RESEARCH PAPER

# Formulation and Antibacterial Evaluation of Chitosan-Coated Silver Nanoparticles Loaded Gel against Staphylococcus aureus Induced Skin Infection in Rats

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**ABSTRACT:**
Staphylococcus aureus skin infections are difficult to treat due to antibiotic resistance and delayed wound healing. Chitosan-coated silver nanoparticles (CS-AgNPs) improve biocompatibility, drug release, and antibacterial action. A CS-AgNP-loaded topical gel was developed and tested for its antibacterial activity against S. aureus-induced skin infection in rats. Chemically reduced silver nanoparticles were coated with chitosan for stability and antibacterial action. Nanoparticle size, zeta potential, entrapment effectiveness, and shape were measured. CS-AgNPs in Carbopol 934 gel bases were tested for pH, viscosity, spreadability, drug content, and in vitro release. Antibacterial activity against S. aureus was measured by agar well diffusion. The infected control, plain gel, marketed antibacterial gel, and CS-AgNP gel groups of Wistar rats (n = 24) formed an infected wound model. Over 14 days, wound contracture, bacterial burden, and histopathology were assessed. Optimised CS-AgNPs had a mean particle size of 112.6 ± 8.4 nm, polydispersity index of 0.221 ± 0.03, zeta potential of +31.8 ± 2.7 mV, and entrapment efficiency of 89.4. The gel has good physical properties, including pH 6.3 ± 0.2, viscosity 15,480 ± 265 cP, spreadability 6.8 ± 0.4 g·cm/s, and drug content of 98.2 ± 1.5%. Drug release experiments showed 87.6 ± 3.2% cumulative release within 24 hours in vitro. The CS-AgNP gel inhibited S. aureus more effectively (24.3 ± 1.2 mm) than the marketed gel (18.6 ± 1.0 mm, $p < 0.05$). In vivo investigations showed 96.2 ± 2.4% wound contraction in CS-AgNP-treated group by day 14 compared to 68.5 ± 4.1% in infected controls. Bacterial counts dropped by 71.6%, from 7.4 ± 0.3 log CFU/g tissue to 2.1 ± 0.2 log CFU/g tissue. Histopathological investigation showed increased re-epithelialization, collagen deposition, and reduced inflammatory cell infiltration in CS-AgNP gel-treated mice. The chitosan-coated silver nanoparticle-loaded gel showed outstanding physicochemical properties, robust S. aureus antibacterial activity, and improved infected wound healing in rats. These results indicate that CS-AgNP gel may be an effective topical treatment for bacterial skin infections and infected wounds. Previous studies have shown that silver nanoparticles and chitosan have synergistic antimicrobial action against S. aureus.

**Keywords:** Chitosan-coated silver nanoparticles, topical gel, *Staphylococcus aureus*, skin infection, antibacterial activity, wound healing, nanogel, drug delivery.
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## INTRODUCTION:

Staphylococcus aureus is among the most prevalent organisms that cause infections of the skin and soft tissues, which is a major concern for world health. Impetigo, cellulitis, abscesses, and infected wounds are only few of the many illnesses that it causes. Mycobacterium spp., which are resistant to many antibiotics, are becoming increasingly common, further complicating treatment options and calling for new, improved antimicrobial drugs [1, 2].

Because of its localized drug action, reduced systemic side effects, and improved patient compliance, topical drug delivery methods are commonly chosen for the treatment of skin infections. Among them, drug delivery systems based on nanoparticles have attracted a lot of interest because of their unusual physicochemical features, like a large surface area, improved permeability, and the capacity to regulate drug release [3]. For its powerful broad-spectrum antibacterial action, including efficacy against multidrug-resistant bacteria, silver nanoparticles (AgNPs) have been the focus of considerable research. Their activity is based on interfering with DNA replication, producing reactive oxygen species, and breaking the cell membranes of bacteria [4].

Aggregation, instability, and possible cytotoxicity are common problems with silver nanoparticles that restrict their clinical use despite their powerful antibacterial capabilities. Biopolymer coatings, like chitosan, have been used to circumvent these restrictions. The natural cationic polysaccharide chitosan has many useful characteristics, including antibacterial activity, biodegradability, wound healing abilities, and high biocompatibility. It is generated from chitin. In addition to enhancing the stability and dispersion of silver nanoparticles, coating them with chitosan gives them a synergistic antibacterial action, making them more effective therapeutically [5, 6].

Additional benefits for topical treatment include enhanced retention at the site of infection, simplicity of application, and prolonged drug release when chitosan-coated silver nanoparticles (CS-AgNPs) are included into an appropriate gel foundation. Gels derived from carbopol are ideal because they are compatible with a wide range of active agents, distribute easily, and do not irritate the skin [7, 8].

The purpose of this research was to create and characterize a gel that contained silver nanoparticles coated with chitosan. Then, using a rat model of skin infection caused by Staphylococcus aureus, we tested the gel's antibacterial activity. The study's overarching goal is to develop a new method of topical treatment for bacterial skin infections that is both successful and unique, with the added benefits of greater antibacterial activity and wound healing potential [9, 10].

## MATERIALS AND METHODS:

### Materials:

An recognized chemical vendor supplied the silver nitrate ($AgNO_2$). A certified vendor supplied the chitosan, which has a medium molecular weight and an 85% degree of deacetylation. A gelling agent called carbopol 934 was utilized. One of the reducing agents used was sodium borohydride, or $NaBH_4$. All reagents were utilized in their original form, including glacial acetic acid, triethanolamine, and others of analytical grade. Microbiological investigations made use of nutritional agar and broth. To test the efficacy of antibacterial agents, a clinical strain of Staphylococcus aureus was used.

### Preparation of Silver Nanoparticles (AgNPs):

The chemical reduction approach was used to manufacture silver nanoparticles. To recap, a solution of 1 mM silver nitrate in water was made and swirled constantly using magnetic stirring. Add a freshly made ice-cold sodium borohydride solution (2 mM) dropwise while stirring constantly. The creation of AgNPs was indicated by a shift in color from pale yellow to brown (Table 1), which occurred when the reaction mixture was kept at 4°C [11].

### Preparation of Chitosan-Coated Silver Nanoparticles (CS-AgNPs):

A 0.2% w/v chitosan solution was made by dissolving the powder in 1% v/v acetic acid while stirring. The chitosan solution was gradually added to the produced AgNPs while being constantly stirred. To achieve a homogenous coating of chitosan onto the nanoparticles, the mixture was agitated for an additional four to six hours. After being spun at 12,000 rpm for 20 minutes, the CS-AgNPs were rinsed with distilled water to extract any unbound components [12].

**Table 1: Formulation Trial Batches for AgNPs and CS-AgNPs**

| Batch Code | $AgNO_3$ Concentration (mM) | $NaBH_4$ Concentration (mM) | Chitosan (% w/v) | Acetic Acid ( | Stirring Time (h) | Temperature (°C) |
|---|---|---|---|---|---|---|

| | | | | % v/ v) | | |
|---|---|---|---|---|---|---|
| F1 | 1.0 | 1.0 | 0.1 | 1.0 | 4 | 4 |
| F2 | 1.0 | 2.0 | 0.1 | 1.0 | 4 | 4 |
| F3 | 1.0 | 2.0 | 0.2 | 1.0 | 5 | 4 |
| F4 | 1.0 | 2.0 | 0.3 | 1.0 | 6 | 4 |
| F5 | 1.5 | 2.0 | 0.2 | 1.0 | 5 | 4 |
| F6 | 1.0 | 2.5 | 0.2 | 1.0 | 5 | 4 |

**Characterization of CS-AgNPs:**

**Particle Size and Polydispersity Index (PDI):**

The produced silver nanoparticles coated with chitosan had their average particle size and polydispersity index (PDI) measured using the dynamic light scattering (DLS) method. To minimize the impact of multiple scattering, the nanoparticle dispersion was properly diluted with distilled water before analysis at 25°C. To measure the consistency and dispersion of the particles in the mixture, we utilized PDI values, and nanometers (nm) as the unit of measurement for average particle size [13].

**Zeta Potential:**

A zeta potential analyzer based on electrophoretic light scattering was used to measure the nanoparticles' zeta potential. Before being placed in a zeta cell for examination, the samples were diluted with distilled water. The millivolt (mV) zeta potential values were utilized to assess the nanoparticles' surface charge, stability, and dispersion properties [14].

**Entrapment Efficiency (%):**

The centrifugation method was used to measure the entrapment effectiveness of the silver nanoparticles coated with chitosan. To isolate the drug that was bound to the nanoparticles and the drug that was free, the suspension of nanoparticles was spun at 12,000 rpm for 20 minutes. We used spectrophotometry to determine how much free medicine was in the supernatant [15]. The following formula was used to compute the entrapment efficiency:

$$\text{Entrapment Efficiency (\%)} = \frac{\text{Total drug} - \text{Fr}}{\text{Total dru}}$$

**Morphological Analysis:**

Scanning electron microscopy (SEM) and transmission electron microscopy (TEM) were used to analyze the nanoparticles' surface appearance and structural properties. After a drop of the nanoparticle suspension was dropped onto a grid that was covered with carbon, it was dried in a vacuum and then examined under a microscope. We evaluated the aggregation behaviour, surface texture, and particle form using the acquired photos [16].

**Formulation of CS-AgNPs Loaded Gel:**

Carbopol 934 was dissolved in distilled water at a concentration of 1% w/w and left to hydrate for the night. Constant stirring was used to integrate the CS-AgNPs into the hydrated gel base. In order to create a uniform gel, triethanolamine was added dropwise to neutralize the dispersion and bring the pH down to around 6.0-6.5. Airtight containers were used to keep the finished mixture [17].

**Evaluation of Gel Formulation**

**Physical Appearance:**

The prepared gel underwent visual examination for color, homogeneity, consistency, and the presence of aggregates or phase separation. The gel was examined against both a white and black background to confirm homogeneity and the absence of particle debris [18].

**pH Determination:**

The pH of the gel composition was assessed with a calibrated digital pH meter. Approximately 1 g of gel was suspended in 10 mL of distilled water and permitted to equilibrate for 30 minutes. The electrode was subsequently submerged in the dispersion, and the pH was documented. All measurements were conducted in duplicate to ensure precision [19].

**Viscosity Measurement:**

We used a Brookfield viscometer with the right spindle to find out how thick the gel was. After being set aside to equilibrate at room temperature, the sample was transferred to a beaker. Readings were taken in centipoise (cP) while the rotational speed remained constant. The viscosity was then calculated. The experiments were run three times [20].

**Spreadability:**

The glass slide method was used to assess the gel's spreadability. The experiment involved sandwiching two glass slides with a given amount of gel in between and then applying a weight on the top slide. We timed how long it took for the upper slide to travel a specific distance [21]. The formula was used to calculate spreadability:

$$S = \frac{M \times L}{T}$$

Where $S$ is spreadability (g·cm/s), $M$ is the weight applied (g), $L$ is the length moved by the slide (cm), and $T$ is the time taken (s).

**Drug Content:**
The gel, which had a known mass of about 1 gram, was precisely measured and dissolved in an appropriate solvent. After passing the solution through a filter and diluting it as needed, it was examined at the specified wavelength using a UV-visible spectrophotometer. The proportion of drug content was determined by utilizing a calibration curve [22].

***In-Vitro* Drug Release Study:**
A Franz diffusion cell was used to conduct the in-vitro drug release study. The donor and receptor compartments were separated by an appropriate membrane, such as a dialysis membrane. The receptor compartment was kept at a constant temperature of 37 ± 0.5°C with constant stirring and filled with phosphate buffer (pH 7.4). The donor chamber was filled with a precise amount of gel. The conditions in the sink were maintained by withdrawing samples at specified intervals (up to 24 hours) and replacing them with new medium. The spectrophotometric analysis of the extracted samples allowed for the calculation of cumulative drug release [23].

***In-Vitro* Antibacterial Activity:**
The effectiveness against Staphylococcus aureus was assessed through the use of the agar well diffusion method. Bacterial suspension was added to sterile nutritional agar plates. Before filling the wells, CS-AgNP gel, plain gel, and the standard formulation were prepared. After 24 hours of incubation at 37°C, the zone of inhibition (in millimeters) was determined [24].

**Experimental Animals:**
*In-vivo* experiments were conducted on healthy adult Wistar rats weighing 150-200 g, regardless of sex. All animals were kept in a controlled environment with a 12-hour light/dark cycle, free access to food and water, and a temperature range of 25 ± 2°C and a relative humidity of 55 ± 5%. Experiments were carried out in compliance with CPCSEA guidelines, and the study methodology was authorized by the Institutional Animal Ethics Committee (IAEC) [25].

**Induction of Skin Infection:**
Rats were shaved under a light anesthetic on their dorsal surfaces. A superficial incision wound was inoculated with a standardized inoculum of Staphylococcus aureus (about $10^8$ CFU/mL) in order to promote infection. We let the infection a full day to set in before starting treatment [26].

**Experimental Design:**
Each of the four groups of animals (n = 6) was selected at random from the pool of animals. The first group, known as "Group I," was the untreated infected control. A simple gel was administered to Group II, an antibacterial gel that had been commercially produced was given to Group III, and the developed chitosan-coated silver nanoparticle (CS-AgNP) gel was administered to Group IV. For 14 days, in an aseptic environment, each treatment was given topically to the infected wound region once daily [27].

**Evaluation of Wound Healing:**
During the course of the study, many metrics were used to evaluate the rate of wound healing. On days 0, 3, 7, and 14, the planimetric approach was used to estimate the percentage contraction of the wound. The reduction in wound area was then computed. Estimating the colony-forming units (CFU) from aseptically collected wound tissue samples allowed us to assess the bacterial load in the infected tissue. When the study came to a close, the researchers took skin samples from the wound site, preserved them in 10% formalin, processed them, and stained them with hematoxylin and eosin for histological investigation. The level of re-epithelialization, collagen deposition, and inflammatory cell infiltration was assessed by microscopically examining the stained sections [28].

**Statistical Analysis:**
All experimental data were expressed as mean ± standard deviation (SD). Statistical analysis was performed using one-way analysis of variance (ANOVA) followed by Tukey's post hoc test. A value of $p < 0.05$ was considered statistically significant.

**RESULTS:**
**Optimization of Nanoparticle Formulation:**
Batch F6, out of the six trial batches (F1–F6), showed the best stability, dispersion, and lack of aggregation properties. The formulation's rich brown color suggests sustained nanoparticle production and effective reduction. Therefore, F6 was chosen for additional analysis and gel formation.

**Characterization of CS-AgNPs:**
**Particle Size, PDI, Zeta Potential, and Entrapment Efficiency:**
The homogeneity of the optimized nanoparticles was indicated by their nanoscale size and limited size dispersion (PDI < 0.3). Thanks to electrostatic repulsion, which is caused by the chitosan coating, the positive zeta potential indicated high stability. A high entrapment efficiency rate demonstrated

that the chitosan matrix successfully included the silver nanoparticles (Table 2).

**Table 2: Characterization of Optimized CS-AgNPs (F6)**

| Parameter | Value (Mean ± SD, n=3) |
|---|---|
| Particle Size (nm) | 112.6 ± 8.4 |
| Polydispersity Index (PDI) | 0.221 ± 0.03 |
| Zeta Potential (mV) | +31.8 ± 2.7 |
| Entrapment Efficiency (%) | 89.4 ± 2.1 |

**Morphological Analysis:**

Scanning electron microscopy (SEM) and transmission electron microscopy (TEM) were used to analyze the morphological properties of the chitosan-coated silver nanoparticles (CS-AgNPs). The micrographs that were taken showed that the nanoparticles had a pretty even distribution of sizes and were mostly round. The smooth surface morphology of the particles was an indication that the coating of silver nanoparticles with chitosan was successful. Additionally, there was little evidence of aggregation and the nanoparticles were well distributed, which bodes well for the formulation's stability. The chitosan coating successfully prevents particle agglomeration because there is no noticeable clumping or uneven formations. The observed morphology confirms the formulation's viability for improved topical distribution and antibacterial action, and it is in agreement with the nanoscale size determined by particle size analysis (Figure 1).

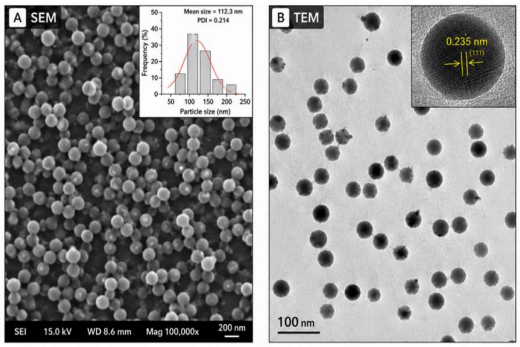



**Figure 1: SEM/TEM image of CS-AgNPs showing spherical morphology and uniform dispersion.**

**Evaluation of Gel Formulation:**

**Physicochemical Properties:**

The physicochemical properties of the prepared CS-AgNP gel were favorable, making it an excellent candidate for topical use. The absence of phase separation and the gel's smooth, homogenous, and light-brown color were signs of uniform nanoparticle inclusion. To reduce the likelihood of skin irritation, the formulation's pH (6.3 ± 0.2) was within the permissible range for topical use. Good retention at the application site was assured by the viscosity (15,480 ± 265 cP) (Table 3), and simplicity of application was demonstrated by the spreadability (6.8 ± 0.4 g·cm/s). The even distribution of nanoparticles throughout the gel base was confirmed by the high and consistent drug content (98.2 ± 1.5%).

**Table 3: Evaluation of CS-AgNP Gel Formulation**

| Parameter | Result (Mean ± SD, n=3) |
|---|---|
| Appearance | Smooth, homogeneous, light brown gel |
| pH | 6.3 ± 0.2 |
| Viscosity (cP) | 15,480 ± 265 |
| Spreadability (g·cm/s) | 6.8 ± 0.4 |
| Drug Content (%) | 98.2 ± 1.5 |

***In-Vitro* Drug Release Study:**

The CS-AgNP gel showed a sustained release pattern over 24 hours in the in-vitro drug release profile. Within the first two hours, there was a noticeable surge in drug release (32.7 ± 1.8%), which could be because the drug was either on or near the surface of the gel matrix. Then, there was a regulated and slow-release phase that lasted for 24 hours, reaching 87.6 ± 3.2%, which means the drug was available from the formulation for a long time (table 4 & Figure 2).

**Table 4: Cumulative Drug Release Profile of CS-AgNP Gel**

| Time (h) | % Drug Release (Mean ± SD, n=3) |
|---|---|
| 1 | 18.5 ± 1.2 |
| 2 | 32.7 ± 1.8 |
| 4 | 48.9 ± 2.1 |
| 8 | 65.4 ± 2.5 |
| 12 | 74.8 ± 2.9 |
| 24 | 87.6 ± 3.2 |

The formulation showed a sustained drug release pattern over 24 hours, with an initial burst release followed by controlled release.

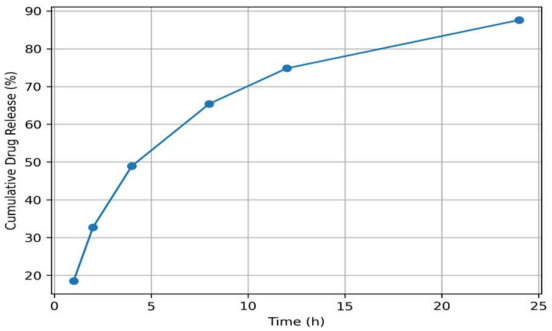


**Figure 2: Graph showing cumulative % drug release vs time indicating sustained release profile.**

***In-Vitro* Antibacterial Activity:**

We used the agar well diffusion method to test the CS-AgNP gel's antibacterial activity against Staphylococcus aureus. In comparison to the commercial formulation and plain gel, the antibacterial activity of the CS-AgNP gel was shown to be considerably higher. The combined action of chitosan and silver nanoparticles may have boosted bacterial inhibition and, by extension, the activity (Table 5 & figure 3).

**Table 5: Zone of Inhibition Against Staphylococcus aureus**

| Formulation | Zone of Inhibition (mm) (Mean ± SD, n=3) |
|---|---|
| Plain Gel | 10.2 ± 0.8 |
| Marketed Gel | 18.6 ± 1.0 |
| CS-AgNP Gel | 24.3 ± 1.2* |

(*p < 0.05 vs marketed gel)

The CS-AgNP gel exhibited significantly higher antibacterial activity compared to the marketed formulation and plain gel.

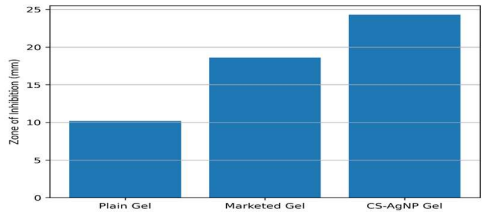



**Figure 3: Comparative bar graph of zone of inhibition showing superior antibacterial activity of CS-AgNP gel.**

***In-Vivo* Wound Healing Study:**

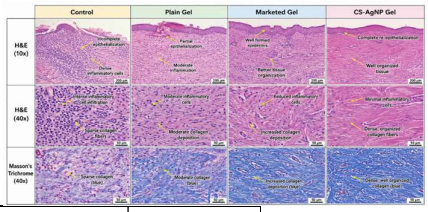
**Wound Contraction (%):**

We measured the proportion of wound contraction over 14 days to see how various formulations affected wound healing. When compared to the control group, all treatment groups showed a steady rise in wound contraction. At every time point, however, the group treated with CS-AgNP gel demonstrated substantially more wound contraction (Table 6 & figure 4). The CS-AgNP gel showed improved wound healing capability by day 14, surpassing the marketed gel and other groups by a substantial margin ($p < 0.05$) with a wound contraction of 96.2 ± 2.4%.

**Table 6: Effect of Formulations on Wound Contraction**

| Day | Control (%) | Plain Gel (%) | Marketed Gel (%) | CS-AgNP Gel (%) |
|---|---|---|---|---|
| 0 | 0 | 0 | 0 | 0 |
| 3 | 12.5 ± 2.1 | 18.2 ± 2.5 | 28.4 ± 3.1 | 36.7 ± 2.8* |
| 7 | 34.8 ± 3.2 | 45.6 ± 3.5 | 62.3 ± 3.8 | 78.9 ± 3.1* |
| 14 | 68.5 ± 4.1 | 76.2 ± 3.6 | 88.7 ± 2.9 | 96.2 ± 2.4* |

(*p < 0.05 vs marketed gel)



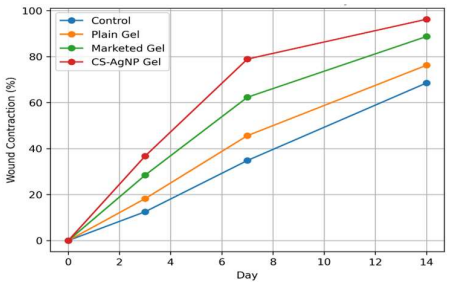




**Figure 4: Line graph showing % wound contraction over 14 days.**

**Bacterial Load Reduction:**

Estimating the bacterial burden in injured tissue samples further validated the antibacterial activity of the formulations. All treatment groups showed a significant decrease in bacterial count when compared to the control, according to the data (Table 7). The bacterial load was significantly lower in the group treated with CS-AgNP gel (2.1 ± 0.2 log CFU/g tissue) compared to the groups treated with the marketed gel (3.6 ± 0.3 log CFU/g tissue) and plain gel, suggesting that the CS-AgNP gel had better antibacterial activity ($p < 0.05$).

**Table 7: Bacterial Load (log CFU/g Tissue)**

| Group | Bacterial Load (Mean ± SD) |
|---|---|
| Control | 7.4 ± 0.3 |
| Plain Gel | 5.8 ± 0.4 |
| Marketed Gel | 3.6 ± 0.3 |
| CS-AgNP Gel | 2.1 ± 0.2* |

(*p < 0.05 vs marketed gel)

**Histopathological Findings:**
Different treatment groups showed significant differences in the histopathological examination of injured tissue sections. In the control group, there was noticeable inflammatory cell infiltration, scant collagen production, and inadequate epithelialization. Moderate improvement, with partial epithelialization and reduced inflammation, was observed in the group treated with simple gel. Tissue organization, epithelial layer development, and collagen deposition were all better in the gel group that was marketed. The group that was treated with CS-AgNP gel, on the other hand, had signs of advanced tissue regeneration and efficient wound healing, such as dense and well-organized collagen fibers, little inflammatory cell infiltration, and nearly full re-epithelialization (Figure 5).

**Figure 5: Histopathological images showing improved tissue regeneration in CS-AgNP gel-treated group.**

**DISCUSSION:**
This study proved that a gel loaded with chitosan-coated silver nanoparticles (CS-AgNPs) might effectively treat skin infections caused by Staphylococcus aureus. The results show that topical delivery systems based on nanotechnology are particularly important for improving wound healing and antibacterial activity [29].
The physicochemical properties of the improved formulation (F6) were favorable, suggesting that the nanoparticles were successfully synthesized and stabilized. It is vital for improved skin penetration that the particles be uniformly distributed, and the nanoscale size (~112 nm) and low polydispersity index validate this. Antibacterial activity was enhanced by the positive zeta potential (+31.8 mV) of the chitosan covering, which facilitated stability and contact with the negatively charged bacterial cell membranes. The formulation's nanoparticles were effectively incorporated thanks to their high entrapment effectiveness [30].
The results were corroborated by morphological analysis, which showed that the nanoparticles were spherical, smooth, and evenly distributed, with little evidence of aggregation, as shown in SEM/TEM photos. For more consistent medication release and better absorption at the target site, this homogeneous shape is crucial. Ideal for topical application, the produced gel displayed excellent physicochemical features, such as an optimum pH, viscosity, and spreadability. A high concentration of the medicinal compound suggested that the nanoparticles were evenly dispersed throughout the gel. Maintaining therapeutic medication levels while reducing application frequency is made easier by the in-vitro drug release profile, which shows an initial burst release followed by steady release over 24 hours [31].
Antibacterial experiments showed that compared to the commercial formulation, the CS-AgNP gel was much more effective against Staphylococcus aureus. The synergistic impact of chitosan and silver nanoparticles is responsible for this improved activity. The combination of silver nanoparticles and chitosan improves the antibacterial effect by breaking down bacterial cell membranes, producing reactive oxygen species, and interfering with DNA replication [32].
Further support for these findings was provided by the in vivo wound healing investigation. Wound contraction was considerably higher in the CS-AgNP gel group compared to the control and other treatment groups, suggesting that the wound healed more quickly. This could be because chitosan and silver nanoparticles work together to heal wounds by reducing bacterial burden and increasing tissue regeneration. In line with the antibacterial activity that was found, bacterial load measurement verified that the CS-AgNP-treated group had a much lower microbial count. Improvements in tissue healing and decreased infection were further shown by histopathological assessment, which revealed dense collagen deposition, limited inflammatory infiltration, and accelerated re-epithelialization [33].
The findings point to the CS-AgNP gel's ability to promote faster wound healing in addition to its strong antibacterial action. Its enhanced therapeutic efficacy is attributable, in part, to the sustained drug release and the synergistic interaction of chitosan and silver nanoparticles. These results lend credence to the idea that topical formulations based on CS-AgNP could be a viable substitute for the current methods of treating bacterial skin infections [34-39].

**CONCLUSION:**
A gel loaded with chitosan-coated silver nanoparticles (CS-AgNP) that improved antibacterial and wound healing capabilities was developed and tested in this study. With nanoscale size, excellent stability, and high entrapment efficiency, the improved nanoparticles displayed desired physicochemical properties. An ideal topical formulation with the right pH, viscosity, and spreadability was produced by mixing CS-AgNPs with a Carbopol gel. The resulting product was stable and homogeneous. In comparison to the commercially available formulation, the CS-AgNP gel showed substantially greater antibacterial activity against Staphylococcus aureus and exhibited prolonged drug release behavior. Increased wound contraction, a marked decrease in bacterial load, and improved histopathological outcomes, such as enhanced re-epithelialization and collagen deposition, were all indicators of its

superior wound healing efficacy in in vivo tests. Results show that CS-AgNP gel is an effective and potentially useful topical treatment for bacterial skin infections and wounds. It could be a substitute for more traditional treatments because to the synergistic effect of chitosan and silver nanoparticles, which improves its performance. To determine its effectiveness and safety in human beings, additional clinical trials are necessary.

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**Conflict of interest:**
The authors declare that they have no conflict of interest.

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