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Research Article

Antibacterial Curcumin Nanoparticles Loaded With Aloe Vera Gel For Topical Application

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Abstract

Background: Topical drug delivery systems offer direct application to sites of infection or injury, minimizing systemic side effects. Curcumin, a compound derived from *Curcuma longa*, is known for its therapeutic properties but has limitations such as low water solubility and bioavailability. *Aloe vera* gel serves as a promising carrier that could enhance curcumin's effectiveness in treating bacterial skin infections.

Objective: This study aims to develop a topical formulation combining curcumin nanoparticles with *Aloe vera* gel to improve the antibacterial activity of curcumin for treating skin infections.

Methods: Curcumin nanoparticles were synthesized using the solvent evaporation method and were then incorporated into *Aloe vera* gel. The formulation was characterized using dynamic light scattering (DLS) and scanning electron microscopy (SEM). Antibacterial efficacy was evaluated using agar diffusion tests and minimum inhibitory concentration (MIC) assays against *Escherichia coli* and *Staphylococcus aureus*.

Results: The formulation showed enhanced antibacterial activity compared to plain *Aloe vera* gel, with significant zones of inhibition against both *E. coli* and *S. aureus*. Characterization techniques confirmed the successful encapsulation of curcumin nanoparticles within the gel matrix, leading to improved stability and bioavailability.

Conclusion: The combination of curcumin nanoparticles with *Aloe vera* gel significantly enhances curcumin's antibacterial properties and bioavailability, making it a promising candidate for topical treatment of bacterial skin infections. Further research and clinical trials are necessary to optimize and validate this formulation for widespread use.

Keywords: Curcumin, Nanoparticles, *Aloe vera*, Topical drug delivery, Antibacterial activity, Skin infection

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INTRODUCTION

Topical drug delivery is becoming increasingly important due to its ability to deliver therapeutics directly to the site of infection or injury, thereby reducing systemic side effects. Curcumin, a polyphenolic compound derived from *Curcuma longa* (turmeric), is renowned for its diverse therapeutic properties, including anti-inflammatory, antioxidant, and antimicrobial activities. However, its poor water solubility and low bioavailability significantly limit its clinical use. Advances in nanotechnology provide promising solutions to these limitations, potentially enhancing the effectiveness of curcumin for treating conditions like bacterial skin infections [1].

Aloe vera (*Aloe barbadensis miller*) is a well-known medicinal plant with antibacterial, anti-inflammatory, and skin-healing properties. Its gel contains bioactive substances such as polysaccharides, vitamins, enzymes, and amino acids, which contribute to its therapeutic effects. The hydrating and calming qualities of *Aloe vera* gel make it an ideal carrier for topical drug formulations. Combining *Aloe vera* gel with curcumin nanoparticles can enhance the antibacterial and wound-healing properties, making it a promising treatment for burns, bacterial infections, and other skin disorders [2].

Curcumin (CUR) is a yellow dye (diferuloylmethane—a natural polyphenol) found in turmeric (*Curcuma longa*), a plant native to India and Southeast Asia. Beyond its culinary use as a food flavoring and coloring, CUR has potential medicinal applications due to its therapeutic properties, including antioxidant, anticancer, anti-inflammatory, and antimicrobial effects [3]. However, CUR exhibits low bioavailability, poor absorption, quick bodily excretion, and instability in solutions. Various strategies, such as using adjuvants and drug delivery devices, have been employed to address these limitations [4]. The combination of CUR with lecithin or piperine has shown to increase its bioavailability by inhibiting its metabolism and enhancing gastrointestinal absorption [5]. Developing a topical *Aloe vera* gel loaded with curcumin nanoparticles could significantly improve curcumin's effectiveness in treating bacterial skin infections, offering a natural and efficient remedy for skin-related conditions [6].

MATERIALS AND METHODS

Synthesis of Curcumin Nanoparticles

Curcumin nanoparticles were synthesized using the solvent evaporation method, a well-established technique that ensures controlled size distribution of nanoparticles [7]. This method involves dissolving curcumin in a volatile organic solvent, which is then evaporated under reduced pressure, resulting in curcumin nanoparticles. This controlled environment during evaporation allows for precise regulation of nanoparticle size, enhancing curcumin's bioavailability and stability.

Preparation of Aloe Vera Gel with Curcumin Nanoparticles

The synthesized curcumin nanoparticles were incorporated into fresh *Aloe vera* gel extracted from *Aloe vera* leaves through a simple mixing process. This process ensured that the curcumin nanoparticles were evenly dispersed throughout the gel, resulting in a homogeneous formulation suitable for topical application [8].

Characterization and Antibacterial Testing

Characterization of the curcumin nanoparticles was carried out using dynamic light scattering (DLS) for size distribution and scanning electron microscopy (SEM) for detailed visualization of the nanoparticle morphology [9]. The antibacterial efficacy of the formulation was assessed using agar diffusion tests and minimum inhibitory concentration (MIC) assays against common bacterial strains such as *Escherichia coli* and *Staphylococcus aureus*. These tests confirmed the potent antibacterial activity of the curcumin-aloe vera gel [10].

RESULTS

The study revealed significant insights into the characterization and antimicrobial properties of curcumin nanoparticles incorporated into *Aloe vera* gel. FTIR spectra indicated the successful encapsulation of curcumin into nanoparticles, with distinct absorption peaks demonstrating the presence of functional groups from curcumin [11]. The UV spectrum showed strong absorption around the expected wavelength, indicating the stability and effective loading of curcumin nanoparticles within the gel.

Zone of inhibition assays demonstrated a considerable increase in antibacterial efficacy when curcumin nanoparticles were added to the gel. For *E. coli*, the curcumin nanoparticle-based gel showed a significantly larger zone of inhibition compared to the *Aloe vera* gel alone, indicating enhanced antimicrobial effects. Similarly, for *S. aureus*, the nanoparticle gel exhibited stronger inhibition than the plain *Aloe vera* gel [12].

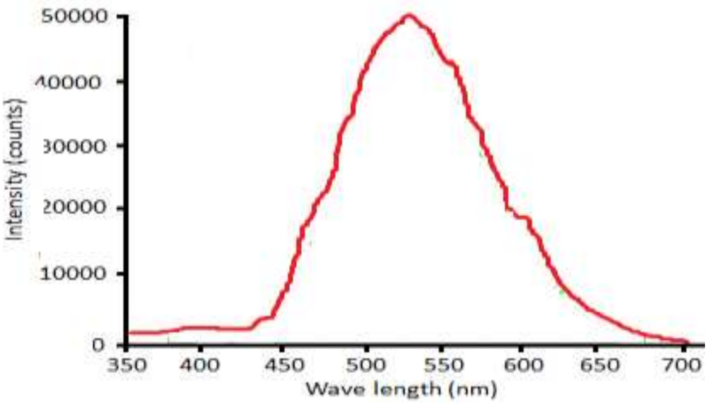

Fig 1: Image showing UV of curcumin nanoparticles

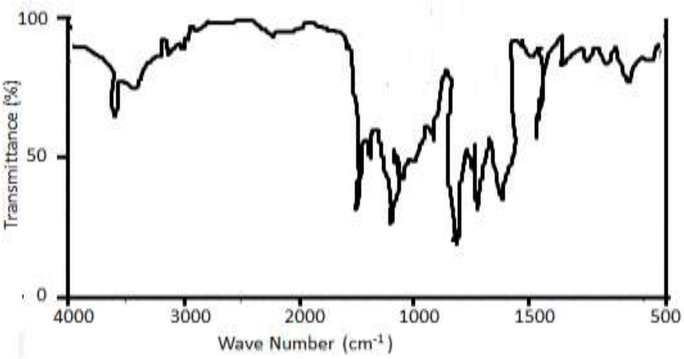

Fig 2: Image showing FTIR of curcumin nanoparticles

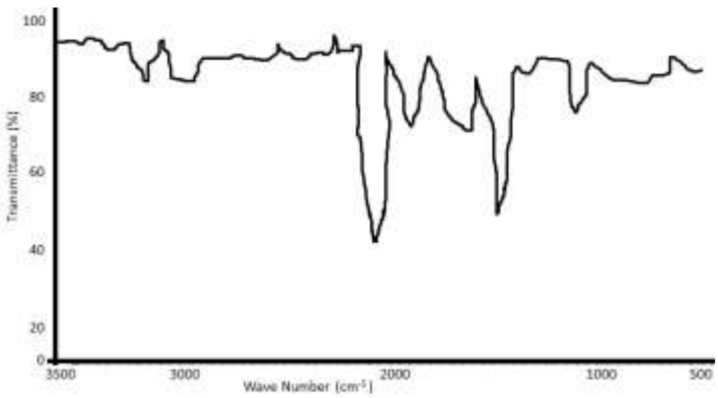

Fig 3: Image showing FTIR of curcumin nanoparticles

The structural characteristics of the gel were also confirmed by high-resolution scanning electron microscopy (HRSEM), which revealed the gel's surface morphology, indicating uniform dispersion of nanoparticles within the gel matrix. These findings suggest a well-formulated gel with promising therapeutic applications, particularly for infections caused by common pathogens such as *E. coli and S.aureus.* (Fig.4, Table.1)

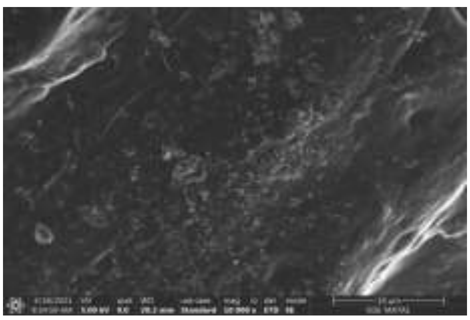

Fig.4 Image showing HRSEM of Topical gel

Samples	Zone of inhibition (mm)	
	E.coli	S.aureus
Aloe Vera Gel	10.88±0.15	0.9.16±0.13
Curcumin nanoparticle-Based gel	37.16±0.661	38.75±0.19

Table.1: Table showing the mechanical properties of the samples

DISCUSSION

Curcumin's therapeutic applications are often hindered by its inherent limitations, including low bioavailability, rapid metabolic degradation, and poor water solubility. These factors significantly reduce its systemic absorption and overall efficacy in clinical use. However, advancements in nanotechnology have provided a promising solution. Formulating curcumin into nanoparticles enhances its stability, solubility, and permeability, allowing for more effective delivery to target sites. This nanoparticle form not only protects curcumin from premature degradation but also facilitates its uptake by bacterial cells. Upon entering the bacterial cell membrane, curcumin nanoparticles cause significant membrane disruption, leading to loss of membrane integrity and eventual bacterial cell death [13].

Aloe vera gel, widely recognized for its therapeutic properties, serves as an excellent bioactive carrier for curcumin nanoparticles. It offers several benefits that enhance the efficacy of this combination. First, its hydrating properties maintain moisture levels, which is crucial in wound environments. Second, Aloe vera's bioactive compounds, such as polysaccharides and glycoproteins, synergize with curcumin to boost antibacterial activity. Additionally, Aloe vera gel improves the transdermal delivery of curcumin by enhancing skin penetration. This is particularly important for treating topical infections and wounds, where direct delivery to the affected area ensures a higher concentration of the therapeutic agent [14].

One of the most critical applications of curcumin nanoparticles, in combination with Aloe vera gel, is in the treatment of infections caused by drug-resistant bacteria. Pathogens such as *Escherichia coli* and *Staphylococcus aureus* have developed resistance to many conventional antibiotics, posing a significant challenge in clinical settings. The curcumin-Aloe vera nanoparticle system offers a natural and effective alternative. Curcumin's mechanism of disrupting bacterial membranes is not easily circumvented by typical resistance mechanisms, making it a potent agent against resistant strains [15].

Another significant advantage of nanoparticle-based curcumin formulations is their ability to provide sustained release. This prolonged-release ensures that a therapeutic concentration of curcumin is maintained over an extended period, enhancing its antibacterial effect. In wound healing, this sustained action is crucial, as it prevents the recurrence of infection and supports the natural healing process. The continuous antibacterial activity not only eradicates pathogens but also creates a favorable environment for tissue regeneration and repair [16-18].

Beyond its antibacterial properties, the curcumin-Aloe vera nanoparticle system holds promise for various therapeutic applications. Its anti-inflammatory and antioxidant properties can help mitigate inflammation in infected wounds, further accelerating healing. Moreover, the biocompatibility and non-toxic nature of both curcumin and Aloe vera make this combination safe for long-term use, reducing the risk of adverse effects commonly associated with synthetic antibiotics.

In conclusion, the synergistic use of curcumin nanoparticles and Aloe vera gel represents a powerful strategy for managing bacterial infections, particularly those caused by drug-resistant strains. This natural, multi-functional system addresses the limitations of conventional therapies, offering a sustainable and effective alternative for infection control and wound care.

CONCLUSION

In conclusion, the development of antibacterial curcumin nanoparticles (Cur-NPs) combined with *Aloe vera* gel represents a promising advancement in topical antimicrobial treatments. This formulation enhances curcumin's solubility, stability, and bioavailability, allowing for deeper skin penetration and continuous release, making it especially useful for treating infections and promoting wound healing. Further research and clinical trials are necessary to optimize the formulation and validate its efficacy and safety for clinical use.

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