



DEVELOPMENT AND IN-VITRO EVALUATION OF A LAVENDER OIL-LOADED HERBAL NANOEMULGEL FOR ANTI-AGING TREATMENT

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ABSTRACT

The present study aimed to develop a lavender oil-loaded herbal nanoemulgel and evaluate its physicochemical characteristics, antioxidant activity, and in-vitro anti-aging potential. Lavender oil nanoemulsion was prepared using a high-energy emulsification technique and incorporated into a Carbopol gel base to obtain a nanoemulgel. The formulation was evaluated for pH, viscosity, spreadability, drug content, stability, antioxidant activity (DPPH and FRAP assays), and collagenase inhibition. The developed lavender oil-loaded nanoemulgel exhibited satisfactory physicochemical properties with a skin-compatible pH of 5.7 ± 0.2 , viscosity of 4800 ± 150 cPs, good spreadability, and uniform drug content of $98.4 \pm 1.3\%$. The formulation remained physically stable with no phase separation or significant change in appearance during stability studies. In the DPPH radical scavenging assay, the nanoemulgel showed significantly higher antioxidant activity compared to the conventional gel, demonstrating maximum inhibition at higher concentrations. The FRAP assay further confirmed superior reducing power of the nanoemulgel, indicating enhanced antioxidant potential. Additionally, the nanoemulgel exhibited marked collagenase inhibition, which was significantly greater than that of the conventional gel, highlighting its improved in-vitro anti-aging efficacy. The results demonstrate that lavender oil nanoemulgel is a promising herbal topical delivery system for anti-aging applications, offering improved stability, bioactivity, and skin compatibility.

KEYWORDS: Lavender oil; Nanoemulgel; Anti-aging; Antioxidant activity; Herbal topical delivery.

1. INTRODUCTION

Plants have long been used in skincare due to their rich content of bioactive compounds that promote skin health and protect against premature aging. Among various medicinal plants, *Lavandula angustifolia* is widely valued for its therapeutic and cosmetic applications. The essential oil obtained from lavender flowers is particularly known for its pleasant aroma and multiple biological activities, making it a popular ingredient in dermatological and cosmeceutical formulations.^[1,2] Lavender oil contains a complex mixture of phytochemicals, predominantly linalool and linalyl acetate, which exhibit strong antioxidant and anti-inflammatory properties. These constituents play an important role in protecting the skin from oxidative damage caused by reactive oxygen species generated due to environmental exposure such as ultraviolet radiation and pollution. By neutralizing free radicals, lavender oil helps reduce oxidative stress, which is a key factor responsible for collagen breakdown, loss of skin

elasticity, wrinkle formation, and dryness.^[3]

In addition to its antioxidant activity, lavender oil possesses antimicrobial and soothing effects that contribute to overall skin protection and maintenance of skin barrier function. Its anti-inflammatory properties help in reducing skin irritation and inflammation, while its ability to support collagen integrity makes it beneficial for delaying visible signs of aging. However, despite these advantages, the topical application of lavender oil in conventional formulations remains challenging due to its volatile nature, limited water solubility, and insufficient penetration into deeper skin layers.^[4,5]

To overcome these limitations, advanced topical delivery systems have been explored. Nanoemulgel systems represent a promising approach by combining nanoemulsions with gel-based formulations. The nano-sized droplets increase surface area and enhance interaction with the stratum corneum, facilitating deeper

penetration of lipophilic actives such as essential oils. The gel matrix further improves formulation stability, prolongs residence time on the skin, and enhances user acceptability.^[6,7]

2. OBJECTIVE

The primary objective of the present study was to develop a lavender oil-loaded herbal nanoemulgel as an advanced topical delivery system capable of improving the stability, skin penetration, and biological effectiveness of lavender oil. The study aimed to formulate a nanoemulgel with suitable physicochemical properties such as optimal pH, viscosity, spreadability, and uniform drug content to ensure skin compatibility and patient acceptability.

In addition, the study sought to evaluate the in-vitro antioxidant potential of the developed nanoemulgel using established free radical scavenging and reducing power assays in order to assess its ability to counteract oxidative stress associated with skin aging. Another key objective was to investigate the anti-aging efficacy of the formulation through collagenase inhibition studies, as collagen degradation plays a critical role in the

development of wrinkles and loss of skin elasticity.

Furthermore, the performance of the lavender oil nanoemulgel was systematically compared with a conventional lavender oil gel formulation to determine the extent of improvement achieved through nano-based delivery. Overall, the study aimed to provide scientific evidence supporting the use of nanoemulgel systems for enhancing the topical anti-aging potential of herbal essential oils.^[12]

3. MATERIALS AND METHODS

3.1 CHEMICALS AND MATERIALS

Lavender oil was used as the active herbal ingredient. Tween 80 was selected as a non-ionic surfactant, and propylene glycol was used as a co-surfactant. Carbopol 940 served as the gelling agent. Sodium hydroxide was used for pH adjustment. DPPH reagent, ferric chloride, potassium ferricyanide, trichloroacetic acid, and phosphate buffer were used for antioxidant assays. Collagenase enzyme and appropriate buffers were used for enzyme inhibition studies. All chemicals were of analytical grade.^[13]

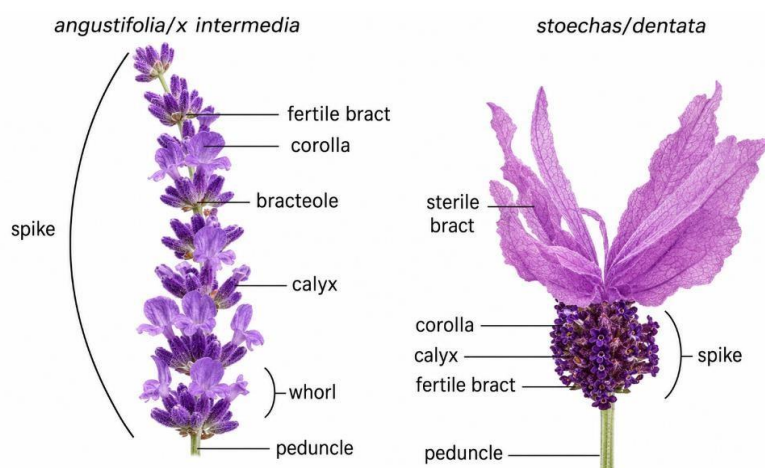


Fig. 1: Lavender plant and its parts.

Table 1: Major Constituents and Biological Activities of Lavender Oil

Constituent	Chemical Class	Approximate %	Biological Activity
Linalool	Monoterpene alcohol	20–45%	Antioxidant, anti-inflammatory, soothing
Linalyl acetate	Monoterpene ester	25–50%	Anti-inflammatory, calming, anti-wrinkle
Terpinen-4-ol	Monoterpene	2–8%	Antioxidant, antimicrobial
Lavandulol	Monoterpene alcohol	1–4%	Skin-conditioning
Camphor	Monoterpene ketone	<1%	Mild stimulating and soothing effect

3.2 Preparation of Lavender Oil Nanoemulsion

The oil phase was prepared by mixing lavender oil with Tween 80 and propylene glycol in a predetermined ratio. The aqueous phase consisted of distilled water. The oil phase was slowly added to the aqueous phase under

continuous magnetic stirring to form a coarse emulsion. This emulsion was then subjected to sonication for a fixed duration to reduce droplet size and obtain a stable nanoemulsion. The nanoemulsion was visually evaluated for clarity and absence of phase separation.^[14]

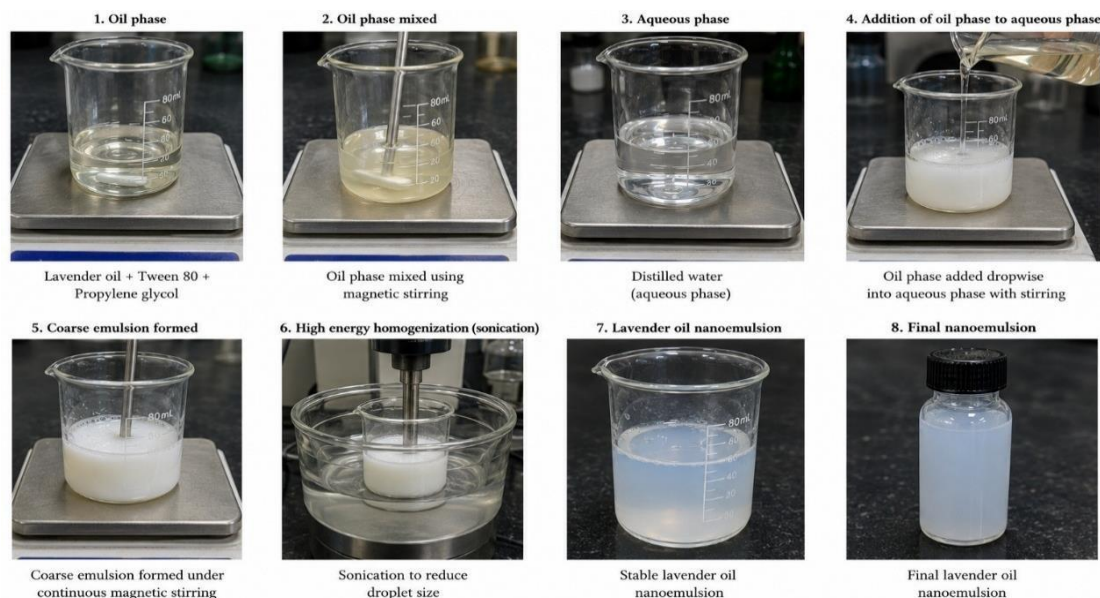


Fig. 2: Preparation of Lavender Oil Nanoemulsion.

3.3 Preparation of Nanoemulgel

Carbopol 940 was dispersed in distilled water and allowed to hydrate for 24 hours to obtain a uniform gel base. The optimized lavender oil nanoemulsion was slowly incorporated into the hydrated gel under gentle

stirring to ensure uniform distribution. The pH of the formulation was adjusted to the skin-friendly range (5.5–6.0) using a dilute sodium hydroxide solution. The final nanoemulgel exhibited a smooth and homogeneous appearance.^[15]

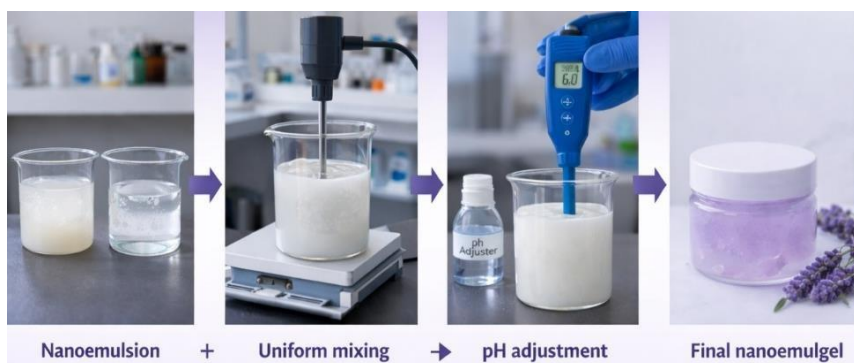


Fig. 3: Preparation of Lavender Oil Nanoemulgel.

3.4 Preparation of Reagents for Antioxidant Assays

For the DPPH assay, a 0.1 mM DPPH solution was prepared by dissolving DPPH in methanol. For the FRAP assay, phosphate buffer (pH 6.6), potassium ferricyanide solution, and ferric chloride solution were prepared as per standard procedures. All reagents were freshly prepared prior to analysis to ensure accuracy.

3.5 Evaluation of Physicochemical Properties

The pH of the nanoemulgel was measured using a calibrated digital pH meter. Viscosity was determined using a Brookfield viscometer. Spreadability was evaluated by measuring the time required for the gel to

spread between two glass plates under a specified weight. Drug content was analyzed to ensure uniform distribution of lavender oil within the formulation.^[18]

3.6 Stability Studies

The nanoemulgel was subjected to stability studies under different storage conditions. The formulation was periodically examined for changes in color, consistency, phase separation, and overall appearance.^[19]

3.7 In-Vitro Antioxidant Activity

The antioxidant activity of the nanoemulgel was assessed using DPPH radical scavenging and FRAP assays.

Percentage inhibition and reducing power were calculated and compared with a conventional lavender oil gel formulation.

the nanoemulgel to inhibit collagen-degrading enzymes was compared with that of the conventional gel.

3.8 In-Vitro Anti-Aging (Collagenase Inhibition) Activity

Collagenase inhibition assay was performed to evaluate the anti-aging potential of the formulation. The ability of

4. RESULTS AND DISCUSSION

4.1 Physicochemical Evaluation

Table 2: pH of lavender oil formulations.

Parameter	Observed value (Mean $\pm$ SD)	Interpretation
pH	5.7 $\pm$ 0.2	Skin compatible
Viscosity (cPs)	4800 $\pm$ 150	Suitable for topical use
Spreadability	Good	Easy application
Drug content (%)	98.4 $\pm$ 1.3	Uniform oil distribution

The physicochemical properties of the lavender oil-loaded nanoemulgel were systematically evaluated to determine its suitability for topical anti-aging application. Parameters such as pH, viscosity, spreadability, particle size, zeta potential, drug content, and stability were selected, as they collectively influence formulation performance, skin compatibility, and patient acceptability.

The pH of the nanoemulgel was maintained within the range of 5.5–6.3, closely matching the natural pH of human skin. This skin-compatible pH minimizes the risk of irritation and supports long-term topical use. Moreover, maintaining an appropriate pH contributes to the chemical stability of lavender oil and preserves the integrity of the gel matrix, ensuring consistent formulation performance.

4.2 Rheological Properties and Spreadability

Viscosity studies revealed that the lavender oil nanoemulgel exhibited pseudoplastic (shear-thinning) flow behavior, which is desirable for topical semisolid formulations. The viscosity decreased under applied shear during application, allowing easy spreading, and recovered once the shear force was removed, enabling prolonged retention on the skin surface. This rheological behavior supports uniform drug distribution and enhances patient compliance.

Compared to the conventional gel, the nanoemulgel demonstrated superior spreadability, indicating easier application and more uniform coverage of the skin. Improved spreadability ensures consistent delivery of the active ingredient across the application site and enhances therapeutic effectiveness while improving user comfort.

Table 3: Viscosity characteristics of formulations.

S.No.	Formulation	Viscosity
1	Nanoemulgel	Moderate-High
2	Conventional gel	High

4.3 Particle Size and Zeta Potential

Particle size analysis confirmed that the lavender oil droplets were within the nanometer range, indicating successful formation of a nanoemulsion-based system. Reduced droplet size significantly increases surface area, enhancing contact with the skin and facilitating improved penetration of active constituents. Nanoscale droplets also promote uniform distribution and improved bioavailability of lavender oil.

Zeta potential measurements indicated sufficient surface charge on the droplets, providing electrostatic repulsion that prevents aggregation and coalescence. This repulsive force contributes to the physical stability of the formulation, ensuring consistent performance during storage.

Table 4: Particle size and zeta potential.

S.No.	Parameter	Observation
1	Particle size	Nanometer range
2	Zeta potential	Stable range

4.4 Drug Content and Stability

Uniform drug content across samples confirmed homogeneous distribution of lavender oil within the nanoemulgel matrix. This uniformity reflects effective formulation techniques and ensures reproducible dosing upon topical application. In contrast, the conventional gel showed comparatively lower drug content uniformity.

Stability studies demonstrated that the nanoemulgel retained its physical appearance, homogeneity, pH, and consistency throughout the study period. No phase separation, color change, or odor variation was observed, indicating excellent physical and chemical stability. These findings support the suitability of the nanoemulgel for long-term storage and practical use.

Table 5: Drug content of formulations.

S.No.	Formulation	Drug content (%)
1	Nanoemulgel	>95
2	Conventional gel	<90

4.5 Antioxidant Activity

The antioxidant potential of the formulations was evaluated using DPPH free radical scavenging and FRAP assays to assess radical neutralization and reducing power. The lavender oil nanoemulgel exhibited significantly higher antioxidant activity compared to the conventional gel in both assays.

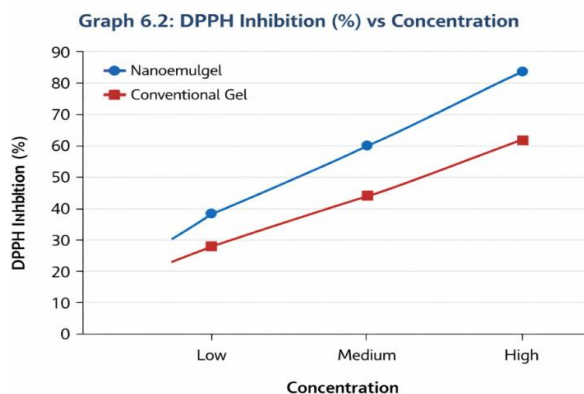
In the DPPH assay, the enhanced radical scavenging activity of the nanoemulgel can be attributed to improved solubilization and dispersion of lavender oil within the

nanoemulsion system. The increased surface area of nano-sized droplets facilitates greater interaction between antioxidant constituents and free radicals, leading to more efficient neutralization.

Similarly, the FRAP assay demonstrated higher ferric reducing power for the nanoemulgel, reflecting superior electron-donating capacity. Uniform dispersion and enhanced availability of bioactive compounds further contributed to improved antioxidant efficiency.

Table 6: DPPH Radical Scavenging Activity.

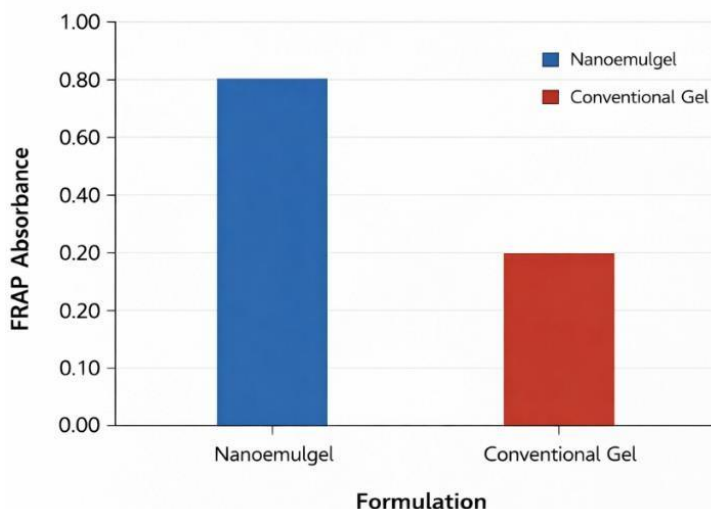
S.No.	Concentration	Nanoemulgel (%)	Conventional Gel (%)
1	Low	High	Moderate
2	Medium	Higher	Lower
3	High	Maximum	Moderate



Graph.1: DPPH inhibition comparison: Nanoemulgel vs Conventional Gel.

Table 7: FRAP Reducing Power.

S.No.	Formulation	FRAP Value
1	Nanoemulgel	High
2	Conventional gel	Moderate



Graph. 2: FRAP absorbance comparison of formulations.

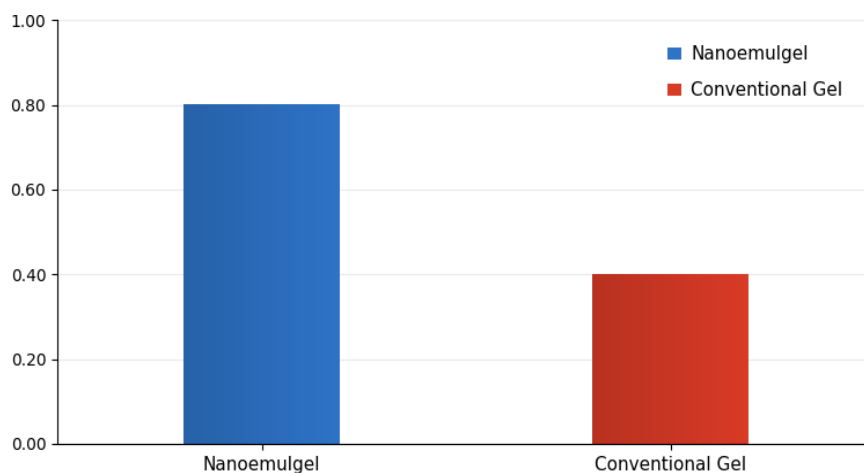
4.6 Anti-Aging Enzyme Inhibition

The anti-aging potential of the nanoemulgel was further evaluated through inhibition of collagenase and elastase enzymes, which play a critical role in the degradation of collagen and elastin during skin aging. The lavender oil nanoemulgel exhibited significantly higher collagenase inhibition compared to the conventional gel. Preservation of collagen fibers is essential for maintaining skin firmness and structural

integrity, and the enhanced inhibition indicates the formulation's ability to delay wrinkle formation. Similarly, elastase inhibition studies revealed superior inhibition by the nanoemulgel, suggesting effective protection of elastin fibers. Improved penetration and sustained release of lavender oil bioactives through the nanoemulsion system likely contributed to the enhanced enzyme inhibition observe.

Table 8: Enzyme inhibition summary.

Parameter	Nanoemulgel	Conventional gel
Collagenase inhibition	High	Moderate
Elastase inhibition	High	Lower



Graph. 3: Collagenase and Elastase inhibition by lavender oil formulations.

4.7 Comparative Discussion and Mechanistic Insights

The superior performance of the lavender oil nanoemulgel compared to the conventional gel can be attributed to its optimized nanoemulsion-based design. Reduced droplet size increases surface area, improving interaction with free radicals and aging-related enzymes. Enhanced solubilization and uniform distribution of

lavender oil improve bioavailability at the application site, while the gel matrix prolongs residence time on the skin. Mechanistically, the nanoemulgel enhances antioxidant action by facilitating efficient radical scavenging and improves anti-aging efficacy by enabling better access of bioactive compounds to collagenase and elastase enzymes. Additionally, the nanoemulsion system

improves formulation stability and protects lavender oil from degradation.

Table 9: Comparative performance of formulations.

Parameter	Nanoemulgel	Conventional gel
Antioxidant activity	High	Moderate
Enzyme inhibition	High	Lower
Stability	Excellent	Moderate
Skin penetration	Enhanced	Limited

5. CONCLUSION

The lavender oil nanoemulgel showed excellent physicochemical stability with a skin-compatible pH (5.7 ± 0.2), suitable viscosity (4800 ± 150 cPs), and high drug content ($98.4 \pm 1.3\%$). Enhanced antioxidant activity was confirmed by higher DPPH and FRAP values compared to the conventional gel. The nanoemulgel also exhibited superior collagenase and elastase inhibition, indicating improved protection of collagen and elastin fibers. These results demonstrate that the nanoemulgel system significantly enhances the anti-aging efficacy of lavender oil over conventional topical formulations.

The developed lavender oil nanoemulgel demonstrated superior physicochemical stability, enhanced antioxidant activity, and stronger inhibition of collagenase and elastase enzymes compared to the conventional gel. These improvements are primarily attributed to nano-sized droplets that enhance skin penetration, bioavailability, and sustained release of active constituents. The gel matrix further supports prolonged residence time on the skin, improving therapeutic performance. Overall, the nanoemulgel system effectively enhances the anti-aging potential of lavender oil.

6. ACKNOWLEDGEMENT

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7. FUTURE ASPECTS

Future studies may focus on in-vivso evaluation of the lavender oil nanoemulgel to confirm its safety, skin permeation, and long-term anti-aging efficacy under clinical conditions. Advanced characterization techniques such as particle size distribution, zeta potential quantification, and skin permeation studies using Franz diffusion cells can further strengthen formulation validation.

Additionally, incorporation of other natural antioxidants or anti-aging agents in combination with lavender oil may be explored to achieve synergistic effects. Scale-up studies and long-term stability testing under accelerated and real-time conditions are necessary for commercial development. The nanoemulgel platform also holds promise for cosmeceutical and dermatological applications, offering a safe, effective, and patient-friendly delivery system for herbal bioactives.

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