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Development and Characterization of Chitosan/PVA Hydrogel Composite with Green-Silver Nanoparticles

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Abstract
This study reports the green synthesis of silver nanoparticles (AgNPs) using banana peel extract (BPE) and their incorporation into chitosan/polyvinyl alcohol (C/PVA) hydrogel composites to enhance antibacterial activity and mechanical stability. AgNPs were synthesized using 5.0 mM $AgNO_3$ and 180 mL BPE, and were incubated at 70°C for 72 hours. The successful formation of AgNPs was confirmed by UV-Vis spectroscopy, which exhibited a surface plasmon resonance peak at 430 nm. Additionally, FTIR analysis identified the functional groups responsible for nanoparticle reduction and stabilization. C/PVA-BPE-AgNP hydrogels were fabricated at varying nanoparticle concentrations (0.5%, 2.5%, and 5.0%) via freeze-thaw crosslinking. Characterization through FTIR and swelling studies revealed that increasing AgNP concentration reduced swelling capacity, indicating a denser, more cross-linked hydrogel network. Antibacterial assays against *Escherichia coli* and *Staphylococcus aureus* showed clear inhibition zones, demonstrating enhanced antimicrobial efficacy. These findings suggest that green-synthesized AgNPs effectively improve the functional properties of C/PVA hydrogels, highlighting their potential for biomedical applications such as wound dressings or antibacterial coatings.
Keywords: green synthesis; silver nanoparticles; chitosan/PVA hydrogel; antibacterial activity; banana peel extract

Introduction

Silver nanoparticles (AgNPs), typically measuring between 1 and 100 nm, are widely known for their powerful antimicrobial properties. Their large surface area-to-volume ratio boosts interactions with microbial cells, enabling them to disrupt bacterial membranes and produce reactive oxygen species (ROS), ultimately causing cell death (Fagbemi, 2023). These qualities make AgNPs particularly useful in biomedical applications, especially in wound care, where preventing infections is essential (Tuzyuk & Pokryshko, 2022).

Despite their advantages, conventional synthesis methods of AgNPs involve hazardous chemicals and high energy consumption, raising environmental and health concerns. In response, green synthesis has emerged as a sustainable alternative, utilizing plant extracts rich in phytochemicals, such as flavonoids, tannins, and saponins, to act as reducing and stabilizing agents (Ibrahim, 2015). Banana peel extract (BPE), an agro-waste material, has shown promising potential in this context due to its natural abundance and rich bioactive content (Bankar et al., 2010; Isa, 2024).

Hydrogels, particularly those composed of chitosan and polyvinyl alcohol (C/PVA), are excellent candidates for wound dressing materials due to their high-water retention, biocompatibility, and flexibility (Wang et al., 2021; Khan & Rumon, 2025). Chitosan offers additional antibacterial and biodegradable properties (Nagahama, 2009), while PVA provides mechanical strength and stability

(Luthfianti et al., 2023). When combined using the freeze-thaw method, these polymers form physically cross-linked hydrogels, which are ideal for biomedical applications (Mounayer et al., 2025).

This study aims to develop and characterize C/PVA hydrogel composites embedded with BPE-synthesized AgNPs. By investigating their structural, swelling, and antibacterial properties, the research evaluates their potential as eco-friendly, biocompatible materials for advanced wound care.

Materials and methods

Preparation of Banana Peel Extract

Fresh banana peels were washed, oven-dried at 70°C for 72 hours, and ground into a powder. 41.6 g of the powder was mixed with 500 mL of ultrapure water, heated at 80°C for 1 hour, cooled to room temperature, and filtered using Whatman No. 1 filter paper to obtain the BPE.

Green Synthesis of Silver Nanoparticles (BPE-AgNPs)

180 mL of BPE was mixed with 1,500 mL of 5.0 mM $AgNO_3$ solution and incubated at 60°C for 72 hours. A visible color change indicated nanoparticle formation. The solution was centrifuged at 10,000 rpm for 30 minutes (×2), and the resulting pellets were dried at 80°C for 24 hours.

Characterization of BPE-AgNPs

UV-Vis spectroscopy was performed to confirm the synthesis of nanoparticles, characterized by a surface plasmon resonance peak at 430 nm. FTIR spectroscopy was conducted to identify functional groups involved in reduction and stabilization.

Preparation of Chitosan/PVA (C/PVA) Hydrogel with BPE-AgNPs

1 g chitosan and 1 g PVA were separately dissolved in 50 mL of ultrapure water, mixed together, and supplemented with a few drops of acetic acid and 100 µL of glutaraldehyde. After stirring for 4 hours, BPE-AgNPs were incorporated at 0.5%, 2.5%, and 5.0% (w/w). The mixtures were subjected to seven freeze-thaw cycles (−20 °C for 20 h, followed by thawing at room temperature for 8 h) to form cross-linked hydrogels.

Characterization of C/PVA-BPE-AgNP Hydrogels

FTIR spectroscopy was used to confirm the integration of AgNPs into the hydrogel network. Water swelling behaviour was assessed by immersing samples in acetate buffer (pH 5.5) at 37 °C for 5 min, 1 h, and 24 h, and the swelling ratio was calculated using the standard formula.

Antibacterial Assay

Mueller-Hinton Agar (MHA) was prepared and inoculated with *Escherichia coli* and *Staphylococcus aureus*. Hydrogel discs (6 mm diameter) were placed on the agar surface, and the plates were incubated at 37°C for 24 hours. Zones of inhibition were measured to assess antibacterial activity.

Results and discussion

Synthesis and Characterization of BPE-AgNPs

Figure 1 shows that the successful formation of silver nanoparticles (AgNPs) was initially indicated by a colour change from pale yellow to dark brown after 72 hours of incubation with banana peel extract (BPE), signifying the reduction of Ag^+ ions to elemental Ag^0. This was further confirmed by UV-Vis spectroscopy, which showed a distinct surface plasmon resonance (SPR) peak at 430 nm, a hallmark of stable AgNPs.

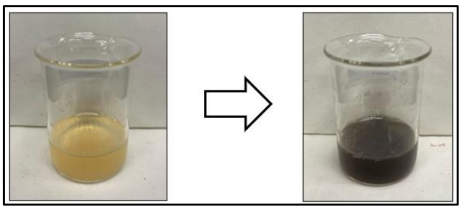


Figure 1 The colour changes of BPE-AgNPs from yellowish to dark brown after 72 hours of incubation at 70°C with concentrations of $AgNO_3$ 5.0 mM

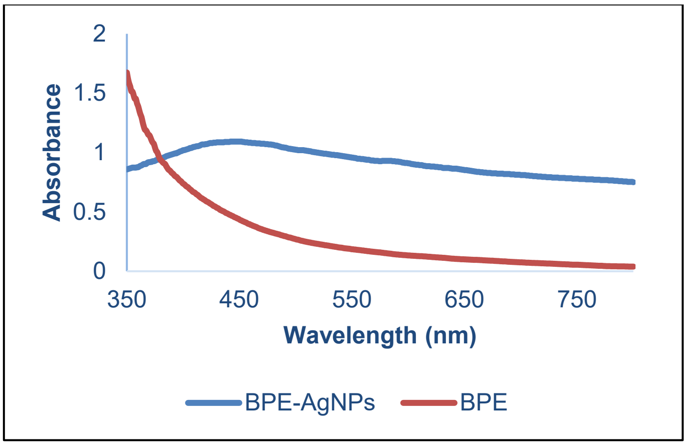


Figure 2 Absorption spectra of banana peel extract (BPE) and synthesized BPE-AgNPs using 5.0 mM $AgNO_3$ solution

FTIR analysis in Figure 3 revealed key functional groups involved in nanoparticle synthesis. Peaks corresponding to hydroxyl (–OH), carbonyl (C=O), and aromatic (C=C) groups in BPE were diminished in the BPE-AgNPs spectrum, indicating their active participation in the reduction and stabilization process. These findings confirm the dual role of BPE as a reducing and stabilizing agent in the green synthesis of AgNPs.

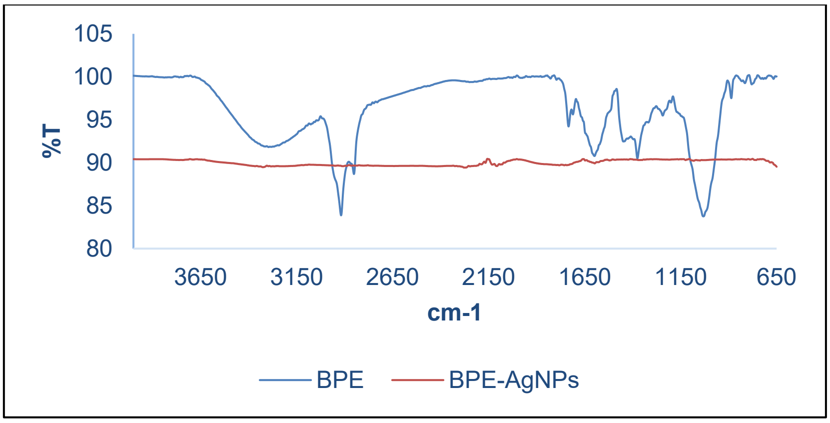


Figure 3 FTIR spectra of BPE-AgNPs

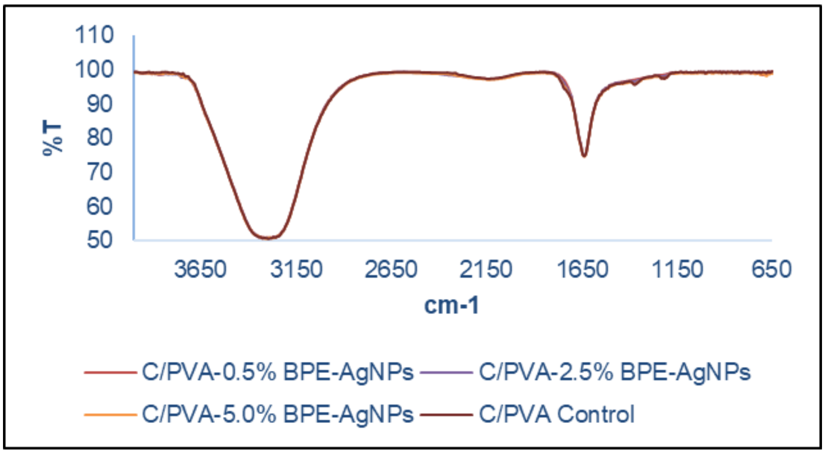


Figure 4 FTIR spectra of C/PVA hydrogel and C/PVA hydrogel with different ratios of BPE-AgNPs; 0.5%, 2.5% and 5.0%

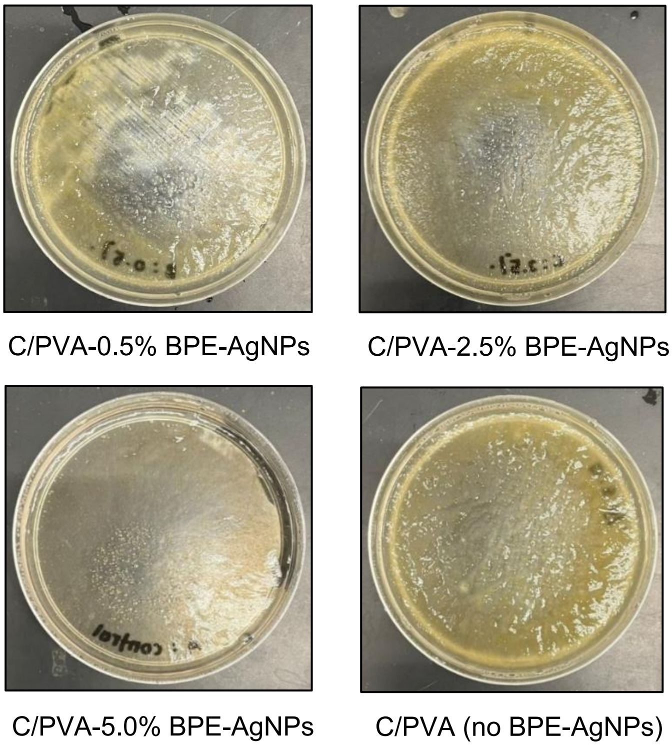


Figure 5 The solidification of C/PVA-BPE-AgNPs hydrogels after seven cycles of freeze-thaw process

Water Swelling Behaviour

Swelling studies (Figure 6) revealed that all hydrogel samples exhibited time-dependent water absorption. However, the swelling percentage decreased with increasing BPE-AgNP concentration. The control hydrogel showed the highest swelling (≈100% at 24 h), while the 5.0% AgNP hydrogel showed the lowest (≈40%). This inverse correlation reflects a denser, cross-linked structure and reduced porosity due to the presence of nanoparticles, which limits water uptake. Such controlled swelling behaviour is beneficial for wound dressing applications as it prevents excessive fluid retention.

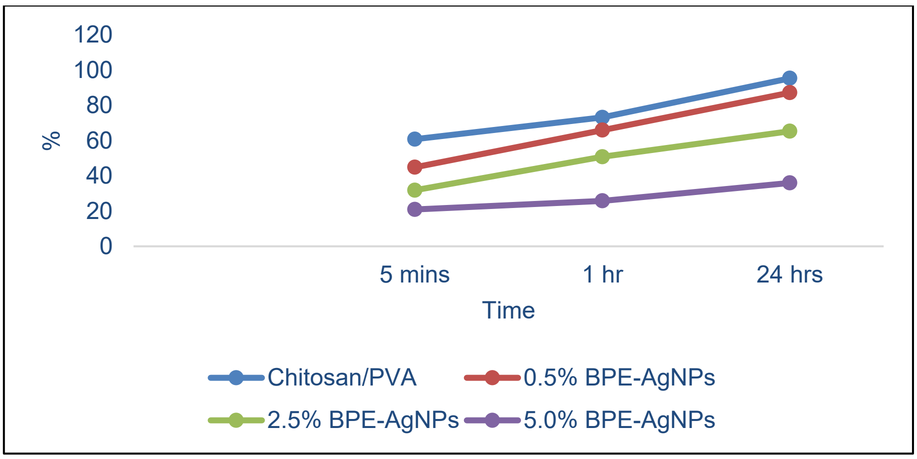
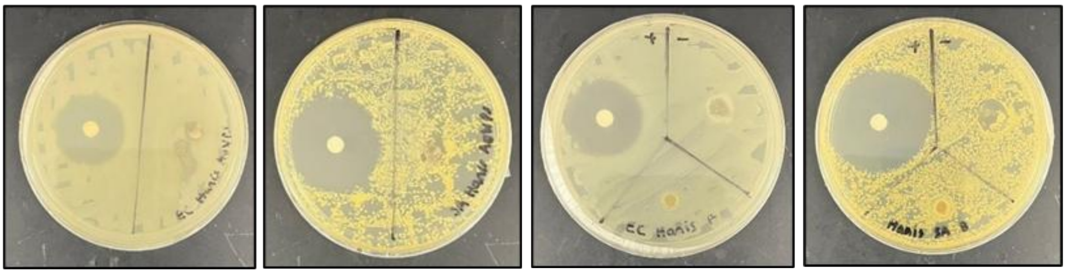


Figure 6 Water swelling (%) of chitosan/PVA hydrogels with varying concentrations of BPE-AgNPs over time (5 minutes, 1 hour, and 24 hours)

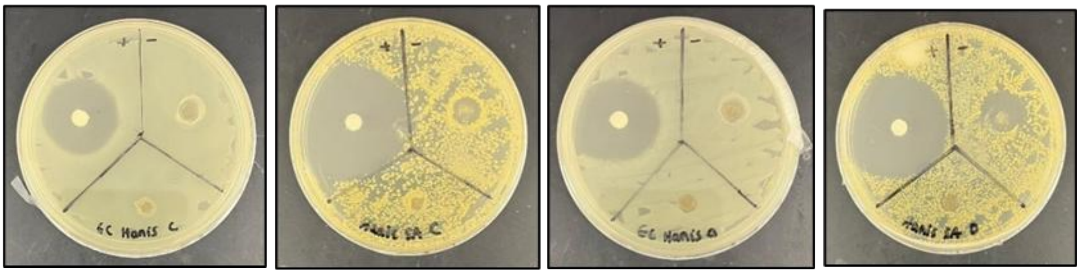
Antibacterial Activity

Disc diffusion assays demonstrated that C/PVA-BPE-AgNPs hydrogels exhibited concentration-dependent antibacterial activity against *E. coli* and *S. aureus*. The control hydrogel showed no inhibition, while the 5.0% AgNP hydrogel displayed the largest inhibition zones (8 mm for *E. coli* and 17 mm for *S. aureus*), highlighting the enhanced antibacterial efficacy of the nanoparticle-loaded hydrogels. The stronger activity against *S. aureus* may be attributed to differences in bacterial cell wall structure, with Gram-positive bacteria generally being more susceptible to AgNPs.

Figure 7 confirms that integrating green-synthesized AgNPs into the C/PVA matrix not only reinforces the hydrogel structure but also imparts significant antimicrobial properties, positioning the composite as a promising candidate for biomedical applications.



BPE-AgNPs Chitosan/PVA-0.5% BPE-AgNPs



Chitosan/PVA-2.5% BPE-AgNPs Chitosan/PVA-5.0% BPE-AgNPs

Figure 7 Zone of inhibition on *E. coli* and *S. aureus*

Table 1: Diameter of inhibitory zone of C/PVA hydrogel and C/PVA-BPE-AgNPs hydrogels by disc diffusion technique on *E. coli* and *S. aureus*

Samples	Inhibitory Zone (mm)	
	E. coli	*S. aureus*
Positive Control: Kanamycin sulphate	27.50	38.50
Negative Control: Chitosan/PVA Hydrogel	0.00	0.00
BPE-AgNPs	7.00	10.00
Chitosan/PVA-0.5% BPE-AgNPs	5.00	7.00
Chitosan/PVA-2.5% BPE-AgNPs	6.00	9.00
Chitosan/PVA-5.0% BPE-AgNPs	8.00	17.00

Conclusion

This study demonstrated the green synthesis of silver nanoparticles (AgNPs) using banana peel extract (BPE) and their integration into chitosan/polyvinyl alcohol (C/PVA) hydrogels. BPE-AgNPs were confirmed via UV-Vis and FTIR spectroscopy, highlighting natural phytochemicals' role in reducing and stabilizing silver ions. Incorporating BPE-AgNPs resulted in a denser, more cross-linked polymer network, evidenced by reduced swelling and increased rigidity. The composite hydrogels showed significant antibacterial activity against E. coli and S. aureus, especially at higher AgNP levels, indicating strong potential for biomedical use.

Acknowledgement

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