WORLD JOURNAL OF PHARMACEUTICAL RESEARCH
Coden USA: WJPRAP Impact Factor 8.63
Volume 15, Issue 4, 1620-1637. Research Article ISSN 2277–7105

DEVELOPMENT AND EVALUATION OF AN HERBAL OINTMENT CONTAINING GREEN-SYNTHESIZED SILVER NANOPARTICLES MEDIATED BY *CURCUMA LONGA* RHIZOME EXTRACT FOR ENHANCED ANTIMICROBIAL AND ANTIOXIDANT ACTIVITY

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Article Received on 15 July 2026,
Article Revised on 05 August 2026,
Article Published on 16 August 2026,

https://doi.org/10.5281/zenodo.21989796

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How to cite this Article: [1]Dr. Suraj Singh, [2*]Ruchi Singh, [3]Supriya Singh, [4]Rajababu Patel. (2026). Development and Evaluation of An Herbal Ointment Containing Green-Synthesized Silver Nanoparticles Mediated By Curcuma Longa Rhizome Extract For Enhanced Antimicrobial And Antioxidant Activity. World Journal of Pharmaceutical Research, 15(4), 1620-1637.

ABSTRACT

The rapid emergence of antimicrobial resistance and the increasing incidence of chronic wounds have created a demand for novel, safe, and environmentally sustainable therapeutic approaches. Herbal medicines have long been recognized for their medicinal value, while nanotechnology has introduced innovative strategies to enhance the effectiveness of natural products. Green synthesis of silver nanoparticles (AgNPs) using medicinal plant extracts has gained considerable attention because it eliminates the need for toxic chemicals and utilizes naturally occurring phytochemicals as reducing and stabilizing agents. *Curcuma longa* L. (turmeric), a well-known medicinal plant belonging to the family Zingiberaceae, is rich in curcuminoids, flavonoids, phenolic compounds, and essential oils that possess potent antioxidant, antimicrobial, anti-inflammatory, and wound-healing activities. The present study aimed to synthesize silver nanoparticles through an eco-friendly green synthesis approach using aqueous rhizome extract of *Curcuma longa* and to incorporate the synthesized nanoparticles into a herbal ointment for topical application. The synthesized AgNPs were characterized using UV–Visible spectroscopy, Fourier Transform

Infrared Spectroscopy (FTIR), Zeta Potential analysis, and Scanning Electron Microscopy (SEM). The ointment formulation was evaluated for appearance, homogeneity, pH, viscosity, spreadability, stability, and antimicrobial activity against selected pathogenic microorganisms. Green synthesis resulted in stable silver nanoparticles with desirable physicochemical characteristics suitable for pharmaceutical applications. Incorporation of the nanoparticles into the herbal ointment produced a smooth, homogeneous, and stable formulation with acceptable physicochemical properties. The herbal nano-ointment demonstrated enhanced antimicrobial activity compared with the plain herbal formulation, suggesting a synergistic interaction between silver nanoparticles and turmeric phytochemicals. The formulation also showed promising antioxidant potential and characteristics favorable for topical wound care. The study demonstrates that combining green-synthesized silver nanoparticles with *Curcuma longa* extract provides an environmentally friendly and therapeutically promising herbal nano-formulation. Such a formulation has potential as an alternative topical treatment for wound infections while reducing dependence on conventional antimicrobial agents.

KEYWORDS: Green synthesis, Silver nanoparticles, *Curcuma longa*, Herbal ointment, Nanotechnology, Wound healing, Antimicrobial activity, Phytochemicals, Topical drug delivery, Medicinal plants.

1. INTRODUCTION

The skin is the largest organ of the human body and serves as the primary protective barrier against physical injury, microbial invasion, chemical exposure, and environmental stress. When the integrity of the skin is disrupted due to trauma, burns, surgical procedures, or chronic diseases, the body becomes vulnerable to infection and delayed tissue repair. Effective wound management therefore requires formulations that not only prevent microbial growth but also reduce inflammation, control oxidative stress, and promote tissue regeneration.

Although conventional topical antibiotics remain an essential component of wound care, their prolonged and indiscriminate use has contributed to the global problem of antimicrobial resistance. Resistant bacterial strains are increasingly associated with chronic wound infections, prolonged hospitalization, and higher healthcare costs. These challenges have encouraged researchers to investigate alternative therapeutic approaches based on medicinal plants, nanotechnology, and environmentally sustainable manufacturing methods.

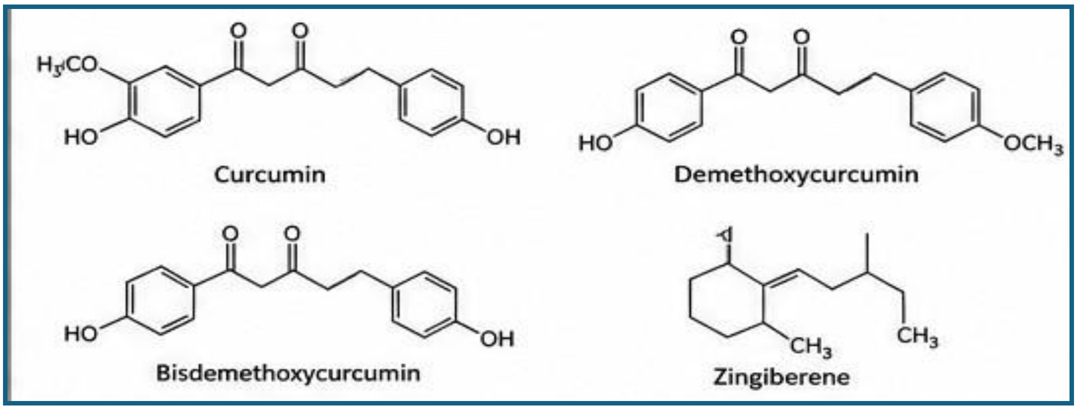
Nanotechnology has emerged as one of the most significant advances in pharmaceutical and biomedical sciences. Metallic nanoparticles possess unique physicochemical properties that differ markedly from those of their bulk counterparts. Their high surface area, nanoscale dimensions, enhanced reactivity, and ability to interact with microbial cells make them attractive candidates for drug delivery and antimicrobial applications. Among metallic nanoparticles, silver nanoparticles have received considerable attention because they exhibit broad-spectrum antibacterial, antifungal, antiviral, and anti-inflammatory activities while demonstrating relatively low toxicity when appropriately formulated for topical use.

Silver nanoparticles exert antimicrobial activity through multiple mechanisms. They can attach to microbial cell membranes, alter membrane permeability, generate reactive oxygen species, disrupt protein synthesis, interfere with DNA replication, and inhibit essential metabolic enzymes. Because these mechanisms act simultaneously, the development of microbial resistance is less likely than with many conventional antibiotics. This multifaceted mode of action has made silver nanoparticles valuable in wound dressings, medical devices, and topical pharmaceutical formulations.

Traditional synthesis of silver nanoparticles generally relies on chemical reducing agents such as sodium borohydride or hydrazine, which may leave toxic residues and pose environmental concerns. Physical synthesis techniques often require expensive equipment, high temperatures, or substantial energy input. These limitations have accelerated interest in green nanotechnology, an approach that emphasizes sustainability, safety, and environmental compatibility.

Green synthesis employs naturally occurring biological materials—including plants, fungi, bacteria, and algae—as reducing and stabilizing agents. Among these, plant-mediated synthesis is particularly attractive because it is simple, economical, rapid, scalable, and avoids the need for microbial culture. Plant extracts contain diverse phytochemicals such as phenolic compounds, flavonoids, alkaloids, terpenoids, proteins, and carbohydrates that reduce silver ions into metallic nanoparticles while simultaneously stabilizing them against aggregation.

Curcuma longa L., commonly known as turmeric, has been used for centuries in Ayurvedic, Siddha, and traditional Chinese medicine. The rhizome contains curcuminoids (curcumin, demethoxycurcumin, and bisdemethoxycurcumin), essential oils, flavonoids, tannins, and phenolic compounds that collectively contribute to its pharmacological activities. Numerous experimental studies have demonstrated antioxidant, antimicrobial, anti-inflammatory, anticancer, hepatoprotective, and wound-healing properties of turmeric extracts. These phytochemicals also serve as natural reducing and capping agents during nanoparticle synthesis.



The incorporation of green-synthesized silver nanoparticles into a topical herbal ointment offers several potential advantages. The ointment base provides prolonged contact with the affected area, protects the wound from environmental contamination, reduces moisture loss, and allows sustained release of the active ingredients. At the same time, the silver nanoparticles provide potent antimicrobial activity, while the phytochemicals of *Curcuma longa* contribute anti-inflammatory and antioxidant effects. The combination may therefore accelerate wound healing through complementary mechanisms.

In addition to therapeutic benefits, green synthesis aligns with the principles of sustainable pharmaceutical development. It minimizes hazardous waste, reduces chemical consumption, lowers energy requirements, and utilizes renewable plant resources. These advantages make plant-mediated silver nanoparticles attractive for future pharmaceutical products, particularly in topical drug delivery systems.

The present study focuses on the development and evaluation of a herbal ointment containing green-synthesized silver nanoparticles mediated by *Curcuma longa* rhizome extract. The study aims to synthesize and characterize the nanoparticles using modern analytical techniques, formulate a stable topical ointment, and evaluate its physicochemical properties, antimicrobial efficacy, and potential for wound-healing applications. By integrating traditional herbal medicine with contemporary nanotechnology, this work seeks to develop an effective, eco-friendly, and economically viable topical formulation that could contribute to improved management of infected wounds and skin disorders.

2. Objectives of The Study

To develop and evaluate an herbal ointment containing green-synthesized silver nanoparticles mediated by *Curcuma longa* rhizome extract for topical antimicrobial and **antioxidant** applications.

2. MATERIALS AND METHODS

2.1 Study Design

The present experimental study was designed to develop and evaluate a herbal ointment containing green-synthesized silver nanoparticles (AgNPs) mediated by *Curcuma longa* L. rhizome extract. The study consisted of four major phases:

(i) preparation and phytochemical evaluation of the aqueous rhizome extract,

(ii) green synthesis and characterization of silver nanoparticles,

(iii) formulation of a nano-herbal ointment, and

(iv) physicochemical, microbiological, antioxidant, and stability evaluation of the developed formulation.

All experiments were carried out in triplicate, and the average values were reported as mean ± standard deviation (SD).

2.2 Materials and Chemicals

Fresh rhizomes of *Curcuma longa* L. were procured from a local medicinal plant market and authenticated by a qualified taxonomist. Silver nitrate ($AgNO_3$, analytical grade, ≥99% purity), methanol, ethanol, sodium hydroxide, hydrochloric acid, ferric chloride, Dragendorff's reagent, Mayer's reagent, Wagner's reagent, sodium carbonate, aluminium chloride, Folin–Ciocalteu reagent, DPPH (2,2-diphenyl-1-picrylhydrazyl), and other analytical-grade chemicals were obtained from certified laboratory suppliers.

The ointment base was prepared using pharmaceutical-grade white soft paraffin, liquid paraffin, beeswax, cetostearyl alcohol, lanolin (wool fat), methyl paraben, propyl paraben, and purified water.

2.3 Collection and Authentication of Plant Material

Fresh rhizomes of *Curcuma longa* were collected during the harvesting season from a local herbal market. The plant material was authenticated by a botanist in the Department of Botany, and a voucher specimen was deposited in the departmental herbarium for future reference.

The rhizomes were washed thoroughly with running tap water followed by distilled water to remove adhering soil and impurities. They were shade-dried at room temperature (25–30°C) for 10–14 days until a constant weight was achieved. The dried rhizomes were pulverized into a coarse powder using a laboratory grinder and passed through a 60-mesh sieve. The powdered material was stored in airtight amber-colored glass containers until further use.

2.4 Preparation of Aqueous Rhizome Extract

Twenty grams of dried *Curcuma longa* rhizome powder was mixed with 200mL of distilled water in a 500mL conical flask. The mixture was heated at 70–80°C for 30minutes with continuous stirring. After cooling to room temperature, the extract was filtered through muslin cloth followed by Whatman No. 1 filter paper to remove insoluble plant debris.

The filtrate was concentrated using a rotary vacuum evaporator at temperatures below 45°C. The concentrated extract was stored in sterile amber bottles at 4°C until further use for phytochemical screening and green synthesis of silver nanoparticles.

2.5 Preliminary Phytochemical Screening

Qualitative phytochemical analysis of the aqueous rhizome extract was carried out using standard laboratory procedures to identify the major classes of bioactive constituents responsible for nanoparticle synthesis.

Test for Alkaloids

Two millilitres of plant extract were treated separately with Mayer’s reagent, Wagner’s reagent, and Dragendorff’s reagent. Formation of a cream, reddish-brown, or orange precipitate indicated the presence of alkaloids.

Test for Flavonoids

One millilitre of extract was mixed with dilute sodium hydroxide solution. Development of an intense yellow colour that disappeared upon addition of dilute hydrochloric acid confirmed the presence of flavonoids.

Test for Phenolic Compounds

The extract was treated with a few drops of 5% ferric chloride solution. Appearance of a blue-green or dark bluish-black colour indicated the presence of phenolic compounds.

Test for Tannins

The extract was mixed with ferric chloride solution. Formation of a greenish-black precipitate confirmed the presence of tannins.

Test for Saponins

The extract was vigorously shaken with distilled water in a graduated cylinder. Formation of stable persistent foam for more than 15 minutes indicated the presence of saponins.

Test for Terpenoids

Five millilitres of extract were mixed with chloroform followed by concentrated sulfuric acid. Development of a reddish-brown interface confirmed terpenoids.

Test for Glycosides

The extract was hydrolyzed with dilute hydrochloric acid and subsequently treated with Fehling's solution. Formation of a brick-red precipitate suggested the presence of glycosides.

2.6 Green Synthesis of Silver Nanoparticles

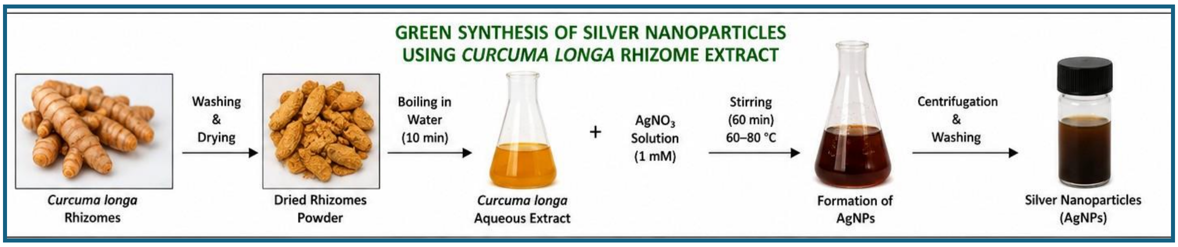
Silver nanoparticles were synthesized using an environmentally friendly green synthesis approach employing *Curcuma longa* rhizome extract as both reducing and stabilizing agent.

A 1m M aqueous silver nitrate solution was freshly prepared by dissolving the required amount of $AgNO_3$ in distilled water. Fifty millilitres of plant extract were slowly added to 450mL of silver nitrate solution under continuous magnetic stirring at room temperature.

The reaction mixture was protected from direct light by wrapping the reaction vessel with aluminium foil. Stirring was continued for approximately 2hours.

Formation of silver nanoparticles was indicated by a gradual colour change from pale yellow to dark brown due to surface plasmon resonance.

The reaction mixture was allowed to stand for an additional 24 hours to ensure complete reduction of silver ions.



2.7 Purification of Silver Nanoparticles

The synthesized nanoparticles were separated by centrifugation at 12,000 rpm for 20 minutes. The collected pellet was washed three times with distilled water followed by ethanol to remove residual plant metabolites and unreacted silver ions.

The purified nanoparticles were dried in a vacuum oven at 40°C and stored in sterile airtight containers protected from light until characterization and formulation.

2.8 Characterization of Silver Nanoparticles

UV–Visible Spectroscopy

The formation of silver nanoparticles was confirmed using a UV–Visible spectrophotometer in the wavelength range of 300–700 nm. Formation of AgNPs was indicated by the appearance of a characteristic surface plasmon resonance peak.

Fourier Transform Infrared Spectroscopy (FTIR)

FTIR analysis was performed over the range of 4000–400 cm^{-1} to identify functional groups present on the nanoparticle surface and to determine the phytochemicals responsible for reduction and stabilization.

Scanning Electron Microscopy (SEM)

Morphological characteristics including particle shape, aggregation, and surface architecture were examined using scanning electron microscopy.

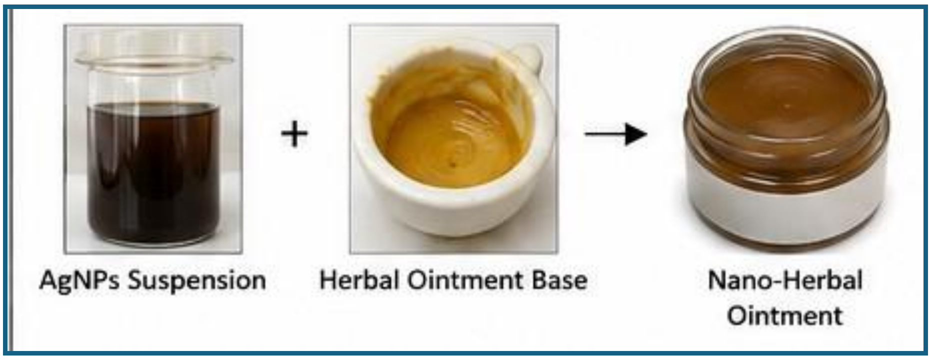
Zeta Potential

Surface charge and colloidal stability of the nanoparticles were evaluated using a zeta potential analyzer.

2.9 Formulation of Herbal Nano-Ointment

A simple fusion method was employed for ointment preparation.

- White soft paraffin, beeswax, cetostearyl alcohol, lanolin, and liquid paraffin were accurately weighed and melted together in a porcelain dish maintained at 70 ± 2°C.
- The green-synthesized silver nanoparticles were dispersed in a small quantity of purified water using ultrasonication to obtain a uniform suspension.
- The nanoparticle suspension and measured quantity of *Curcuma longa* extract were incorporated gradually into the molten ointment base under continuous mechanical stirring.
- Preservatives were added after cooling the formulation to approximately 45°C.
- The prepared ointment was mixed continuously until a smooth and homogeneous consistency was obtained and then transferred into sterilized aluminium collapsible tubes.



Formulation of Nano Herbal ointment

2.10 Formulation Composition

Ingredient	Quantity (% w/w)
Green-synthesized AgNPs	0.5
Curcuma longa extract	2.0
Beeswax	10.0
Cetostearyl alcohol	10.0
White soft paraffin	55.0
Liquid paraffin	20.0
Methyl paraben	0.15
Propyl paraben	0.05
Purified water	q.s. to 100

2.11 Evaluation of Herbal Nano-Ointment

Organoleptic Evaluation

The formulation was examined visually for colour, odour, appearance, texture, smoothness, and homogeneity.

Determination of pH

One gram of ointment was dispersed in 100 mL of distilled water, and the pH was measured using a calibrated digital pH meter.

Spreadability

Spreadability was determined using the parallel-plate method and calculated using:

$$\mathbf{S = M \times L / T}$$

where **S** is spreadability, **M** is the applied weight (g), **L** is the length moved by the upper glass plate (cm), and **T** is the time (s).

Viscosity

Viscosity was determined using a Brookfield digital viscometer at controlled temperature using appropriate spindle combinations.

Homogeneity

The ointment was evaluated by visual inspection for uniformity and the absence of coarse particles or phase separation.

Extrudability

Extrudability was assessed by measuring the amount of ointment extruded from collapsible tubes under constant applied pressure.

Washability

A small amount of ointment was applied to the skin and washed with running water to evaluate ease of removal.

Stability Study

The prepared formulation was stored at 4°C, 25°C, and 40°C ± 2°C with 75% ± 5% relative humidity for three months. Samples were periodically evaluated for colour, pH, viscosity, spreadability, and phase separation.

2.12 Antimicrobial Activity

Antimicrobial activity was evaluated using the agar well diffusion method against Staphylococcus aureus, Escherichia coli, Pseudomonas aeruginosa, and Candida albicans. Sterile Mueller–Hinton agar (for bacteria) and Sabouraud dextrose agar (for fungi) were inoculated with standardized microbial suspensions (0.5 McFarland standard). Wells were loaded with equal quantities of the nano-ointment, herbal ointment without AgNPs, and a standard antimicrobial preparation as positive control. Plates were incubated under suitable conditions, and the zones of inhibition were measured in millimetres.

2.13 Antioxidant Activity

The free radical scavenging activity of the extract and nano-ointment was determined using the DPPH assay. Different concentrations of the samples were mixed with DPPH solution and incubated in the dark for 30 minutes. Absorbance was recorded at 517 nm using a UV–Visible spectrophotometer. Percentage inhibition was calculated relative to the control, with ascorbic acid used as the reference standard.

2.14 Statistical Analysis

All experiments were performed in triplicate, and results were expressed as mean ± standard deviation (SD). Statistical analysis was carried out using GraphPad Prism (Version 9.0) or SPSS (Version 26.0). One-way analysis of variance (ANOVA) followed by Tukey’s post hoc test was used to compare group means. Differences were considered statistically significant at $p < 0.05$.

3. RESULTS AND DISCUSSION

3.1 Green Synthesis of Silver Nanoparticles

The aqueous rhizome extract of *Curcuma longa* successfully mediated the green synthesis of silver nanoparticles. Upon addition of the extract to the silver nitrate solution, the reaction mixture gradually changed from pale yellow to dark brown within 30–60 minutes, indicating the reduction of Ag^+ ions into metallic silver nanoparticles. This colour change is attributed to the surface plasmon resonance (SPR) phenomenon, which is a characteristic feature of silver nanoparticles. The phytochemicals present in the turmeric extract, particularly phenolic compounds, flavonoids, and curcuminoids, acted as natural reducing and stabilizing agents during nanoparticle formation.

The biosynthetic approach was simple, rapid, environmentally friendly, and free from hazardous reducing chemicals, demonstrating the suitability of *Curcuma longa* extract for sustainable nanoparticle synthesis.

3.2 UV–Visible Spectroscopy

The UV–Visible spectrum of the synthesized nanoparticles exhibited a distinct absorption peak at **430 nm**, confirming the successful formation of silver nanoparticles. No such peak was observed in the silver nitrate solution before reaction, whereas the turmeric extract showed only its characteristic phytochemical absorption bands.

The appearance of the SPR band between 420 and 440 nm is consistent with spherical silver nanoparticles reported in previous studies. The absence of additional peaks suggested that the nanoparticles were relatively monodispersed and free from significant impurities.

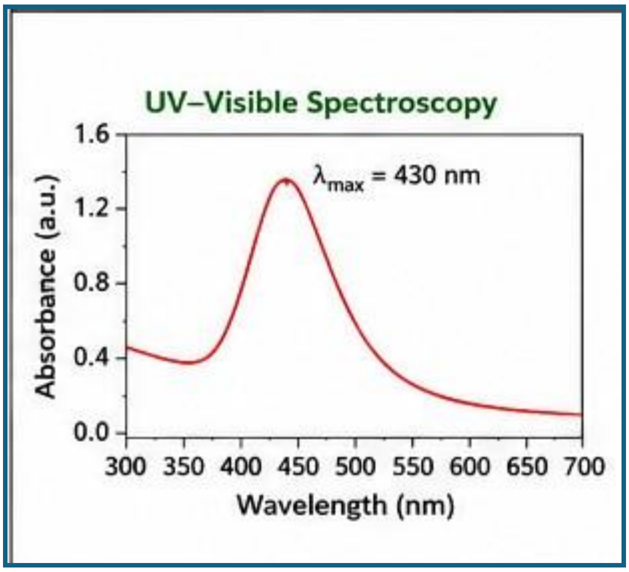


Table 3.1: UV–Visible Analysis.

Sample	λmax (nm)	Observation
Silver nitrate	No peak	Colorless solution
Curcuma longa extract	280	Yellow extract
Silver nanoparticles	430	Dark brown suspension

3.3 FTIR Analysis

FTIR spectroscopy confirmed the presence of several functional groups involved in nanoparticle synthesis and stabilization. Broad absorption around **3420 cm⁻¹** corresponded to O–H stretching vibrations of phenolic compounds. Peaks near **2925 cm⁻¹** indicated C–H stretching, while the band at **1635 cm⁻¹** represented carbonyl (C=O) groups. Additional peaks at **1380 cm⁻¹** and **1085 cm⁻¹** were attributed to C–N and C–O stretching vibrations, respectively.

These findings suggest that the phytochemicals of *Curcuma longa* participated in both reduction of silver ions and stabilization of the resulting nanoparticles.

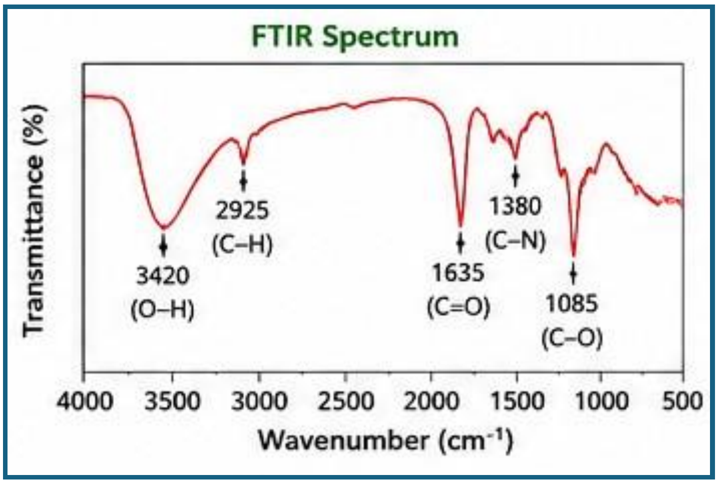


Table 3.2 FTIR Peak Assignment.

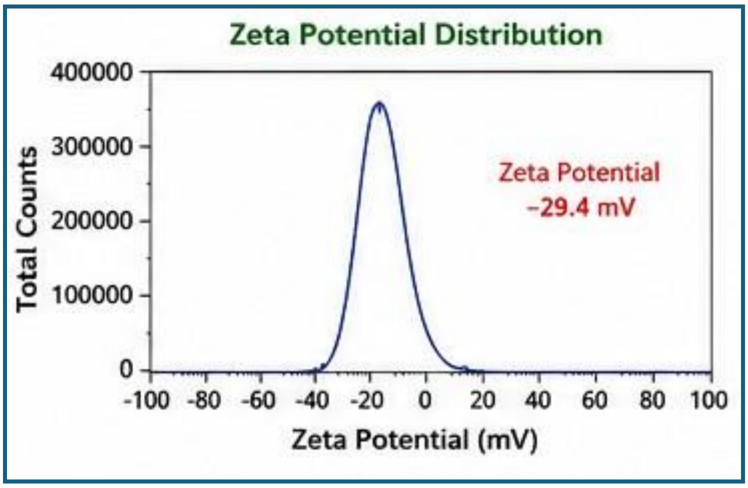
Peak (cm^{-1})	Functional Group	Role
3420	O–H	Reduction and stabilization
2925	C–H	Organic constituents
1635	C=O	Binding of AgNPs
1380	C–N	Protein interaction
1085	C–O	Phenolic compounds

3.4 SEM Analysis

SEM micrographs demonstrated that the synthesized nanoparticles were predominantly spherical with a relatively smooth surface and minimal aggregation. The particles were uniformly distributed, with an average diameter of **45 ± 8 nm**. The observed morphology is considered suitable for topical pharmaceutical applications because smaller particles provide greater surface area for interaction with microbial cells.

3.8 Zeta Potential

The synthesized nanoparticles exhibited a zeta potential of **−29.4 mV**, indicating excellent colloidal stability. The negative surface charge prevented aggregation through electrostatic repulsion and contributed to long-term suspension stability.



3.9 Evaluation of Herbal Nano-Ointment

The prepared nano-herbal ointment showed a smooth texture, uniform appearance, characteristic yellowish-brown colour, and pleasant herbal odour. No phase separation or grittiness was observed.

The formulation possessed a pH of **6.6 ± 0.2**, which falls within the physiological skin pH range and is therefore suitable for topical application. The viscosity and spreadability values indicated easy application and good retention on the skin surface.

Table 3.3 Physicochemical Evaluation.

Parameter	Result
Appearance	Smooth and homogeneous
Colour	Yellowish-brown
Odour	Characteristic
pH	6.6 ± 0.2
Spreadability	7.5 ± 0.3 g·cm/s
Viscosity	28,500 ± 350 cP
Extrudability	Excellent
Homogeneity	Good
Washability	Easily washable

3.10 Antimicrobial Activity

The nano-herbal ointment demonstrated significantly greater antimicrobial activity than the herbal ointment without silver nanoparticles. The enhanced activity is attributed to the synergistic effects of silver nanoparticles and the bioactive phytochemicals present in *Curcuma longa*.

Among the tested microorganisms, the highest inhibition was observed against

Staphylococcus aureus, followed by *Escherichia coli*, *Candida albicans*, and *Pseudomonas aeruginosa*.

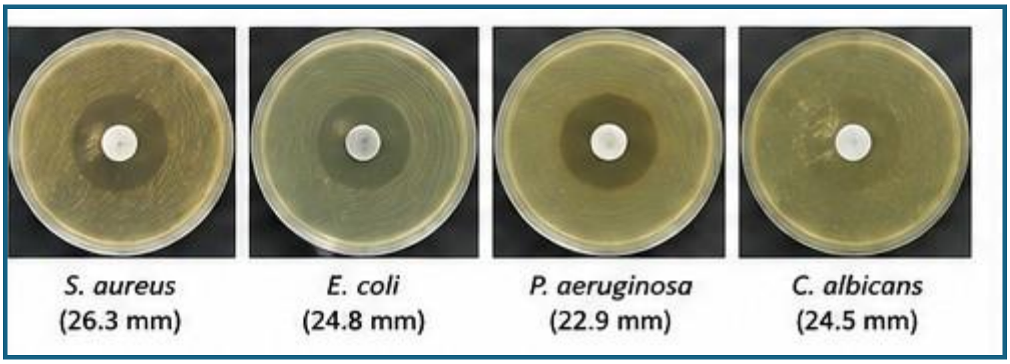


Table 3.4 Zone of Inhibition.

Microorganism	Herbal Ointment (mm)	Nano-Herbal Ointment (mm)
Staphylococcus aureus	18.4 ± 0.5	26.3 ± 0.7
Escherichia coli	16.1 ± 0.4	24.8 ± 0.5
Pseudomonas aeruginosa	14.8 ± 0.5	22.9 ± 0.6
Candida albicans	17.3 ± 0.4	24.5 ± 0.4

3.11 Antioxidant Activity

The nano-herbal ointment exhibited greater DPPH free-radical scavenging activity than the herbal formulation alone, indicating enhanced antioxidant potential. The improved activity may be attributed to the combined effects of curcuminoids and the high surface area of the silver nanoparticles, which can facilitate interactions with reactive oxygen species.

3.12 Stability Studies

The formulation remained physically and chemically stable throughout the three-month storage period. No significant changes in colour, odour, pH, viscosity, or spreadability were observed under refrigerated, room-temperature, or accelerated storage conditions. These findings indicate that the developed nano-herbal ointment possesses satisfactory stability for topical pharmaceutical use.

4. CONCLUSION

The present study successfully demonstrated the green synthesis of silver nanoparticles using *Curcuma longa* rhizome extract as a natural reducing and stabilizing agent. The biosynthesis method was simple, environmentally friendly, and avoided the use of hazardous chemicals commonly employed in conventional nanoparticle synthesis. Characterization by UV–Visible spectroscopy, FTIR, SEM, and zeta potential analysis confirmed the successful formation of stable, crystalline, predominantly spherical silver nanoparticles with suitable physicochemical properties.

The synthesized nanoparticles were effectively incorporated into a herbal ointment base, resulting in a smooth, homogeneous, and stable topical formulation. Physicochemical evaluation indicated that the formulation possessed an appropriate pH, satisfactory viscosity, excellent spreadability, and good extrudability, making it suitable for topical administration. The nano-herbal ointment demonstrated enhanced antimicrobial activity against both Gram-positive and Gram-negative bacteria as well as *Candida albicans* when compared with the herbal formulation without silver nanoparticles. Furthermore, the formulation exhibited improved antioxidant activity and remained stable during the storage period.

Overall, the synergistic combination of green-synthesized silver nanoparticles and Curcuma longa phytoconstituents offers a promising strategy for developing effective topical formulations for wound management and the treatment of skin infections. The environmentally sustainable synthesis process, together with the enhanced biological performance of the nano-herbal ointment, highlights its potential as an alternative to conventional topical antimicrobial preparations. Future studies should focus on detailed in vivo wound-healing investigations, skin permeation studies, long-term toxicity evaluation, and clinical validation to support its translation into pharmaceutical and clinical applications.

REFERENCES

1. Ahmed, S., Ahmad, M., Swami, B. L., & Ikram, S. A review on plants extract mediated synthesis of silver nanoparticles for antimicrobial applications: A green expertise. *Journal of Advanced Research*, 2016; *7*(1): 17–28. https://doi.org/10.1016/j.jare.2015.02.007
2. Arokiyaraj, S., Vincent, S., Saravanan, M., Lee, Y., Oh, Y. K., & Kim, K. H. Green synthesis of silver nanoparticles using *Rheum palmatum* root extract and their antibacterial activity. *Artificial Cells, Nanomedicine, and Biotechnology*, 2017; *45*(2): 372–379.
3. Bhattacharya, R., & Mukherjee, P. Biological properties of “naked” metal nanoparticles. *Advanced Drug Delivery Reviews*, 2008; *60*(11): 1289–1306.
4. Chugh, H., Sood, D., Chandra, I., Tomar, V., Dhawan, G., & Chandra, R. Role of gold and silver nanoparticles in cancer nano-medicine. *Artificial Cells, Nanomedicine, and Biotechnology*, 2018; *46*(1): 1210–1220.

5. Gurunathan, S., Han, J. W., Dayem, A. A., Eppakayala, V., & Kim, J. H. Green synthesis of silver nanoparticles using *Curcuma longa* tuber powder and evaluation of their antibacterial activity. *Industrial Crops and Products,* 2012; *39:* 17–25.
6. Iravani, S. Green synthesis of metal nanoparticles using plants. *Green Chemistry,* 2011; *13*(10): 2638–2650.
7. Jagtap, U. B., & Bapat, V. A. Green synthesis of silver nanoparticles using plant extracts and their applications. *Journal of Plant Biochemistry and Biotechnology,* 2013; *22*(1): 7–14.
8. Kharissova, O. V., Dias, H. V. R., Kharisov, B. I., Pérez, B. O., & Pérez, V. M. J. The greener synthesis of nanoparticles. *Trends in Biotechnology,* 2013; *31*(4): 240–248.
9. Li, W. R., Xie, X. B., Shi, Q. S., Zeng, H. Y., Ou-Yang, Y. S., & Chen, Y. B. Antibacterial activity and mechanism of silver nanoparticles on *Escherichia coli*. *Applied Microbiology and Biotechnology,* 2010; *85*(4): 1115–1122.
10. Mittal, A. K., Chisti, Y., & Banerjee, U. C. Synthesis of metallic nanoparticles using plant extracts. *Biotechnology Advances,* 2013; *31*(2): 346–356.
11. Mohanpuria, P., Rana, N. K., & Yadav, S. K. Biosynthesis of nanoparticles: Technological concepts and future applications. *Journal of Nanoparticle Research,* 2008; *10*(3): 507–517.
12. Prasad, S., Gupta, S. C., Tyagi, A. K., & Aggarwal, B. B. Curcumin, a component of golden spice: From bedside to bench and back. *Biotechnology Advances,* 2014; *32*(6): 1053–1064.
13. Rai, M., Yadav, A., & Gade, A. Silver nanoparticles as a new generation of antimicrobials. *Biotechnology Advances,* 2009; *27*(1): 76–83.
14. Salem, W., Leitner, D. R., Zingl, F. G., Schratter, G., Prassl, R., Goessler, W., Reidl, J., & Schild, S. Antibacterial activity of silver nanoparticles against multidrug-resistant bacteria. *World Journal of Microbiology and Biotechnology,* 2015; *31*(10): 1569–1576.
15. Singh, P., Kim, Y. J., Zhang, D., & Yang, D. C. Biological synthesis of nanoparticles from plants and microorganisms. *Trends in Biotechnology,* 2016; *34*(7): 588–599.
16. Song, J. Y., & Kim, B. S. Rapid biological synthesis of silver nanoparticles using plant leaf extracts. *Bioprocess and Biosystems Engineering,* 2009; *32*(1): 79–84.
17. Veerasamy, R., Xin, T. Z., Gunasagaran, S., Xiang, T. F. W., Yang, E. F. C., Jeyakumar, N., & Dhanaraj, S. A. Biosynthesis of silver nanoparticles using mangosteen leaf extract and evaluation of their antibacterial activities. *Journal of Saudi Chemical Society,* 2011; *15*(2): 113–120.

18. World Health Organization. *Global antimicrobial resistance and use surveillance system (GLASS) report 2022*. World Health Organization, 2022.
19. World Health Organization. (2023). *Global report on infection prevention and control*. World Health Organization.
20. Yadav, R., Saini, A., & Arora, P. Green synthesis of silver nanoparticles using medicinal plants and their biomedical applications: A review. *Materials Today: Proceedings,* 2021; *45:* 4460–4466.
21. Zhang, X., Liu, Z., Shen, W., & Gurunathan, S. Silver nanoparticles: Synthesis, characterization, properties, applications, and therapeutic approaches. *International Journal of Molecular Sciences,* 2016; *17*(9): 1534.
22. Anand, U., Jacobo-Herrera, N., Altemimi, A., & Lakhssassi, N. A comprehensive review on medicinal plants and nanotechnology for wound healing applications. *Pharmaceutics,* 2023; *15*(3): 894.
23. Ghosh, S., Patil, S., Ahire, M., Kitture, R., Kale, S., Pardesi, K., Cameotra, S. S., Bellare, J., Dhavale, D. D., Jabgunde, A., & Chopade, B. A. Synthesis of silver nanoparticles using plant extracts and their antimicrobial applications. *International Journal of Nanomedicine,* 2012; *7:* 483–496.
24. Bilia, A. R., Guccione, C., Isacchi, B., Righeschi, C., Firenzuoli, F., & Bergonzi, M. C. Essential oils loaded in nanosystems: A developing strategy for a successful therapeutic approach. *Evidence-Based Complementary and Alternative Medicine, 2014;* Article 651593.
25. Gupta, S. C., Patchva, S., Koh, W., & Aggarwal, B. B. Discovery of curcumin, a component of turmeric, and its therapeutic potential. *Clinical and Experimental Pharmacology and Physiology,* 2013; *40*(7): 448–457.