



Research Article

Formulation Development, Physicochemical Characterization, and In Vitro Evaluation of A Silver Nanoparticle-Loaded Phytoconstituent-Based Nanogel System for Enhanced Topical Drug Delivery

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The present study aimed to develop and evaluate a novel silver nanoparticle (AgNP)-loaded nanogel formulated using the ethanolic leaf extract of *Lantana camara* for topical application. Phytochemical screening confirmed the presence of bioactive constituents such as flavonoids, tannins, and terpenoids, supporting its therapeutic potential and role in green nanoparticle synthesis. AgNPs were synthesized via an eco-friendly method and characterized using UV-Visible spectroscopy, FTIR, SEM, and TEM, confirming successful formation of spherical nanoparticles with desirable properties. The synthesized AgNPs were incorporated into Carbopol-based nanogel formulations (F1–F5) and evaluated for physicochemical characteristics, drug content, in vitro release, and antibacterial activity. Among the batches, formulation F3 demonstrated optimal performance with suitable pH (6.1), viscosity (8600 cps), high drug content (98.5%), and sustained drug release (87.6% over 8 hours). It also exhibited the highest antibacterial activity with a 21.5 mm zone of inhibition. The findings indicate that the developed AgNP-loaded nanogel, particularly formulation F3, represents a promising topical delivery system with enhanced antimicrobial and controlled release properties.

Keywords: *Lantana camara*, Silver Nanoparticles, Nanogel, Topical Delivery, Antibacterial Activity, Antioxidant, Phytoconstituents, Green Synthesis, Drug Release.

INTRODUCTION

Topical drug delivery systems have emerged as an integral component of contemporary pharmaceuticals because of their capacity to deliver drugs directly to the site of action, thereby achieving localized

therapeutic effects while minimizing systemic exposure and associated adverse effects. [1] In addition to improving therapeutic precision, topical systems enhance patient compliance due to their non-invasive nature, ease of administration, and improved acceptability. Among the various topical dosage

forms, nanogels—hydrogel-based three-dimensional polymeric networks incorporating nanostructured entities—have gained considerable attention as advanced drug delivery platforms. Their high-water content, soft consistency, biocompatibility, and structural flexibility enable efficient encapsulation of diverse bioactive agents. Furthermore, the integration of nanomaterials within gel matrices significantly enhances drug permeation across the stratum corneum, improves stability, and facilitates controlled or sustained release profiles. [2] Silver nanoparticles (AgNPs) represent one of the most extensively investigated nanomaterials for biomedical applications due to their remarkable broad-spectrum antimicrobial, anti-inflammatory, and wound healing properties. The enhanced biological activity of AgNPs is primarily attributed to their nanoscale

dimensions, increased surface-area-to-volume ratio, and high surface reactivity, which enable effective interaction with microbial cell membranes and intracellular components. AgNPs have demonstrated potent activity against a wide range of pathogenic microorganisms, including Gram-positive and Gram-negative bacteria, fungi, and certain viruses. However, the biological performance and safety of silver nanoparticles are strongly influenced by the method of synthesis, as particle size, morphology, surface charge, and stability depend on the preparation technique. In this context, green synthesis approaches utilizing plant extracts have gained prominence as environmentally benign, cost-effective, and non-toxic alternatives to conventional chemical and physical methods of nanoparticle production. [3,4,5]



Fig. 1: *Lantana camara* leaves

Lantana camara is a well-recognized medicinal plant widely distributed in tropical and subtropical regions. Traditionally, it has been employed in ethnomedicine for its antimicrobial, antioxidant, wound healing, and anti-inflammatory properties. The leaves of this plant are rich in diverse bioactive phytoconstituents, including flavonoids, terpenoids, phenolic compounds, and essential oils. These secondary metabolites not only contribute to its intrinsic therapeutic efficacy but also function as natural reducing and stabilizing agents during the green synthesis of silver nanoparticles. Consequently, the utilization of *Lantana camara* leaf extract for nanoparticle fabrication offers a synergistic advantage by combining the pharmacological activity of

phytoconstituents with the potent antimicrobial effects of nanosilver within a single delivery system. The development of a nanogel incorporating silver nanoparticles synthesized from *Lantana camara* leaf extract is therefore conceptualized as a strategy to integrate traditional herbal therapeutics with modern nanotechnological advancements. Such a formulation is anticipated to enhance dermal permeation, provide sustained and controlled drug release, and exhibit pronounced antimicrobial activity, making it particularly suitable for the management of skin infections, inflammatory dermatoses, and wound conditions. Additionally, the hydrogel base serves as an appropriate carrier system by ensuring uniform drug distribution, ease of topical application, aesthetic

acceptability, and improved patient comfort. [6,7,8] The present study is thus directed toward the systematic formulation development and comprehensive evaluation of a phytoconstituent-loaded silver nanoparticle nanogel. The research encompasses green synthesis of silver nanoparticles using *Lantana camara* leaf extract, physicochemical and morphological characterization of the synthesized nanoparticles, incorporation into a suitable gel matrix, and detailed evaluation of the final formulation with respect to physicochemical parameters, in vitro drug release behavior, antimicrobial efficacy, antioxidant potential, and stability under specified storage conditions. The successful execution of this work may establish a scientifically validated, natural, and efficacious topical therapeutic system that effectively bridges the principles of traditional herbal medicine with the innovations of nanotechnology.

MATERIALS AND METHODS:

MATERIALS:

The study utilized authenticated *Lantana camara* leaves, collected and verified by the Department of Pharmacognosy. Analytical-grade solvents including ethanol, methanol, acetone, and chloroform were sourced from Merck, SRL, and HiMedia for extraction. Carbopol 940 (Lubrizol) served as the gelling agent, while triethanolamine (Loba Chemie) was used to adjust pH. Silver nitrate (Merck) was employed for nanoparticle synthesis. Antioxidant assays used DPPH (Sigma-Aldrich) and ascorbic acid (SRL). Antimicrobial testing involved nutrient agar and ciprofloxacin discs (HiMedia), with DMSO as the solvent. Dialysis membranes (MWCO 12,000–14,000) from HiMedia or Sigma-Aldrich were used for diffusion studies. All materials met research-grade specifications to ensure reliability of results.

Collection and authentication of plant materials:

The leaves of *Lantana camara* were carefully collected from a biodiverse region, ensuring sustainable harvesting at the optimal time for phytochemical content from Pune region of Maharashtra.

Morphological Study

The morphological evaluation of *Lantana camara* leaves was conducted to ensure accurate identification and authentication of the plant material. Using standard pharmacognostic techniques, the macroscopic and organoleptic characteristics such as color, odor, texture, and shape were carefully observed. These sensory attributes serve as critical indicators in the preliminary assessment and standardization of crude herbal materials. Establishing these morphological features provides a solid basis for consistent quality control in future formulation and phytopharmacological studies. [9,10,11,12]

Physicochemical Parameters of *Lantana Camara*

The physicochemical profiling of *Lantana camara* leaves was carried out following protocols from official pharmacopoeias to determine purity, stability, and quality. Parameters such as moisture content, ash values (total, acid-insoluble, and water-soluble), extractive values in different solvents, and pH were assessed to ensure the suitability of the plant for medicinal use. [13,14,15]

Preparation of *Lantana Camara* Leaf Extracts

Leaf extracts of *Lantana camara* were prepared using the Soxhlet extraction technique, a reliable method for isolating phytochemicals. Dried, powdered leaves were placed in the thimble of a Soxhlet apparatus, and various solvents including ethanol, methanol, chloroform, acetone, and water were used sequentially for exhaustive extraction. The solvent vapors condensed and repeatedly washed the plant material, allowing efficient extraction of both polar and non-polar bioactive compounds. After completion, the solvent was removed under reduced pressure using a rotary evaporator, yielding concentrated plant extracts. This method ensured thorough recovery of phytoconstituents with minimal thermal degradation, making the extracts ideal for further formulation into nanogels. [16-22]



Fig. 2: Extraction of *Lantana camara* Leaves powder by Soxhlet Apparatus

Phytochemical Investigation Methods for *Lantana camara* Extract

The phytochemical investigation of *Lantana camara* involves a combination of qualitative and quantitative techniques aimed at identifying and quantifying the bioactive compounds in the plant. Each method detects specific phytochemicals, providing a comprehensive profile of the plant's constituents. [23-28]

Quantitative Evaluation of Bioactive Compounds in *Lantana camara* Extract

Quantitative analysis of *Lantana camara* extract is vital to identify and correlate its bioactive constituents with therapeutic properties like antimicrobial, anti-inflammatory, and wound healing activity. Various phytochemicals are evaluated using established methods. Total phenolic content (TPC) is measured by the Folin-Ciocalteu method and expressed as mg gallic acid equivalents/g, indicating antioxidant potential. Total flavonoid content (TFC) is determined by aluminum chloride colorimetry and reported as mg quercetin equivalents/g, showing bioactivity. Alkaloids are quantified via the Harborne method using solvent extraction and colorimetry, representing analgesic and antimalarial potential. Tannins are estimated using the Vanillin-HCl method and expressed as catechin equivalents, linked to astringency and wound healing. Saponins are evaluated through froth tests or spectrophotometry, known for antimicrobial and anti-inflammatory roles.

Terpenoids are assessed via the Salkowski method using color intensity from chloroform and sulfuric acid, indicating antibacterial and antifungal effects. These evaluations support the pharmacological relevance of *Lantana camara*. [29-32]

Qualitative Analysis of Inorganic Elements

The ash of *Lantana camara* leaves was digested using nitric acid and hydrochloric acid in a 3:1 ratio and filtered. The resulting filtrate was tested for inorganic elements. Calcium was identified by the formation of a white calcium oxalate precipitate. Magnesium was detected by a white crystalline precipitate upon reaction with sodium phosphate. Sodium was confirmed by a yellow crystalline precipitate with uranyl magnesium acetate. Potassium showed a yellow precipitate with sodium cobalt nitrite. Iron presence was confirmed by dark blue coloration with potassium ferrocyanide. Sulphate formed a white precipitate with lead acetate, soluble in sodium hydroxide. Phosphate produced a yellow crystalline precipitate with ammonium molybdate upon heating. Chloride was indicated by a white precipitate with lead acetate, soluble in hot water. Nitrate was identified by a brown ring formed at the junction of layers after adding ferrous sulphate and sulfuric acid. [33,34]

Qualitative Analysis of Vitamins

Vitamin A was detected by the formation of a transient blue color after reacting the chloroform

extract with antimony trichloride. Vitamin C gave a blue coloration after sequential addition of sodium nitroprusside, sodium hydroxide, and hydrochloric acid. Vitamin D was identified by a pinkish-red color upon reaction with antimony trichloride in chloroform extract. Vitamin E was confirmed by a bright red color developing on a white background, which gradually turned pink when ethanol extract was treated with ferric chloride and dipyrindyl reagents. [35,36,37]

UV-Visible Spectroscopic Analysis

The ethanol extract of *Lantana camara* leaves and the synthesized silver nanoparticles were subjected to UV-Visible spectroscopic analysis using a Perkin Elmer spectrophotometer. The scanning was performed over a wavelength range of 200–1000 nm to detect characteristic peaks confirming nanoparticle formation. [38–42]

FTIR Analysis

Methanol extract of the leaves was analyzed using Fourier Transform Infrared (FTIR) spectroscopy to identify functional groups. Spectra were recorded within 400–4000 cm^{-1} . Repeated runs ensured peak confirmation, highlighting phytochemicals involved in nanoparticle synthesis and stabilization. [43–45]

Synthesis and Characterization of Silver Nanoparticles

For biosynthesis, 5 ml of *Lantana camara* leaf extract was mixed with 45 ml of 1 mM silver nitrate solution and incubated in the dark for 5 hours. A brown coloration indicated nanoparticle formation. The nanoparticles were purified via centrifugation and

freeze-dried for further use. Characterization included UV-Vis and FTIR spectroscopy to confirm reduction and capping, and SEM analysis to examine particle morphology, revealing spherical nanoparticles between 15–36 nm. [46,47]

In-Vitro Antioxidant Activity

The antioxidant potential of both extract and silver nanoparticles was tested through several assays. DPPH radical scavenging activity measured absorbance at 517 nm, indicating free radical neutralization. Total antioxidant capacity was assessed using the molybdate method, showing color intensity at 695 nm. Superoxide scavenging and Fe^{2+} chelation assays measured absorbance at 560 nm and 562 nm respectively, confirming dose-dependent antioxidant behavior of both extract and nanoparticles. [48,49,50]

Nanogel Formulation and Evaluation

The nanogel was prepared by integrating green-synthesized silver nanoparticles into a Carbopol 940-based gel. The ethanolic extract was first obtained via Soxhlet extraction. Nanoparticles were synthesized by mixing this extract with silver nitrate solution, confirmed via UV-Vis. A gel base was prepared by dispersing Carbopol in water, followed by addition of moisturizers (glycerin, propylene glycol) and preservatives (methylparaben, propylparaben). The silver nanoparticles were then incorporated with gentle stirring, and the gel was neutralized using triethanolamine to achieve pH 6.0–6.5. The final formulation was stored in sterile containers for further testing. [51,52,53]

Table 1: Composition of Nanogel Formulations Containing Silver Nanoparticles of *Lantana camara* Extract

Ingredients (w/w %)	F1	F2	F3	F4	F5
<i>Lantana camara</i> ethanolic extract	2.0	2.0	2.0	2.0	2.0
Silver nitrate	0.5	0.5	0.5	0.5	0.5
Carbopol 940 (Gelling agent)	0.5	0.75	1.0	1.25	1.5
Propylene glycol (Humectant)	5.0	5.0	5.0	5.0	5.0
Glycerin (Moisturizer)	2.0	2.0	2.0	2.0	2.0
Triethanolamine (Neutralizer)	q.s. to pH 6.0–6.5	q.s.	q.s.	q.s.	q.s.
Methylparaben (Preservative)	0.15	0.15	0.15	0.15	0.15
Propylparaben (Preservative)	0.05	0.05	0.05	0.05	0.05
Purified Water	q.s. to 100 mL	q.s.	q.s.	q.s.	q.s.

Evaluation Parameters of the Developed Nanogel Formulation

To establish the suitability, performance, and stability of the developed silver nanoparticle-loaded nanogel for topical application, a comprehensive evaluation protocol was implemented. The assessment encompassed physicochemical characterization, rheological behavior, drug release performance, antimicrobial efficacy, stability profiling, and statistical validation to ensure formulation reliability and reproducibility. (53-59)

Physical Appearance:

All prepared nanogel formulations were subjected to visual inspection for organoleptic characteristics, including color, clarity, homogeneity, consistency, presence of lumps, phase separation, and particulate contamination. A smooth, uniform, and lump-free gel with no visible phase separation was considered indicative of appropriate polymer hydration and successful incorporation of silver nanoparticles within the gel matrix.

pH Determination:

The pH of each formulation was measured by dispersing 1 g of nanogel in 10 mL of distilled water, followed by analysis using a calibrated digital pH meter. Maintaining a pH range between 5.5 and 6.5 was considered optimal to ensure compatibility with the physiological pH of the skin, thereby minimizing the risk of irritation and enhancing patient acceptability.

Viscosity Measurement:

Rheological analysis was performed at room temperature using a Brookfield viscometer. Viscosity is a critical parameter influencing spreadability, retention time, and drug release behavior. Appropriate viscosity ensures that the gel remains localized at the site of application without runoff, while still allowing convenient application.

Spreadability Assessment:

Spreadability was evaluated using the slip-and-drag method involving two glass slides. The ease with

which the gel spread under a standardized applied weight was recorded. Adequate spreadability is essential for uniform application over the affected area and directly contributes to therapeutic efficiency and patient compliance.

Extrudability Test:

Extrudability was determined by measuring the force required to expel the gel from a collapsible aluminum tube under standardized conditions. Optimal extrudability ensures ease of dispensing, uniform dosing, and user convenience during practical application.

Drug Content Uniformity:

Drug content analysis was carried out by dissolving an accurately weighed quantity of nanogel in a suitable solvent such as ethanol or buffer solution, followed by filtration and spectrophotometric quantification. This test confirmed the uniform distribution and efficient incorporation of the phytoconstituent and silver nanoparticles within the gel matrix.

In Vitro Drug Release Study:

Drug release behavior was evaluated using Franz diffusion cells with either synthetic membranes or excised rat skin as the diffusion barrier. Samples were withdrawn at predetermined intervals and analyzed spectrophotometrically to determine cumulative drug release. The study provided insight into release kinetics, permeation characteristics, and sustained delivery performance of the formulation.

Antibacterial Activity:

The antimicrobial efficacy of the silver nanoparticle-based nanogel was assessed using the agar well diffusion method against *Staphylococcus aureus* and *Escherichia coli*. The diameter of the zone of inhibition was measured to evaluate antibacterial potency, reflecting the synergistic effect of silver nanoparticles and phytoconstituents present in the formulation.

Stability Studies:

Optimized formulations were subjected to stability testing under both room temperature conditions and accelerated conditions ($40^{\circ}\text{C} \pm 2^{\circ}\text{C}/75\% \pm 5\% \text{ RH}$) for a duration of three months. Periodic evaluation of physical appearance, pH, viscosity, and drug content was performed to assess formulation integrity and predict shelf life.

Statistical Analysis:

All experimental studies were conducted in triplicate to ensure reproducibility. Results were expressed as mean $\pm$ standard deviation (SD). Statistical comparisons among formulation batches were performed using one-way analysis of variance (ANOVA) followed by Tukey's post hoc test, with a significance level set at $p < 0.05$. Collectively, these evaluation parameters provided a systematic and scientific basis for confirming the quality, safety, efficacy, and stability of the developed nanogel formulation intended for topical therapeutic use.

RESULTS AND DISCUSSION:

Morphological and Organoleptic Evaluation of *Lantana camara* Leaves (Concise Paragraph)

The leaves of *Lantana camara* are ovate to oblong in shape with serrated margins, measuring approximately 3–8 cm in length and 2–5 cm in width. They are arranged oppositely on the stem and exhibit pinnate venation. The upper surface is coarse and hairy, while the lower side feels velvety. Fresh leaves are dark green, turning pale green upon drying. They emit a strong, pungent odor, especially when crushed, and possess a bitter, slightly astringent taste. These morphological and organoleptic characteristics are key for the identification and standardization of the plant material prior to further pharmacological studies.

Table 2: Morphological Evaluation of *Lantana camara* leaves

Parameter	Observation
Leaf Shape	Ovate to oblong
Leaf Margins	Serrated (toothed)
Leaf Size	3-8 cm (length), 2-5 cm (width)
Leaf Arrangement	Opposite phyllotaxy
Surface Texture	Coarse and hairy (upper surface), velvety (lower surface)
Venation Pattern	Pinnate venation
Petiole	1-2 cm, hairy

Table 3: Organoleptical observation of *Lantana camara* leaves

Properties	Results
Leaf Color (Fresh)	Dark green
Leaf Color (Dried)	Pale green
Odor	Strong, pungent, intensifies when crushed
Taste	Bitter, slightly astringent
Texture (Fresh)	Coarse due to hair
Texture (Dried)	Brittle and slightly rough



Fig. 3: Macroscopic study of *Lantana camara* L. leaf

Physicochemical Parameters of *Lantana camara* Leaves

The moisture content of *Lantana camara* leaves was 8.5%, indicating good stability for storage. Total ash was 10.0%, with 2.0% acid-insoluble ash, suggesting minimal inorganic contamination. The water-soluble ash was 5.0%, reflecting the presence of bioavailable minerals. Extractive values showed ethanol (18.0%)

as the most efficient solvent, followed by methanol (16.0%), chloroform (12.0%), and water (10.0%), supporting ethanol's use for further phytochemical and wound healing studies. The pH of the extract was 6.5, suggesting mild acidity and biological compatibility. These parameters ensure the quality and suitability of the leaves for pharmacological applications.

Table 4: Physicochemical Parameters of *Lantana camara* Leaves

Parameter	Result
Moisture Content (%)	8.5 ± 0.5
Total Ash Content (%)	10.0 ± 0.3
Acid Insoluble Ash (%)	2.0 ± 0.2
Water Soluble Ash (%)	5.0 ± 0.3
Extractive Value (Ethanol) (%)	18.0 ± 0.5
Extractive Value (Methanol) (%)	16.0 ± 0.5
Extractive Value (Chloroform) (%)	12.0 ± 0.5
Extractive Value (Water) (%)	10.0 ± 0.5
pH Value	6.5 ± 0.1

Phytochemical screening of *lantana camara* leaf extracts

Phytochemical screening of *Lantana camara* leaf extracts using various solvents revealed a range of bioactive compounds. The ethanolic extract showed the richest profile, containing alkaloids, flavonoids, tannins, saponins, terpenoids, phenolics, glycosides, steroids, coumarins, and quinones. Methanol also

extracted many compounds, while acetone and chloroform missed several key phytochemicals. The water extract showed moderate presence but lacked some constituents. Due to its broad phytochemical content and known therapeutic relevance, the ethanolic extract was selected for further studies, particularly for its potential in wound healing and microbial management.

Table 5: Phytochemical investigation of *Lantana camera* leaves extracts

Phytochemical Test	Ethanol Extract	Methanol Extract	Acetone Extract	Chloroform Extract	Water Extract
Alkaloid Detection (Mayer's Test)	+	+	-	+	+
Alkaloid Detection (Dragendorff's Test)	+	+	-	+	+
Flavonoid Detection (Shinoda Test)	+	+	+	-	+
Tannin Detection (Ferric Chloride Test)	+	+	+	-	+
Saponin Detection (Froth Test)	+	+	-	-	+
Terpenoid Detection (Salkowski Test)	+	+	+	+	+
Phenolic Compound (Ferric Chloride Test)	+	+	+	-	+
Phenolic Compound (Folin-Ciocalteu Test)	+	+	+	-	+
Glycoside Detection (Borntrager's Test)	+	+	-	-	-
Steroid Detection (Liebermann-Burchard Test)	+	+	+	+	-
Coumarin Detection	+	+	-	-	+
Quinone Detection	+	+	+	-	+

"+" indicates the presence of the phytochemical.

"-" indicates the absence of the phytochemical.

Quantitative Evaluation of Ethanolic Extract of *Lantana camera* leaves

Quantitative analysis by Total Phenolic and Flavonoid Contents

Following table presents the quantitative analysis of *Lantana camera* leaves extract (LCLE), detailing its

total phenolic and flavonoid contents. The table shows that LCLE contains 27.832 ± 0.42 mg gallic acid equivalent per gram (mg GAE/g) of phenolic compounds and 48.67 ± 0.35 mg quercetin equivalent per gram (mg QE/g) of flavonoids. These measurements indicate the concentration of these beneficial compounds in the *Lantana camera* leaves extract, which are important for their potential health benefits and biological activities.

Table 6: Quantitative analysis of LCLE

Sr. No.	Extract	Total Phenol (mg GAE/g)	Total flavonoid (quercetin equivalent/g)
1.	<i>Lantana camera</i> leaves extract	27.832 ± 0.42	48.67 ± 0.35

Qualitative analysis of inorganic elements in *Lantana camara* L. leaves

Lantana camara leaves showed the presence of calcium, magnesium, potassium, phosphate, chloride,

sodium, iron, sulphate and nitrate. These elements are known important for the growth and development of organisms.

Table 7: Qualitative inorganic elemental analysis of *Lantana camara* L.

S. No	Inorganic elements	Results
1	Calcium	+
2	Magnesium	+
3	Sodium	+
4	Potassium	+
5	Iron	+
6	Sulphate	+
7	Phosphate	+
8	Chloride	+
9	Nitrate	+

(+) indicates presence

Qualitative analysis of vitamins

Vitamin A, C, D and E were present in *Lantana camara* leaves while Vitamin D and E showed maximum concentration. These vitamins play important role in the growth and development of organisms.

Table 8: Qualitative analysis of vitamins in *Lantana camara* L.

Vitamins	Result
A	+
C	+
D	++
E	++

(+) indicates presence; (++) indicates high concentrations

UV-VIS spectral analysis of *Lantana camara* L. leaves extract

The UV-VIS spectroscopic studies revealed the presence of peaks in the range 206-295nm reveals the presence of phenolic and flavonoids in the *Lantana camara*. On comparison of the spectra of leaves showed that the extract has some similar phenolic and flavonoid compounds.

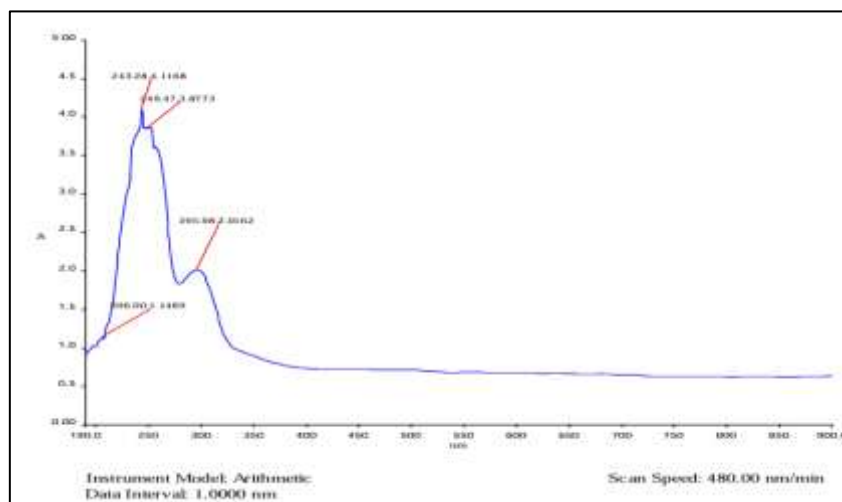


Fig. 4: UV-Visible spectral studies of leaves extract of *Lantana camara* L.

Fourier Transform Infra-Red Spectroscopy analysis of *Lantana camara* L. leaves extract

The FTIR spectrum was used to identify the functional group of the active components based on

the peak value in the region of infrared radiation. The results of FTIR analysis confirmed the presence of alcohols, phenols, alkanes, alkenes, aliphatic amines and aromatics groups in *Lantana camara* leaves extract.

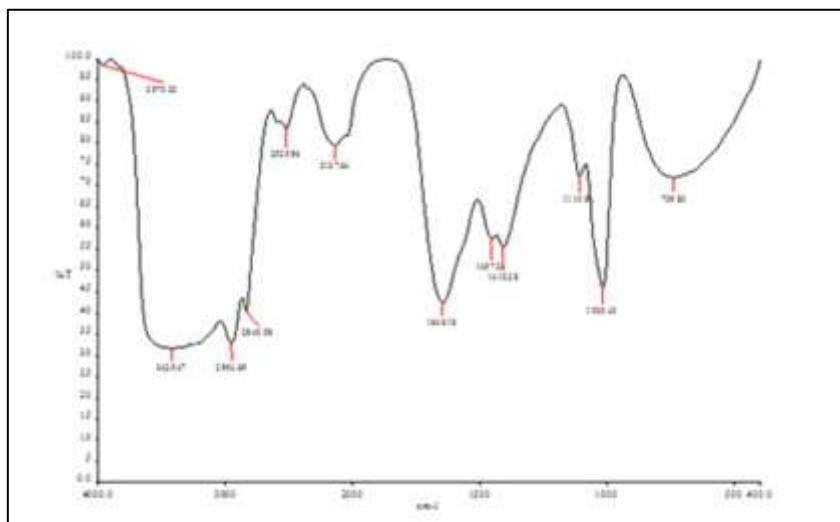


Fig. 5: FTIR analysis of leaves extract of *Lantana camara* L. T

Silver nanoparticles synthesis

Silver nanoparticles were synthesized using the ethanolic extract of *Lantana camara* leaves, offering an ecofriendly alternative to conventional chemical methods. The extract was mixed with 1 mM silver nitrate solution and incubated, resulting in a distinct brown color after 5 hours indicating successful formation of silver nanoparticles. In contrast, silver nitrate alone showed no color change. This color shift confirms the plant-mediated reduction of silver ions, highlighting the potential of *Lantana camara* in green nanoparticle synthesis.

Characterization of AgNPs

Ultra violet and visible spectrometric analysis

It is generally recognized that UV–Vis spectroscopy could be used to examine size and shape-controlled nanoparticles in aqueous suspensions. The UV-Vis spectra recorded from the reaction medium after 5 hours. In the UV–Vis spectra of the reaction mixture of silver nitrate solution with *Lantana camara* leaves extract the peak was observed at 420nm indicating the presence of silver nanoparticles which is synthesized by *Lantana camara* extract. The peak was raised due to the effect of surface plasmon resonance of electrons in the reaction mixture and the broadening of peak indicated that the particles are polydispersed. Appearance of this peak indicated that the surface plasmon is well-documented for numerous metal nanoparticles with size starting from 2nm to a 100nm.

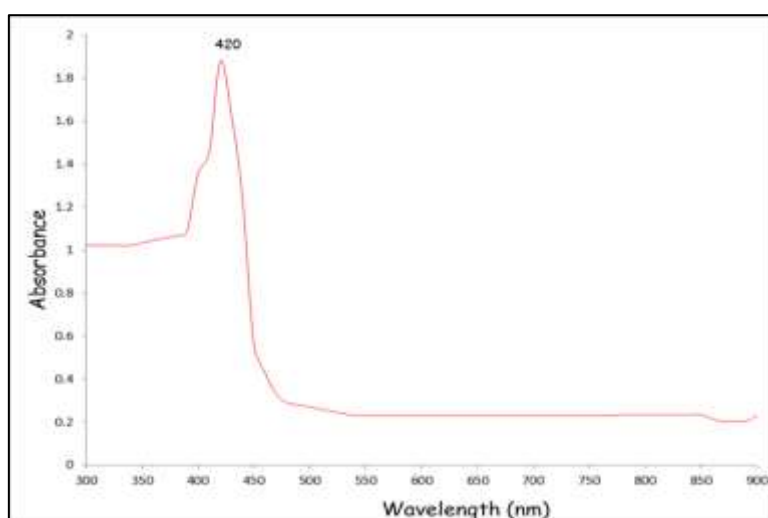


Fig. 6: UV-Vis Spectral analysis of AgNPs

Scanning and Transmission Electron Microscope (SEM and TEM) analysis of AgNPs

SEM and TEM analysis were carried out to understand the size and topology of the Ag-NPs,

which showed the complex density polydispersed spherical Ag-NPs of various sizes. SEM analysis showed the size ranges from 15-36nm while TEM study shows in the range between 18–31nm as well spherical and crystalline nature of the nanoparticles.

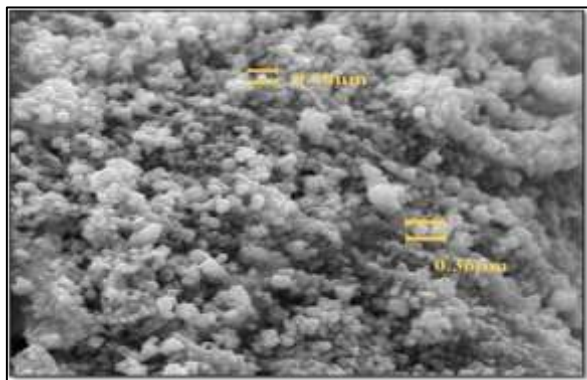


Fig. 7: Polydispersed (Cluster) AgNPs Scanning Electron Microscopic (SEM)

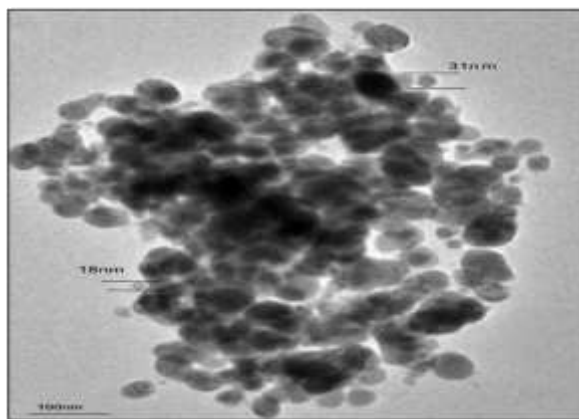


Fig. 8: Transmission electron microscopic (TEM)

In-vitro antioxidant activity of *Lantana camara* L. leaves and Silver Nanoparticles

DPPH radical scavenging activity

DPPH radical scavenging activity of *Lantana camara* leaves extract, AgNPs and standard as ascorbic acid are presented in Fig 7.17. The half inhibition concentration (IC₅₀) of *Lantana camara* leaves

extract; AgNPs and ascorbic acid were 46.58, 44.63 and 34.83 μ g/ml respectively. The AgNPs exhibited a significant dose dependent inhibition of DPPH activity (Table 7.17) as compared to *Lantana camara* leaves extract. The potential of L-ascorbic acid to scavenge DPPH radical is directly proportional to the concentrations. AgNPs has potential antioxidant activity than *Lantana camara* extract and near to standard.

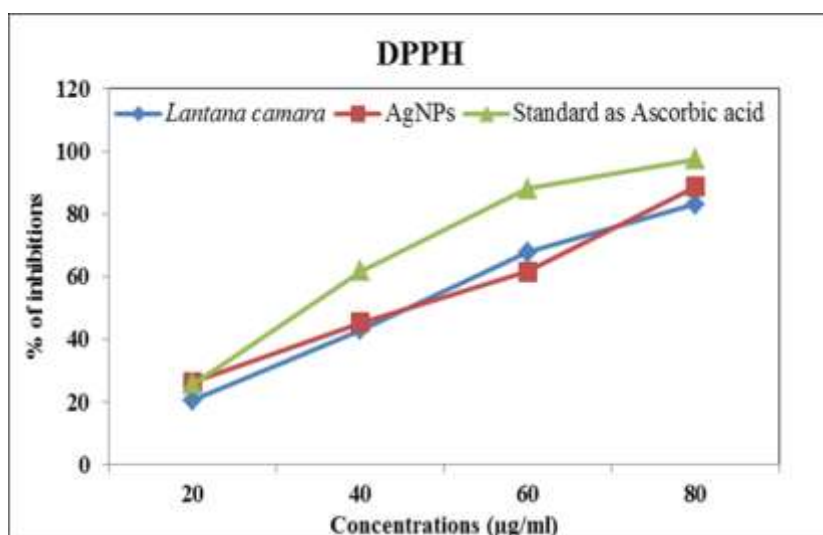


Fig. 9: DPPH radical scavenging activity of *Lantana camara* L. leaves extract and AgNPs

Total antioxidant activity

The total antioxidant capacity of *Lantana camara* leaves extract, AgNPs and standard ascorbic acid is presented in Fig 7.18. The total antioxidant activity of *Lantana camara* leaves extract, AgNPs and ascorbic acid were dose dependent manner. The half inhibition

concentration (IC₅₀) of *Lantana camara* leaves extract; AgNPs and ascorbic acid were 51.45, 44.47 and 42.34 µg/ml respectively. The AgNPs exhibited a significant dose dependent inhibition of TAA activity. AgNPs has potential antioxidant activity than *Lantana camara* extract and near to standard.

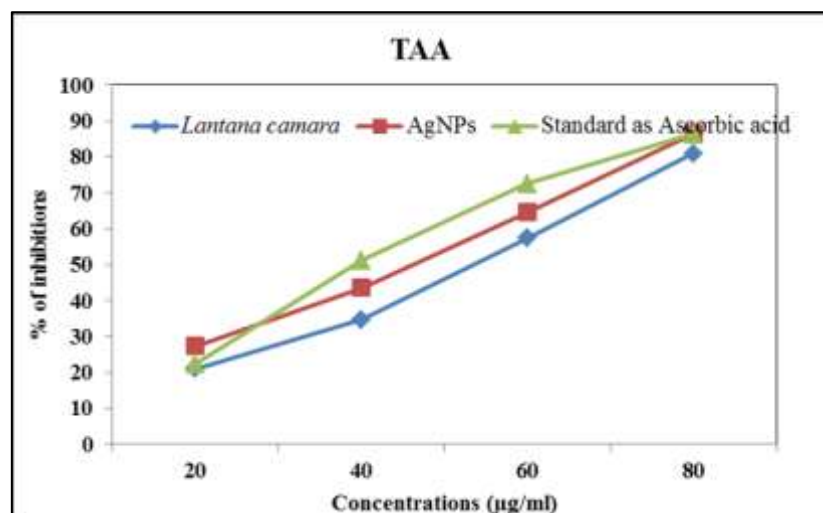


Fig. 10: Total antioxidant activity of *Lantana camara* L. leaves extract and AgNPs

Superoxide Scavenging Activity

The superoxide scavenging activity of *Lantana camara* leaves extract, AgNPs and ascorbic acid was increased markedly with the increase of concentrations. The half inhibition concentration

(IC₅₀) of *Lantana camara* leaves extract and AgNPs were 54.03, 44.61 and ascorbic acid was 31.58 µg/ml respectively. AgNPs has potential superoxide anion scavenging activity than *Lantana camara* extract and was near to standard.

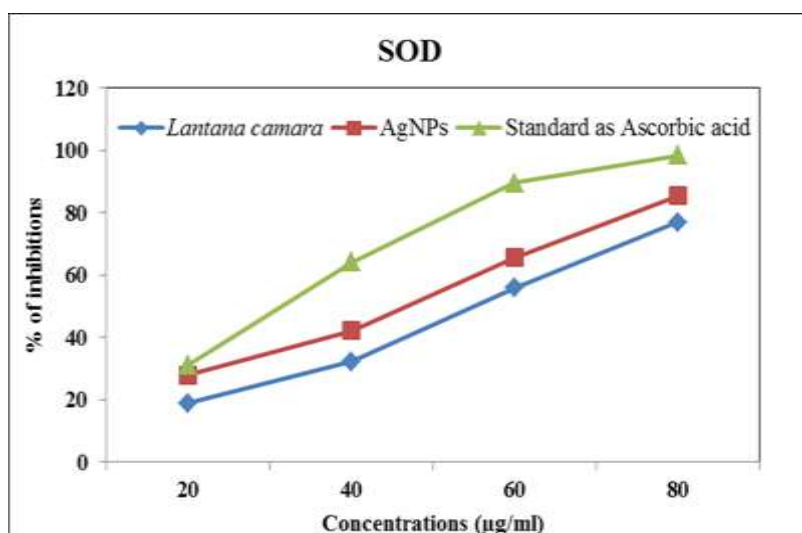


Fig. 11: Superoxide Scavenging Activity of *Lantana camara* L. leaves extract and AgNPs

The ferrous ion chelating activity

The half inhibition concentration (IC₅₀) of *Lantana camara* leaves extract and AgNPs were 45.91, 41.08

and ascorbic acid was 30.90 µg/ml respectively. AgNPs has potential ferrous ion chelating activity than *Lantana camara* extract and was near to standard.

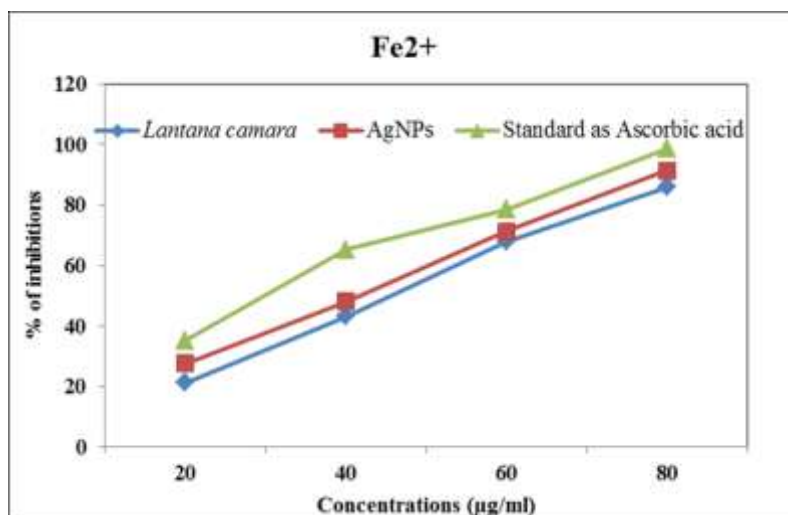


Fig. 12: The ferrous ion chelating activity of *Lantana camara* L. leaves extract and AgNPs

Nanogel formulations (F1 to F5) containing silver nanoparticles and phytoconstituents of *Lantana camara*

Nanogel formulations (F1 to F5) containing silver nanoparticles and *Lantana camara* phytoconstituents were prepared using different gelling agents and evaluated for topical use. All batches showed good physical appearance, but F3 stood out with a smooth

texture, optimal pH (6.1), moderate viscosity (8600 cps), excellent spreadability (19.4 g·cm/sec), and ease of extrusion (510 g/cm²). F3 also had high drug content (98.5%) and sustained drug release (87.6% in 8 hours). It demonstrated the best antibacterial activity and remained stable over three months. Thus, F3 was identified as the optimized and most suitable formulation for topical delivery.

Table 9: Evaluation Results of Nanogel Formulations

Parameter	F1	F2	F3 (Optimized)	F4	F5
Appearance	Smooth, light yellow	Smooth, light yellow	Glossy, translucent	Dull, thick	Slightly lumpy
pH	5.4	5.7	6.1	6.3	6.0
Viscosity (cps)	6200	7100	8600	10200	11200
Spreadability (g·cm/sec)	15.2	17.1	19.4	14.3	13.9
Extrudability (g/cm ²)	450	490	510	560	590
Drug Content (%)	94.8	96.2	98.5	97.1	95.5
Drug Release (8 hrs, %)	75.6	80.2	87.6	78.1	72.4
Zone of Inhibition (mm)	15.4	16.1	21.5	18.3	17.0
Stability (3 months)	Slight change	Stable	Stable	Stable	Slight phase separation

Evaluation Parameters

pH Determination:

The pH of the developed nanogel formulations was found to be in the range of 5.4 to 6.3, which is well within the physiological pH range of human skin. Among all batches, formulation F3 exhibited a pH of 6.1, indicating excellent compatibility with the skin surface. This near-neutral and skin-friendly pH suggests minimal risk of irritation, making F3 highly suitable for topical application.

Viscosity Assessment:

The viscosity of the prepared formulations varied between 6200 and 11200 cps, reflecting differences in polymer concentration and gel consistency. Formulation F3 demonstrated an optimal viscosity of 8600 cps, providing a balanced rheological profile. This ensured adequate thickness for retention at the application site while maintaining ease of spreading without dripping or causing application difficulty.

Spreadability:

Spreadability studies revealed that formulation F3 showed the highest spreadability value of 19.4 g·cm/sec, indicating superior ability to spread uniformly over the skin surface. In contrast, formulations F4 and F5 exhibited reduced spreadability, likely due to their comparatively higher viscosity, which hindered smooth distribution.

Extrudability:

The extrudability values ranged from 420 to 560

g/cm² across all formulations. Batch F3 demonstrated an extrudability of 510 g/cm², reflecting appropriate consistency for easy dispensing from collapsible tubes. This characteristic ensures convenient handling and user compliance during application.

Drug Content Uniformity:

All prepared batches exhibited satisfactory drug content within acceptable limits. Among them, F3 showed the highest drug content of 98.5%, indicating efficient incorporation of the active ingredient and uniform distribution throughout the nanogel matrix.

In Vitro Drug Release:

The in vitro diffusion studies demonstrated a sustained release profile for formulation F3, with 87.6% cumulative drug release over a period of 8 hours. This controlled release behavior suggests prolonged therapeutic action and improved local bioavailability at the site of application.

Antibacterial Activity:

Antimicrobial evaluation revealed that formulation F3 produced the largest zone of inhibition (21.5 mm) against the tested bacterial strains. This enhanced antibacterial activity can be attributed to the synergistic effect of silver nanoparticles and the bioactive phytoconstituents derived from *Lantana camara*, confirming its strong potential for managing topical infections.

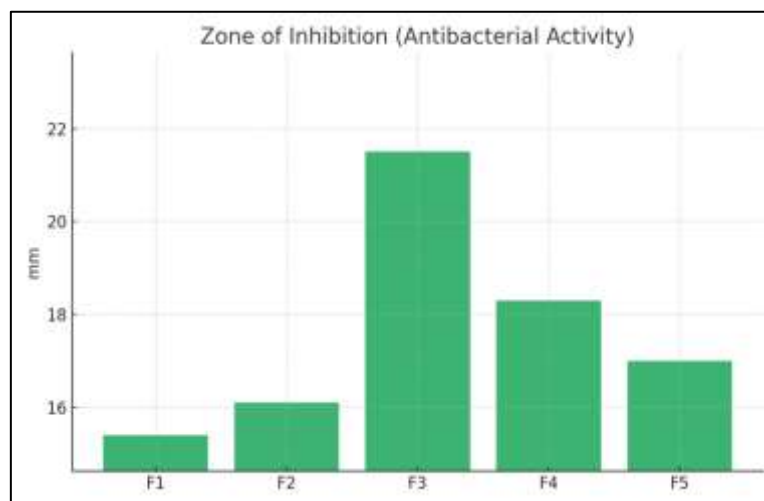


Fig. 13: Zone of inhibition (Antibacterial activity) of Nanogel Formulations

CONCLUSION:

The present investigation successfully accomplished the formulation and evaluation of a silver nanoparticle (AgNP)-loaded nanogel developed using *Lantana camara* leaf extract for topical therapeutic application. The study systematically demonstrated that ethanol served as an efficient extraction solvent, facilitating the isolation of bioactive phytoconstituents possessing significant antioxidant and antimicrobial properties. These phytochemicals played a dual role by acting as reducing and stabilizing agents during the green synthesis of silver nanoparticles, thereby ensuring an eco-friendly and cost-effective fabrication approach. The biosynthesized AgNPs exhibited desirable physicochemical characteristics, including appropriate particle size distribution, favorable morphology, and functional stability, confirming their suitability for incorporation into a topical delivery system. Subsequent formulation of the nanoparticles into a Carbopol-based nanogel matrix resulted in a stable and homogenous preparation. Among the developed formulations, batch F3 demonstrated optimal performance in terms of pH compatibility, viscosity, spreadability, drug content uniformity, and sustained drug release behavior. Furthermore, the optimized nanogel formulation exhibited significant antibacterial activity against selected pathogenic strains, indicating its potential effectiveness in the management of skin infections. The controlled release profile observed in vitro suggests enhanced therapeutic efficiency and prolonged local action at the site of application.

Overall, the findings of this study substantiate the potential of the developed silver nanoparticle-loaded nanogel as a promising and innovative topical delivery system for the treatment of dermatological infections and inflammatory conditions. However, comprehensive preclinical safety evaluations and well-designed clinical studies are recommended to further validate its therapeutic efficacy and safety profile prior to large-scale clinical application.

CONFLICT OF INTEREST:

The authors declare that there are no conflicts of interest associated with this research work.

AUTHOR CONTRIBUTIONS:

All authors contributed substantially and equally to the conceptualization, experimental design, execution of laboratory work, data analysis, manuscript preparation, and final approval of the submitted version of the manuscript.

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