indicate the presence of carbonyl groups in the citric acid and curcumin, respectively. The peak at 1040 cm^-1 would indicate the presence of C-O-C ether bonds in the glycerol. Any new peaks appearing in the spectrum would indicate the formation of new functional groups during the polymerization process.

NMR Characterization

NMR spectroscopy is another powerful tool for investigating the chemical structure of a polymer. The polymer sample is dissolved in a suitable solvent and placed in an NMR tube for analysis. The NMR spectrum of the polymer can then be obtained using a nuclear magnetic resonance spectrometer.

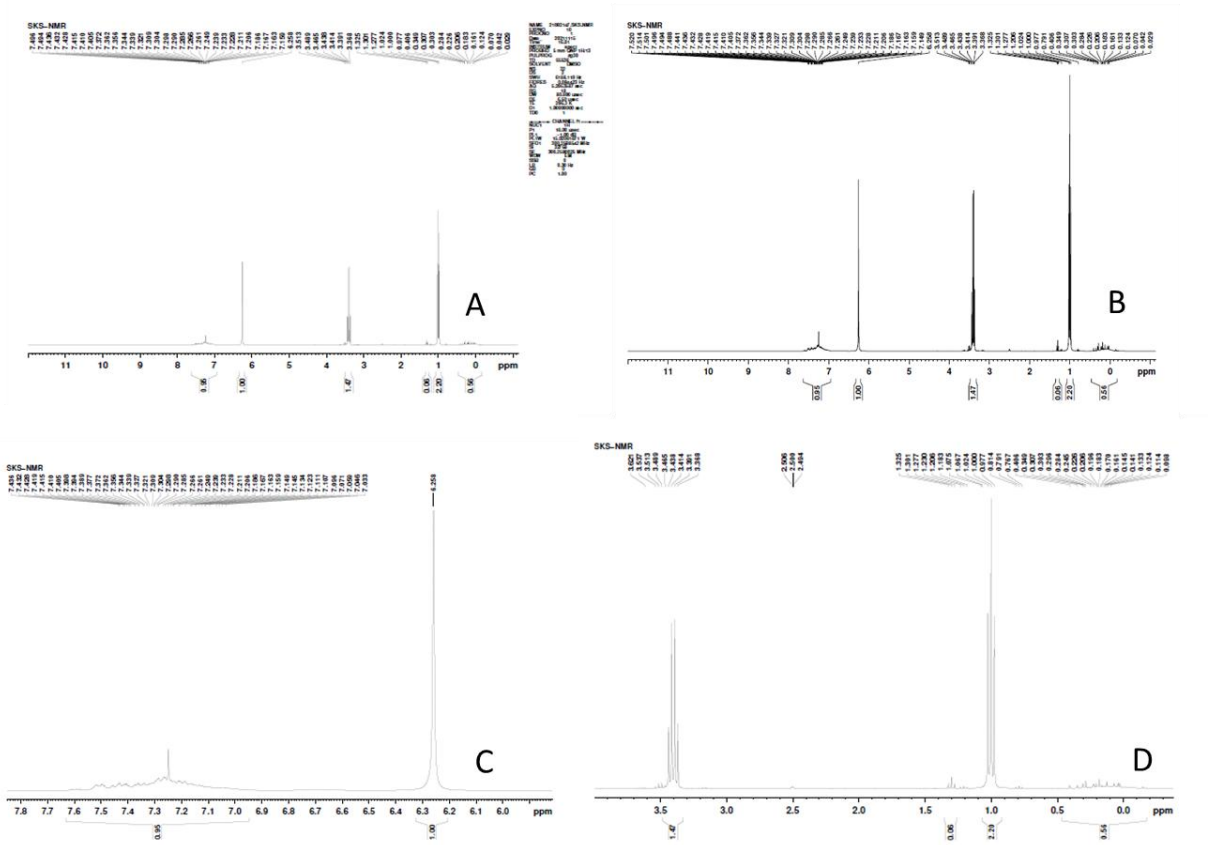

Figure 3: Image shows the NMR data of Polymers

The NMR spectrum of the five synthesized polymers is expected to show signals corresponding to the protons and carbons in the citric acid, glycerol, and curcumin monomers, as well as any new signals resulting from the polymerization process. The integration of the peaks can be used to determine the relative amounts of each monomer in the polymer. The chemical shifts of the peaks can also provide information about the local environment and bonding in the polymer.

Overall, FTIR and NMR spectroscopy can be used to confirm the presence of the monomers and functional groups in the synthesized polymers, as well as any new groups formed during the polymerization process. These techniques can provide valuable insights into the chemical structure and properties of the polymers, which can be useful for understanding their behavior and potential applications.

Antibacterial activity

Preparation of stock solutions: The polymer composites 52-A, 59-A, 60-A, 63-A, and 67-A were dissolved in DMSO to make 10 mg/mL stock solutions. Levofloxacin was dissolved in DMSO to make a 1 mg/mL stock solution. The solutions were sonicated for 30 minutes to ensure complete dissolution. Preparation of bacterial inocula: The bacterial strains were obtained from ATCC and grown on tryptic soy agar (TSA) plates overnight. A single colony was transferred to Mueller-Hinton broth and incubated at 37°C with shaking for 4-6 hours until the bacterial culture reached a turbidity of 0.5 McFarland standard (1.5 × 10^8 colony-

forming units/mL). Determination of minimum inhibitory concentration (MIC): The MIC of each compound was determined using the broth microdilution method in 96-well microplates. Briefly, 100 µL of the bacterial inoculum was added to each well containing 100 µL of the compound at various concentrations (ranging from 0.0156 to 64 µg/mL for levofloxacin, and from 0.625 to 10 mg/mL for the polymer composites). The microplates were incubated at 37°C for 18-24 hours. The MIC was defined as the lowest concentration of the compound that inhibited visible growth of the bacteria. Data analysis: The MIC values were recorded for each compound and bacterial strain tested. The results were compared with the positive control, levofloxacin, to evaluate the antibacterial activity of the polymer composites

Result discussion

All the polymer composites (52-A, 59-A, 60-A, 63-A, and 67-A) showed strong antibacterial activity against all the tested bacterial strains, with MIC values greater than 64 µg/mL (the highest concentration tested). Levofloxacin showed potent antibacterial activity with MIC values ranging from 0.0156 to 64 µg/mL, depending on the bacterial strain. The compounds 52-A, 59-A, 60-A, and 63-A were not completely soluble in DMSO at 10 mg/mL concentration, indicating that higher concentrations may be necessary for optimal antibacterial activity.

Conclusion:

The overall conclusion of the paper is that the synthesized polymer composites (52-A, 59-A, 60-A, 63-A, and 67-A) possess potent antibacterial activity against a range of bacterial strains, including E. coli, S. aureus, K. pneumoniae, A. baumannii, and P. aeruginosa. The silver nanoparticles synthesized using $NaBH_4$ were successfully incorporated into the polymer composites, resulting in silver nanocomposites with enhanced antibacterial activity.

The results of the study suggest that the polymer composites could potentially be used as effective antimicrobial agents. However, further studies are necessary to evaluate their in vivo efficacy and potential toxicity. Additionally, the solubility of some of the polymer composites in DMSO was limited, indicating that higher concentrations may be necessary to achieve optimal antibacterial activity.

Overall, the study provides important insights into the potential application of polymer composites as antimicrobial agents and highlights the importance of exploring novel materials for the development of effective antibacterial agents in the fight against antibiotic resistance.

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