RESEARCH PAPER

Formulation and Evaluation of Herbal Nanoemulgel for Anti-inflammatory Activity

Shivangi Verma[1], Sushma Chauhan[2], Manisha Dubey[3*], Snehlata Verma[4], Diksha Agrahari[5]

[1]Kashi Institute of Pharmacy, Varanasi, Uttar Pradesh

[2]Ashoka Institute of Technology and Management (Pharmacy), Paharia-Sarnath, Varanasi, Uttar Pradesh

[3*]Ashoka Institute of Technology and Management (Pharmacy), Paharia-Sarnath, Varanasi, Uttar Pradesh

[4]Kashi Institute of Pharmacy, Varanasi, Uttar Pradesh

[5]Apex Institute of Pharmacy, Varanasi, Uttar Pradesh

Corresponding author:

Manisha Dubey*

Ashoka Institute of Technology and Management (Pharmacy), Paharia-Sarnath, Varanasi, Uttar Pradesh

Email: dubeymanisha008@gmail.com

Received: 16th April, 2026; Revised: 13rd May, 2026; Accepted: 23rd May, 2026; Available Online: 29th May, 2026

ABSTRACT

Herbal medicines have gained considerable attention due to their therapeutic potential, safety, and minimal side effects. However, poor aqueous solubility and limited skin permeation of many herbal constituents reduce their effectiveness in topical drug delivery systems. Nanoemulgel is an advanced topical delivery system that combines the advantages of nanoemulsion and hydrogel to improve drug stability, penetration, and patient compliance. The present study was aimed at the formulation and evaluation of herbal nanoemulgel containing *Swietenia macrophylla* for enhanced anti-inflammatory activity. Nanoemulsion formulations were prepared using suitable oil, surfactant, and co-surfactant systems by spontaneous emulsification method and subsequently incorporated into a Carbopol-based gel matrix to obtain nanoemulgel formulations. Physicochemical characteristics such as appearance, pH, viscosity, spreadability, globule size, polydispersity index, zeta potential, drug content, and stability were assessed for the produced formulations. The anti-inflammatory activity was evaluated using carrageenan-induced paw edema method. The optimized nanoemulgel formulation exhibited nanosized globules with good stability, satisfactory rheological properties, and enhanced spreadability suitable for topical application. Stability studies revealed no significant changes in the formulation during storage conditions. Furthermore, the developed nanoemulgel demonstrated significant anti-inflammatory activity compared to conventional herbal preparations, indicating improved penetration and therapeutic effectiveness. Thus, the formulated *Swietenia macrophylla* nanoemulgel may serve as a promising herbal topical delivery system for the management of inflammatory conditions.

Keywords: Nanoemulgel, *Swietenia macrophylla*, Herbal formulation, Anti-inflammatory activity, Nanoemulsion, Topical drug delivery.

How to cite this article: Verma S, Chauhan S, Dubey M, Verma S, Agrahari D. Formulation and Evaluation of Herbal Nanoemulgel for Anti-inflammatory Activity. Int J Drug Deliv Technol. 2026;16(51s): 1987-2000. DOI: 10.25258/ijddt.16.51s.161

Source of support: Nil.

Conflict of interest: None

Introduction

1.1 Herbal Drug Delivery Systems

Since ancient times, a variety of illnesses have been prevented and treated with herbal remedies. Numerous bioactive phytoconstituents found in medicinal plants, including alkaloids, flavonoids, terpenoids, tannins, glycosides, and phenolic compounds, have important pharmacological properties, such as anti-inflammatory, antioxidant, antimicrobial, anticancer, and wound-healing effects. [1]. Due to their natural origin, herbal drugs are generally considered safer, more economical, and associated with fewer adverse effects compared to synthetic drugs [2] For increasing the therapeutic efficacy and patient compliance, new herbal drug delivery systems have been developed in response to the growing interest in herbal therapy around the world in recent years [3].

Topical herbal formulations are widely used for the treatment of skin disorders, inflammation, pain, infections, and wound healing because they allow direct application of active constituents to the affected site [4]. Conventional formulations such as creams, ointments, lotions, and gels are commonly employed for herbal drug delivery. However, these traditional dosage forms possess several limitations including poor drug penetration through the skin barrier, low bioavailability, instability of phytoconstituents, poor spreadability, greasiness, and difficulty in delivering lipophilic herbal compounds effectively [5]. The stratum corneum acts as a major barrier that restricts the permeation of herbal active constituents into deeper skin layers, thereby reducing therapeutic

effectiveness [6].

Furthermore, many herbal extracts exhibit poor aqueous solubility and low stability when exposed to environmental conditions leading to degradation of active phytochemicals [7]. Advanced drug delivery systems that can enhance the stability, penetration, and bioavailability of herbal medicines for topical administration are therefore becoming more and more necessary. [8].

1.2 Nanoemulsion Technology

Nanoemulsion which are made up of oil , water , surfactant and co-surfactant form a thermodynamically or kinetically stable colloidal dispersions whose droplet size range between 20-200 nm [9]. Depending on the composition, nanoemulsions may exist as oil-in-water (O/W), water-in-oil (W/O), or bicontinuous systems [10]. Due to their extremely small droplet size and large interfacial surface area, nanoemulsions exhibit transparent or translucent appearance, high kinetic stability, and improved solubilization capacity for poorly soluble drugs [11].

Nano-sized delivery systems have gained considerable attention in pharmaceutical research because they provide several advantages over conventional formulations. The small droplet size enhances surface area available for drug absorption, thereby improving dissolution rate and bioavailability of active compounds [12]. Nanoemulsions also provide protection to sensitive phytoconstituents against chemical degradation and environmental stress [13]. In addition, they improve physical stability by minimizing sedimentation, creaming, coalescence, and phase separation [14].

In topical drug delivery, nanoemulsions play a significant role in enhancing skin permeation and retention of active ingredients. The nanosized droplets can penetrate more efficiently through the stratum corneum and facilitate drug transport into deeper skin layers [15]. Surfactants present in nanoemulsion systems further reduce interfacial tension and modify skin barrier properties, thereby improving transdermal permeation [16]. Nanoemulsions also provide controlled and sustained release of drugs, reduce irritation, and enhance patient acceptability due to their non- greasy and elegant appearance [17]. These advantages make nanoemulsions promising carriers for herbal bioactive compounds used in topical therapy [18].

1.3 Nanoemulgel System

A new topical formulation called nanoemulgel is created by mixing nanoemulsion with a gel matrix. It improves drug delivery performance by combining the benefits of hydrogel and nanoemulsion technologies.(19) Nanoemulsions are highly effective in solubilizing lipophilic drugs, whereas gels provide suitable consistency, spreadability, bioadhesion, and patient convenience [20]. The incorporation of nanoemulsion into gel base overcomes the limitations associated with low viscosity of nanoemulsions and improves formulation stability for topical application [21].

Conventional topical formulations such as ointments and creams often suffer from poor patient acceptability due to greasiness, stickiness, staining, and difficulty in removal after application [22]. In contrast, nanoemulgels exhibit superior physicochemical and cosmetic properties including better spreadability, thixotropic behavior, non-greasy nature, ease of application, and improved aesthetic appearance [23]. Nanoemulgels also provide higher drug loading capacity and improved stability for lipophilic herbal constituents [24].

One of the major advantages of nanoemulgel systems is enhanced skin penetration. The nano- sized globules present in nanoemulsions increase the surface area available for absorption and facilitate closer interaction with the skin surface [25]. Surfactants and co-surfactants present in the system disrupt the lipid structure of the stratum corneum, thereby enhancing permeation of active constituents through the skin [26]. In addition, the gel matrix prolongs residence time of the formulation at the application site, resulting in sustained drug release and improved therapeutic activity [27].

Nanoemulgels also improve the stability of herbal bioactive compounds by protecting them from hydrolysis, oxidation, and photodegradation [28]. The gel network stabilizes the dispersed nanoemulsion droplets and reduces the chances of coalescence and phase separation during storage [29]. Due to these advantages, nanoemulgels have emerged as promising carriers for topical delivery of herbal medicines intended for anti-inflammatory, analgesic, antimicrobial, and wound healing applications [30].

1.4 *Swietenia macrophylla*

Swietenia macrophylla King, commonly known as big-leaf mahogany, belongs to the family Meliaceae. It is a large tropical medicinal tree widely distributed in South America, Central America, and several Asian countries including India, Malaysia, and Indonesia

[31]. The plant grows up to 30–40 meters in height and possesses pinnate leaves, small greenish-white flowers, and large woody capsules containing winged seeds [32]. Various parts of the plant including seeds, bark, leaves, and oil have been traditionally used in folk medicine for the treatment of inflammation, hypertension, diabetes, fever, pain, malaria, and microbial infections [33].

Traditionally, the seeds of *Swietenia macrophylla* have been used as anti-inflammatory, analgesic, antipyretic, and antimicrobial agents in different herbal systems of medicine [34]. Seed oil and extracts are also employed for wound healing and skin-related disorders due to their medicinal properties [35]. The presence of many bioactive phytoconstituents, including flavonoids, alkaloids, limonoids, saponins, tannins, triterpenoids, and phenolic chemicals, is primarily responsible for the plant's therapeutic potential. [36].

Among these constituents, limonoids and flavonoids are considered major compounds responsible for anti-inflammatory and antioxidant activities [37]. The antioxidant potential of *Swietenia macrophylla* is associated with its ability to scavenge free radicals and inhibit oxidative stress-mediated cellular damage [38]. Several studies have also reported significant antimicrobial activity of the plant extracts against both Gram-positive and Gram-negative microorganisms [39].

The anti-inflammatory activity of *Swietenia macrophylla* has been demonstrated in various experimental models where the plant extract and oil significantly reduced edema, inflammation, and inflammatory mediator release [40]. Due to these pharmacological properties, *Swietenia macrophylla* has emerged as a promising herbal candidate for the development of topical anti- inflammatory formulations.

1.5 Rationale of Study

Inflammatory skin conditions are commonly associated with pain, redness, swelling, and irritation that require effective topical treatment. Conventional topical herbal formulations often exhibit limited therapeutic efficacy due to poor skin permeation, inadequate retention at the application site, and instability of herbal bioactive compounds [41]. In addition, many phytoconstituents present in herbal oils and extracts are lipophilic in nature and show poor aqueous solubility, thereby reducing their bioavailability through conventional dosage forms [42].

Nanoemulgel systems have gained significant attention as advanced topical drug delivery carriers because they combine the penetration-enhancing properties of nanoemulsions with the stability and patient acceptability of hydrogels [43]. The nano-sized globules provide larger surface area and improved contact with the skin, leading to enhanced permeation and bioavailability of active phytoconstituents [44]. Furthermore, nanoemulgels offer better spreadability, non-greasy texture, controlled drug release, and improved stability compared to traditional topical formulations [45].

Considering the potent anti-inflammatory activity of *Swietenia macrophylla* and the advantages offered by nanoemulgel systems, The goal of the current study was to create and assess a herbal nanoemulgel formulation with improved topical anti-inflammatory properties.

1.6 Aim and Objectives Aim

To formulate and evaluate herbal nanoemulgel containing *Swietenia macrophylla* for anti-inflammatory activity.

Objectives

- To prepare nanoemulsion containing *Swietenia macrophylla* oil/extract.
- To formulate nanoemulgel using suitable gelling agents.
- To evaluate physicochemical properties such as pH, viscosity, spreadability, globule size, polydispersity index, and zeta potential.
- To perform stability studies of the prepared nanoemulgel formulation.
- To assess anti-inflammatory activity using suitable experimental models.

2. Materials and Methods

2.1 Materials

Swietenia macrophylla seeds were used as the herbal source for extraction of bioactive constituents and oil. Tween 80 was selected as the surfactant due to its excellent emulsifying efficiency and biocompatibility, while polyethylene glycol 400 (PEG 400) was used as the co- surfactant to improve the flexibility and stability of the nanoemulsion system. Carbopol 940 was employed as the gelling agent for the preparation of nanoemulgel because of its high viscosity and excellent bioadhesive properties. Triethanolamine was

utilized for pH adjustment and neutralization of the gel base. Distilled water was used as the aqueous phase during formulation development. Analytical grade ethanol, methanol, chloroform, and other reagents used in the study were procured from standard chemical suppliers and used without further purification.

2.2 Collection and Authentication of Plant Material

The seeds of *Swietenia macrophylla* were collected from local herbal markets and medicinal plant sources. The collected plant material was carefully cleaned to remove dust, foreign particles, and impurities. Botanical authentication of the plant material was carried out by a qualified taxonomist from the Department of Botany of a recognized institution. A voucher specimen was prepared and preserved for future reference and identification purposes.

2.3 Extraction of Herbal Material

The gathered Swietenia macrophylla seeds were properly cleaned, allowed to dry in the shade at room temperature, and then ground into a coarse powder using a mechanical grinder. Until it was needed again, the powdered substance was kept in airtight containers.

The collected seeds of *Swietenia macrophylla* were washed thoroughly, shade dried at room temperature, and pulverized into coarse powder using a mechanical grinder. The powdered material was stored in airtight containers until further use.

Soxhlet Extraction Method

Approximately 100 g of powdered seed material was subjected to Soxhlet extraction using ethanol as the extraction solvent. The extraction process was continued for 6–8 hours until complete extraction was achieved. The obtained extract was filtered and concentrated under reduced pressure using a rotary evaporator to remove excess solvent. The concentrated extract was then dried and stored in a desiccator for further formulation studies [46].

Cold Maceration Method

Alternatively, the powdered plant material was soaked in ethanol for 72 hours with intermittent shaking at room temperature. Whatman filter paper was used after muslin cloth to filter the mixture. The filtrate was concentrated by evaporation and preserved in airtight containers for further use.

Yield Calculation

The percentage yield of the extract was calculated using the following formula:

Percentage Yield = Weight of Dried Extract / Weight of Powdered Plant Material × 100

The obtained extract was evaluated for further formulation and characterization studies.

2.4 Preformulation Studies

Preformulation studies were performed to determine the physicochemical properties and compatibility of the herbal extract with formulation excipients before development of the nanoemulgel.

2.4.1 Organoleptic Properties

The herbal extract was evaluated for organoleptic characteristics including color, odor, appearance, texture, and consistency by visual inspection. These parameters provide preliminary information regarding the quality and acceptability of the extract.

2.4.2 Solubility Study

The solubility of *Swietenia macrophylla* extract was determined in various solvents using distilled water, ethanol, methanol, chloroform, Tween 80, and PEG 400. Excess amount of extract was added to each solvent and shaken continuously until equilibrium was achieved. The mixtures were observed visually to determine the solubility behavior of the extract in different media [47].

2.4.3 pH Determination

The pH of the herbal extract and prepared formulations was determined using digital pH meter. Approximately 1 g of the prepared formulation was added in distilled water and the pH was measured at room temperature. The pH values were recorded to ensure suitability for topical application and skin compatibility.

2.4.4 Compatibility Study (FTIR)

Fourier Transform Infrared (FTIR) spectroscopy was performed to investigate the compatibility between *Swietenia macrophylla* extract and formulation excipients. FTIR spectra of the pure extract, individual

excipients, and physical mixtures were recorded using an FTIR spectrophotometer over a scanning range of 4000–400 cm^{-1}. The obtained spectra were analyzed for characteristic peaks, functional groups, and possible interactions between the drug and excipients [48].

3. Formulation Development

3.1 Preparation of Nanoemulsion

Selection of Oil Phase

Swietenia macrophylla oil/extract was selected as the oil phase because of its reported anti- inflammatory and antioxidant activities. The oil phase was selected based on its solubilization capacity, compatibility with surfactants, and suitability for topical application. The herbal oil also served as the active therapeutic component in the nanoemulsion system.

Selection of Surfactant and Co-surfactant

Tween 80 was selected as the surfactant due to its non-ionic nature, low toxicity, high emulsification efficiency, and ability to reduce interfacial tension effectively. PEG 400 was selected as the co-surfactant to improve flexibility of the interfacial film and facilitate formation of stable nano-sized droplets. The surfactant and co-surfactant mixture (Smix) was prepared in different ratios to identify the optimum concentration required for stable nanoemulsion formation [49].

Preparation Method

The nanoemulsion was prepared by combining high-speed homogenization, ultrasonication, and self-emulsification techniques.

High-Speed Homogenization

The oil of swietenia macrophylla was mixed with the mixture of surfactant and co- surfactant. The aqueous phase which was distilled water was added slowly to oil phase under high speed homogenizer operating at 10,000–15,000 rpm for 15–20 minutes. This process resulted in the formation of a coarse emulsion.

Ultrasonication

After homogenization, the coarse emulsion was ultrasonically sonicated for ten to fifteen minutes using a probe sonicator in order to decrease droplet size. and obtain a transparent nanoemulsion. Ultrasonication helps in producing uniform nanosized droplets and improving formulation stability [50].

Self-Emulsification Method

In the self-emulsification technique, the oil phase ontaining surfactant and co-surfactant spontaneously formed fine oil droplets upon addition of aqueous phase under gentle agitation. The method facilitates spontaneous formation of nanoemulsion due to reduction in interfacial tension between oil and water phases [51].

3.2 Construction of Pseudo-ternary Phase Diagram

To determine the nanoemulsion region and maximize the concentrations of oil, surfactant, co-surfactant, and water, pseudo-ternary phase diagrams were created.

Different ratios of oil and Smix were prepared and titrated gradually with distilled water under continuous stirring. The mixtures were visually observed for transparency, phase separation, and turbidity. The transparent and stable regions were identified as nanoemulsion regions and selected for further formulation development [52].

The phase diagrams helped in determining the optimum ratio of oil, surfactant, and co-surfactant required for stable nanoemulsion formation.

3.3 Optimization of Nanoemulsion

The prepared nanoemulsion formulations were optimized based on physicochemical characteristics and stability parameters.

Droplet Size

Droplet size analysis was carried out using dynamic light scattering technique. Nanoemulsions exhibiting smaller droplet size were considered more suitable due to enhanced surface area and improved skin penetration.

Polydispersity Index (PDI)

PDI values were determined to evaluate the uniformity of droplet distribution within the formulation. Lower PDI values indicated homogeneous distribution and better stability of the nanoemulsion system.

Zeta Potential

Zeta potential analysis was performed to assess the surface charge and stability of nanoemulsion droplets.

Higher absolute zeta potential values indicated greater electrostatic repulsion between droplets and improved physical stability [53].

Stability Study

Optimized formulations were evaluated for thermodynamic and physical stability by observing phase separation, creaming, cracking, and changes in droplet size during storage at different temperatures. Stable formulations without visible instability were selected for incorporation into gel base.

3.4 Preparation of Nanoemulgel

Preparation of Gel Base

A homogenous gel basis was created by gradually dispersing carbopol 940 in distilled water while stirring constantly. For several hours, the dispersion was let to fully hydrate in order to achieve the appropriate swelling of the polymer. To achieve a translucent gel with the right viscosity, triethanolamine was added dropwise to neutralize the dispersion and change the pH..

Incorporation of Nanoemulsion into Gel

The optimized nanoemulsion was incorporated into the prepared Carbopol gel base under gentle continuous stirring to obtain nanoemulgel. Continuous mixing was performed to ensure uniform distribution of nanoemulsion droplets throughout the gel matrix without formation of air bubbles. For additional analysis, the finished nanoemulgel mixture was kept in sealed containers. [54].

3.5 Formulation Table

Table 1: Composition of *Swietenia macrophylla* Nanoemulgel Formulations

Ingredients	F1 (%)	F2 (%)	F3 (%)	F4 (%)	F5 (%)	F6 (%)
Swietenia macrophylla O	5	7.5	10	12.5	15	20
Tween 80	20	20	25	25	30	30
PEG 400	10	10	15	15	20	20
Carbopol 940	0.5	0.5	0.75	0.75	1	1
Triethanolamin	q.s.	q.s.	q.s.	q.s.	q.s.	q.s.
Distilled Water	q.s. t 100	q.s. t 100	q.s. t 100	q.s. t 100	q.s. t 100	q.s. t 100

The electrode of the pH meter was immersed into the dispersion and readings were recorded in triplicate. The pH of all formulations was maintained within the acceptable skin pH range to minimize the possibility of skin irritation.

4.3 Viscosity Study

The viscosity of the nanoemulgel formulations was determined using a Brookfield viscometer equipped with suitable spindle at room temperature. Approximately 50 g of formulation was placed in the sample holder and viscosity measurements were carried out at different rotational speeds. The viscosity values were recorded in centipoise (cP).

4.4 Spreadability Test

4. Evaluation of Nanoemulgel

4.1 Physical Appearance

The prepared nanoemulgel formulations were evaluated visually for physical appearance including color, homogeneity, consistency, and presence of any phase separation or grittiness. The formulations were examined against both white and black backgrounds under normal lighting conditions. The prepared nanoemulgels showed smooth texture, uniform appearance, and good homogeneity without any visible aggregates or coarse particles. Consistency of the formulations was evaluated manually by gentle application on the skin surface to determine suitability for topical administration.

4.2 pH Determination

The pH of the prepared nanoemulgel was determined using a calibrated digital pH meter. Approximately 1 g of nanoemulgel was dispersed in 25 mL of distilled water.

Glass slide method was used to determine the spreadability of the prepared nanoemulgel. A fixed amount of prepared formulation was placed in between the glass slides and compressed with a standard weight for a specified time. The time was noted and spreadability was calculated using the following equation:

Where:
S = Spreadability
M = Weight tied to upper slide L = Length moved by glass slide T = Time takenM × L

$$S = \frac{}{T}$$

The formulations showing higher spreadability values were considered more suitable for topical application due to ease of spreading over the skin surface.

4.5 Drug Content Estimation

To ascertain the homogeneous distribution of Swietenia macrophylla extract within the nanoemulgel formulations, drug content estimation was carried out. To fully extract the active ingredients, a precisely weighed amount of nanoemulgel equal to a known amount of extract was mixed in an appropriate solvent and continuously stirred. A UV-visible spectrophotometer was used to filter the solution and perform spectrophotometric analysis at the chosen wavelength. The calibration curve of the extract was used to determine the drug content.

Drug content estimation was performed to determine the uniform distribution of *Swietenia macrophylla* extract within the nanoemulgel formulations. Accurately weighed quantity of nanoemulgel equivalent to a known amount of extract was dissolved in suitable solvent and stirred continuously to obtain complete extraction of active constituents. The solution was filtered and analyzed spectrophotometrically at the selected wavelength using UV-visible spectrophotometer. The drug content was calculated using the calibration curve of the extract.

4.6 Globule Size Analysis

Globule size analysis of the prepared formulations was carried out using dynamic light scattering technique with a particle size analyzer. Samples were suitably diluted with distilled water before to analysis in order to prevent multiple scattering effects. The diluted samples were placed in disposable cuvettes and analyzed at room temperature.

The average globule size of the formulations was determined based on intensity distribution patterns generated by the instrument. Smaller globule size indicated efficient emulsification and better stability of the nanoemulsion system. Nano-sized globules provide larger surface area for drug absorption and facilitate enhanced permeation through the skin barrier. The optimized nanoemulgel formulations exhibited uniform nanosized droplets with narrow distribution, indicating formation of stable nanoemulsion systems suitable for topical delivery.

4.7 Polydispersity Index (PDI)

The dynamic light scattering method was used to calculate the PDI of the nanoemulsion formulations. The homogeneity of the droplet size distribution was assessed using PDI values. Improved physical stability and a homogeneous distribution were indicated by lower PDI values.

Formulations exhibiting PDI values below 0.5 were considered suitable for stable nanoemulsion preparation.

4.8 Zeta Potential Measurement

Zeta potential analysis was used to determine the surface charge and stability of nanoemulsion droplets using a zeta potential analyzer. Diluted samples were transferred into zeta cells and measurements were carried out at room temperature.Higher absolute zeta potential values suggested better stability and lower chances of droplet aggregation.

4.9 Rheological Study

Rheological behavior of the prepared nanoemulgel formulations was evaluated using a Brookfield rheometer at different shear rates. The formulations were subjected to gradual increase in rotational speed and corresponding viscosity values were recorded. The rheological study was carried out to determine flow characteristics and structural behavior of the nanoemulgel systems. The formulations exhibited non-Newtonian pseudoplastic flow behavior, which is considered desirable for topical preparations because it facilitates easy application and improved retention at the site of administration.

4.10 Texture Analysis

Texture analysis of the nanoemulgel formulations was performed using a texture analyzer to determine parameters such as firmness, cohesiveness, adhesiveness, and consistency. The

formulations were placed in sample containers and subjected to compression using a probe attached to the instrument. Texture profile analysis was conducted under controlled conditions and the obtained parameters were recorded. Texture analysis provided information regarding the mechanical characteristics and patient acceptability of the prepared formulations.

4.11 In Vitro Drug Release Study

Franz diffusion cell apparatus was used to study in vitro drug release. It was having two compartment called as donor and receptor compartment between which cellophane membrane was adjusted. The phosphate

buffer 7.4 was filled in receptor compartment and the temperature was maintained at 37 ± 0.5°C with continuous stirring.

The weighed quantity of the prepared formulation was placed in donor compartment . At a particular time intervals , aliquots were withdrawn from the receptor compartment and fresh sample was added to it . The samples were analyzed using UV- visible spectrophotometer. The cumulative percentage drug release was calculated

4.12 Ex Vivo Skin Permeation Study

By using franz diffusion cell the ex vivo skin permeation was performed with the help of excised rat abdominal skin.. The skin was carefully removed, cleaned, and mounted between donor and receptor compartments with stratum corneum facing the donor side. The receptor compartment was filled with phosphate buffer pH 7.4 maintained at 37 ± 0.5°C under continuous magnetic stirring.

The donor compartment's skin surface was evenly coated with the nanoemulgel formulation. At certain intervals, samples were taken out of the receptor compartment and replaced with an equivalent volume of new buffer solution. Cumulative drug penetration was calculated using spectrophotometric analysis of the extracted samples. The purpose of the study was to assess the nanoemulgel ability to pass through biological membranes.

The nanoemulgel formulation was applied uniformly over the skin surface in the donor compartment. Samples were withdrawn from the receptor compartment at specified time intervals and replaced with equal volume of fresh buffer solution. The withdrawn samples were analyzed spectrophotometrically and cumulative drug permeation was calculated.

4.13 Stability Study

The prepared formulations stability studies were carried out to evaluate chemical and physical stability at different storage conditions. The optimized formulations were stored at refrigerated temperature (4°C), room temperature (25°C), and accelerated temperature condition (40°C ± 2°C) for a period of three months. During the storage period, formulations were periodically evaluated for the following parameters:

Temperature Effect

The formulations were observed for any changes in appearance, viscosity, and consistency under different temperature conditions.

Droplet Size

Globule size analysis was performed periodically to determine any increase in droplet size during storage, which may indicate instability of the nanoemulsion system.

Phase Separation

The prepared Formulations were examined visually for signs of creaming, cracking or phase separation.

pH Variation

The pH values of the stored formulations were measured periodically to determine formulation stability and compatibility during storage.

There was no change in pH , phase separation , droplet size and physical appearance of the prepared nanoemulgel. This indicated the good stability of the prepared formulation.[55]

5. Results

5.1 Preformulation Results

The *Swietenia macrophylla* extract was found to be dark brown in color with characteristic odor and semi-solid appearance. The extract showed good solubility in ethanol, methanol, Tween 80, and PEG 400, while limited solubility was observed in distilled water. The pH of the extract solution was found to be 5.8 ± 0.12, indicating suitability for topical application. FTIR compatibility studies showed no significant interaction between the herbal extract and formulation excipients, confirming compatibility of ingredients used in nanoemulgel preparation.

5.2 Phase Diagram Results

Pseudo-ternary phase diagrams were successfully constructed using different ratios of oil, surfactant, co-surfactant, and water. The nanoemulsion region was identified based on transparent and stable formulations without phase separation. It was observed that increasing surfactant concentration expanded the nanoemulsion region significantly. The Smix ratio of 2:1 (Tween 80:PEG 400) produced

maximum nanoemulsion area and was selected for further optimization studies.

Table 2: Observed Nanoemulsion Region with Different Smix Ratios

Smix Ratio	Nanoemulsion Region Observation
1:1	Moderate transparent region
2:1	Large transparent stable region
3:1	Slightly viscous nanoemulsion region
1:2	Reduced nanoemulsion formation

5.3 Nanoemulsion Characterization

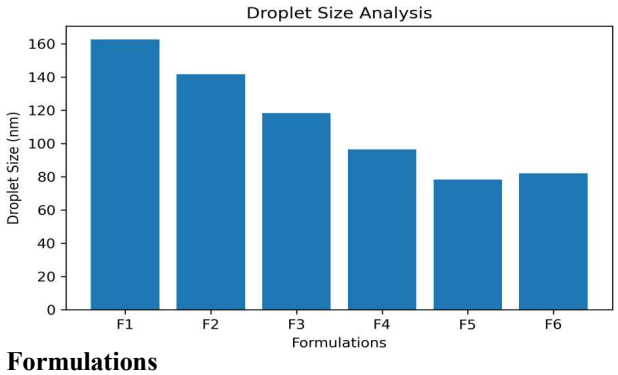
Droplet Size

The globule size analysis revealed that all formulations were within nano range. The optimized formulation (F5) exhibited minimum droplet size of 78.4 ± 2.6 nm, indicating efficient emulsification and uniform dispersion.

Table 3: Droplet Size Analysis of Nanoemulsion Formulations

Formulation	Droplet Size (nm)	PDI
F1	162.5 ± 4.2	0.436 ± 0.02
F2	141.7 ± 3.5	0.382 ± 0.01
F3	118.3 ± 2.8	0.315 ± 0.02
F4	96.4 ± 2.1	0.267 ± 0.01
F5	78.4 ± 2.6	0.218 ± 0.01
F6	82.1 ± 3.0	0.241 ± 0.02

Figure 1: Droplet Size Analysis of Nanoemulsion Formulations



Polydispersity Index (PDI)

The PDI values ranged from 0.218 to 0.436, indicating narrow size distribution and homogeneity of nanoemulsion droplets. Formulation F5 showed the lowest PDI value of 0.218 ± 0.01.

Table 4: PDI Values of Nanoemulsion Formulations

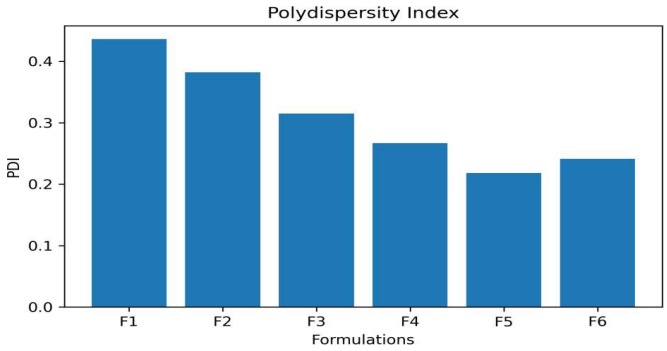


Figure 2: Polydispersity Index

Zeta Potential

The zeta potential was found to be in range between -21.4 mV and -38.7 mV. The optimized formulation F5 exhibited zeta potential of -38.7 ± 1.4 mV, indicating excellent physical stability.

Table 5: Zeta Potential of Nanoemulsion Formulations

Formulation	Zeta Potential (mV)
F1	-21.4 ± 1.1
F2	-25.7 ± 1.5
F3	-29.8 ± 1.2
F4	-34.2 ± 1.6
F5	-38.7 ± 1.4
F6	-36.5 ± 1.3

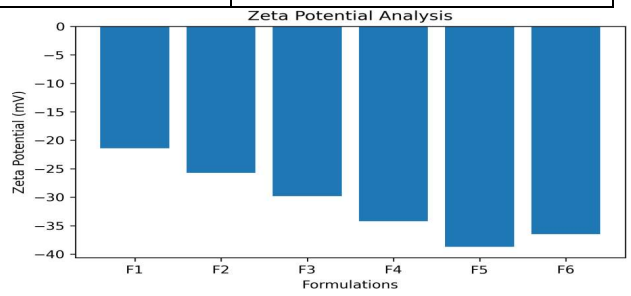


Figure 3: Zeta Potential Analysis

5.4 Nanoemulgel Evaluation Results

pH

The pH of prepared formulation ranged from 5.6 ± 0.11 to 6.8 ± 0.14, which was within acceptable skin pH range.

Viscosity

The viscosity of formulations ranged between 4,520 ± 76 cP and 6,980 ± 82 cP. Higher Carbopol concentration resulted in increased viscosity.

Spreadability

Spreadability values ranged from 5.2 ± 0.18 to 8.6 ± 0.21 g·cm/sec. Formulation F5 exhibited optimum spreadability.

Drug Content

The drug content of the herbal extract within the nanoemulgel formulations was found to be in values ranging from 91.4 ± 1.5% to 98.7 ± 1.2%.

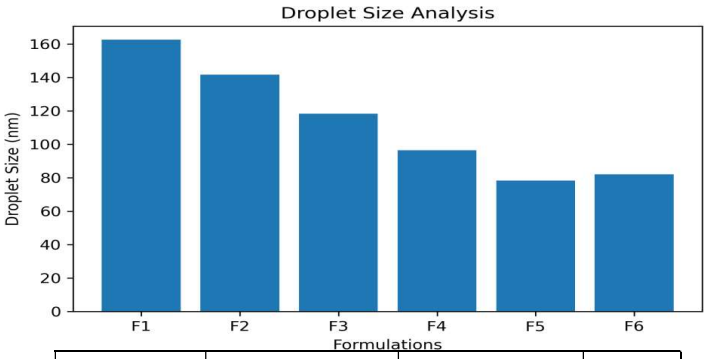
Table 6: Evaluation Parameters of Nanoemulgel Formulations

Formulatio	pH	Viscosit (cP)	Spreadability (g·cm/sec)	Drug Content (%)
F1	5.6 ± 0.11	4520 ± 76	8.6 ± 0.21	91.4 ± 1.5
F2	5.8 ± 0.09	4980 ± 81	8.1 ± 0.19	93.2 ± 1.3
F3	6.0 ± 0.12	5420 ± 72	7.4 ± 0.16	95.6 ± 1.4
F4	6.3 ± 0.10	6010 ± 78	6.9 ± 0.17	96.9 ± 1.1
F5	6.5 ± 0.13	6480 ± 75	6.4 ± 0.18	98.7 ± 1.2
F6	6.8 ± 0.14	6980 ± 82	5.2 ± 0.18	97.5 ± 1.4

5.5 Stability Study Results

The optimized formulation F5 remained stable during three months of storage at different temperatures. No significant phase separation or cracking was observed.

Table 7: Stability Study of Optimized Formulation F5



Storage Condition	Initial Droplet Size (nm)	Final Droplet Size (nm)	pH Change
4°C	78.4	80.1	6.5–6.4
25°C	78.4	82.6	6.5–6.3
40°C	78.4	87.2	6.5–6.2

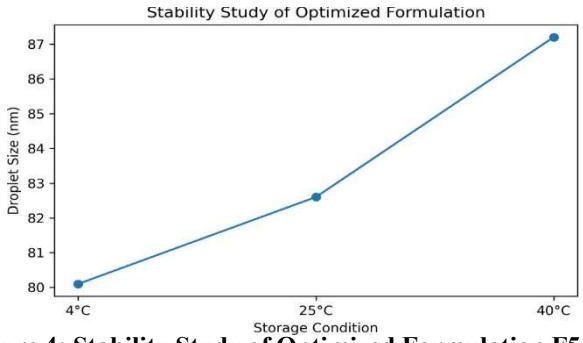


Figure 4: Stability Study of Optimized Formulation F5

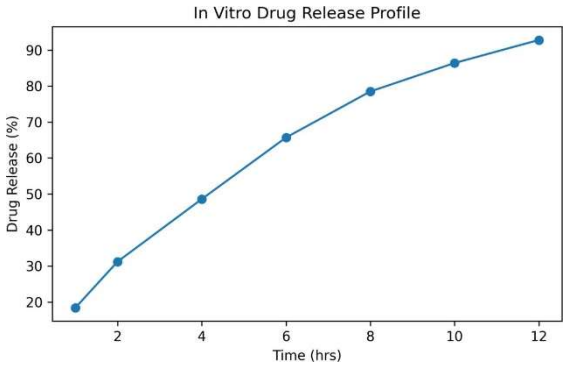
6.6 In Vitro Drug Release Results

The in vitro drug release study demonstrated sustained release behavior of the nanoemulgel formulations over 12 hours. Formulation F5 showed maximum cumulative drug release of 92.8 ± 1.6%.

Table 8: In Vitro Drug Release of F5

Time (hrs)	Drug Release (%)
1	18.4 ± 1.1
2	31.2 ± 1.3
4	48.6 ± 1.4
6	65.7 ± 1.2
8	78.5 ± 1.5
10	86.4 ± 1.3
12	92.8 ± 1.6

Figure 5: In Vitro Drug Release of F5



6. Discussion

The present study successfully developed and evaluated a *Swietenia macrophylla* loaded nanoemulgel formulation intended for topical delivery. The preformulation studies confirmed the suitability of the herbal extract for nanoemulsion development due to its good solubility in surfactant and co-surfactant systems. FTIR compatibility studies revealed absence of significant interaction between the extract and excipients, indicating chemical compatibility and stability of the formulation components.

Pseudo-ternary phase diagram studies demonstrated that the ratio of surfactant and co-surfactant significantly influenced nanoemulsion formation. The Smix ratio of 2:1 produced a larger nanoemulsion region with transparent and stable formulations, suggesting efficient reduction of interfacial tension and improved emulsification. Increased concentration of Tween 80 facilitated formation of smaller globule size due to better stabilization of oil droplets within the aqueous phase.

The prepared nanoemulsion formulations exhibited droplet sizes within nanometer range, which is an important characteristic for enhanced topical delivery. The optimized formulation F5 showed the smallest droplet size with low PDI value, indicating uniform droplet distribution and homogeneity of the system. Lower droplet size increases surface area available for interaction with skin, thereby enhancing penetration and drug release. The zeta potential values obtained for

the formulations indicated good physical stability due to sufficient electrostatic repulsion between dispersed droplets, minimizing the chances of aggregation and coalescence.

Nanoemulgel formulations prepared using Carbopol

940 showed smooth texture, good consistency, and excellent homogeneity suitable for topical application. The pH values of all formulations were found within acceptable skin pH range, suggesting reduced risk of skin irritation. Viscosity studies indicated that increasing concentration of Carbopol increased the viscosity of formulations due to formation of a stronger gel network structure. However, excessive viscosity slightly reduced spreadability of the formulations. The optimized formulation exhibited balanced rheological behavior with satisfactory spreadability and consistency, which are desirable properties for topical administration.

Drug content analysis demonstrated uniform incorporation of *Swietenia macrophylla* extract within the nanoemulgel system, indicating proper mixing and formulation uniformity. The in vitro drug release study showed sustained and controlled release of active constituents over an extended period. The sustained release behavior may be attributed to the presence of gel matrix surrounding the nanoemulsion droplets, which slowed diffusion of active constituents from the formulation. Nano-sized globules further enhanced dissolution and release characteristics by increasing the surface area available for drug diffusion.

The optimized nanoemulgel formulation remained physically stable under various storage settings, according to the stability studies, with no appreciable changes in droplet size, pH, appearance, or phase separation. The stability of the formulation may be attributed to effective stabilization of nanoemulsion droplets by surfactant molecules and the protective network provided by the Carbopol gel matrix.

Enhanced skin permeation observed in nanoemulgel systems can be explained by several mechanisms. The nanosized droplets provide close contact with the skin surface and improve penetration through the stratum corneum. Surfactants present in the formulation disrupt the lipid arrangement of the skin barrier and increase permeability of active constituents. In addition, the gel system prolongs residence time of the prepared formulation at the site of application, thereby improving retention and localized delivery of the herbal extract.

Overall, the developed *Swietenia macrophylla* nanoemulgel demonstrated promising physicochemical characteristics, good stability, controlled drug release, and suitability for topical drug delivery. The nanoemulgel system may therefore serve as an effective platform for delivery of herbal bioactive compounds in topical therapeutic applications.

7. Conclusion

A herbal nanoemulgel formulation including Swietenia macrophylla extract for topical administration was successfully created. The homogeneity and stability of the formulation were demonstrated by the nanosized globules, low PDI and good zeta potential of the nanoemulsion system made with appropriate surfactant and co-surfactant combinations. When the tailored nanoemulsion was included into the Carbopol gel base, nanoemulgel with adequate pH, viscosity, homogeneity, spreadability, and drug content for topical administration were produced..

The developed nanoemulgel demonstrated sustained drug release behavior and good stability under different storage conditions without significant changes in formulation characteristics. The nanosized droplets and gel matrix collectively contributed to improved penetration, prolonged retention, and enhanced delivery of herbal bioactive constituents through the skin. The study confirmed that nanoemulgel technology is an effective approach for improving the topical delivery performance of *Swietenia macrophylla* extract.

Overall, the formulated herbal nanoemulgel may serve as a promising and stable topical delivery system for herbal therapeutics and can be further explored for advanced pharmaceutical and dermatological applications.

References

1. Ekor M. The growing use of herbal medicines: issues relating to adverse reactions and challenges in monitoring safety. *Front Pharmacol*. 2014;4:177.
2. Patwardhan B, Vaidya AD, Chorghade M. Ayurveda and natural products drug discovery. *Curr Sci*. 2004;86(6):789-799.
3. Mukherjee PK, Wahile A. Integrated approaches towards drug development from Ayurveda and other Indian system of medicines. *J Ethnopharmacol*. 2006;103(1):25-35.
4. Benson HAE. Transdermal drug delivery: penetration enhancement techniques. *Curr Drug Deliv*. 2005;2(1):23-33.
5. Panwar A, Upadhyay N, Bairagi M, et al. Emulgel: a review. *Asian J Pharm Life Sci*. 2011;1(3):333-343.
6. Prausnitz MR, Langer R. Transdermal drug

delivery. *Nat Biotechnol*. 2008;26(11):1261-1268.
7. Gupta A, Mishra AK, Bansal P, et al. Stability studies of herbal formulations. *Int J Pharm Sci Rev Res*. 2010;5(3):67-72.
8. Ajazuddin, Alexander A, Khichariya A, et al. Recent expansions in an emergent novel drug delivery technology: emulgel. *J Control Release*. 2013;171(2):122-132.
9. Solans C, Izquierdo P, Nolla J, et al. Nano-emulsions. *Curr Opin Colloid Interface Sci*. 2005;10(3-4):102-110.
10. Tadros T, Izquierdo P, Esquena J, et al. Formation and stability of nano-emulsions. *Adv Colloid Interface Sci*. 2004;108-109:303-318.
11. Shah P, Bhalodia D, Shelat P. Nanoemulsion: a pharmaceutical review. *Syst Rev Pharm*. 2010;1(1):24-32.
12. Shakeel F, Ramadan W, Ahmed MA. Investigation of nanoemulsions for transdermal potential. *J Drug Target*. 2009;17(6):435-441.
13. Anton N, Vandamme TF. Nano-emulsions and micro-emulsions: clarifications of the critical differences. *Pharm Res*. 2011;28(5):978-985.
14. Rao J, McClements DJ. Food-grade nanoemulsions. *Food Hydrocoll*. 2011;25(5):1413-1423.
15. Gannu R, Palem CR, Yamsani VV, et al. Enhanced bioavailability through nanoemulsion-based gels. *Int J Pharm*. 2010;388(1-2):231-241.
16. Chen H, Chang X, Du D, et al. Microemulsion-based hydrogel formulation for topical delivery. *Int J Pharm*. 2006;315(1-2):52-58.
17. Yilmaz E, Borchert HH. Effect of nanoemulsions on skin hydration and elasticity. *Int J Pharm*. 2006;307(2):232-238.Abdulkarim MF, Abdullah GZ, Chitneni M, et al. Topical anti-inflammatory effects from nanocream systems. *Int J Nanomedicine*. 2010;5:915-924.
18. Baibhav J, Gurpreet S, Rana AC, et al. Emulgel: a comprehensive review. *Int Res J Pharm*. 2011;2(12):66-70.
19. Singla V, Saini S, Joshi B, et al. Emulgel: a new platform for topical drug delivery. *Int J Pharma Bio Sci*. 2012;3(1):485-498.
20. Asija R. Emulgel: a novel approach to topical drug delivery. *J Biomed Pharm Res*. 2013;2(6):91- 94.
21. Khullar R, Kumar D, Seth N, et al. Emulgels: a surrogate approach for topically used hydrophobic drugs. *Int J Pharm Biol Sci*. 2011;1(3):117-128.
22. Shah AA, Kadam SS, Mahaparale PR, et al. Emulgel: topical preparation for hydrophobic drugs. *PharmTechMedica*. 2013;2(1):370-376.
23. Panwar AS, Upadhyay N, Bairagi M. Emulgel formulation and evaluation. *Asian J Pharm Life Sci*. 2011;1:333-343.
24. Eid AM, El-Enshasy HA, Aziz R, et al. Preparation, characterization and anti-inflammatory activity of *Swietenia macrophylla* nanoemulgel. *J Nanomed Nanotechnol*. 2014;5:190.
25. Ghai I, Chaudhary H, Ghai S, et al. Transdermal drug delivery using nano-vesicular carriers. *Recent Pat Nanomed*. 2012;2(3):164-171.
26. Zhu W, Guo C, Yu A, et al. Microemulsion-based hydrogel for topical delivery. *Int J Pharm*. 2009;378(1-2):152-158.
27. Salim N, Basri M, Rahman MB, et al. Modification of nanoemulsions with hydrocolloid gums. *Int J Nanomedicine*. 2012;7:4739-4747.
28. Mohamed MI. Optimization of chlorphenesin emulgel formulation. *AAPS J*. 2004;6(3):e26.
29. Ajazuddin, Alexander A, Patel RJ, et al. Advances in emulgel technology. *J Control Release*. 2013;171(2):122-132.
30. Pennington TD, Styles BT. *A monograph of the American Meliaceae*. New York Botanical Garden; 1975.
31. Lim TK. *Edible Medicinal and Non-Medicinal Plants*. Springer; 2012.
32. Moghadamtousi SZ, Goh BH, Chan CK, et al. Biological activities and phytochemicals of *Swietenia macrophylla*. *Molecules*. 2013;18(9):10465-10483.
33. Eid AM, El-Enshasy HA, Aziz R, Elmarzugi NA. Preparation, characterization and anti-inflammatory activity of *Swietenia macrophylla* nanoemulgel. *J Nanomed Nanotechnol*. 2014;5:190.
34. Basri DF, Fan SH. The potential of aqueous and acetone extracts of *Swietenia macrophylla* seeds in antimicrobial activity. *Int J Microbiol*. 2005;2(1):1-6.
35. Rahman AHMM, Islam AKMR. Phytochemical screening of *Swietenia macrophylla*. *World J Agric Sci*. 2013;9(1):24-28.

36. Guevara AP, Apilado A, Sakurai H, et al. Anti-inflammatory and antitumor-promoting activities of mahogany seeds. *Phytother Res*. 1996;10(6):537-540.
37. Sahgal G, Ramanathan S, Sasidharan S, et al. Phytochemical and antioxidant activity of *Swietenia macrophylla* extracts. *Molecules*. 2009;14(2):970-978.
38. Kadri A, Zarai Z, Ben Chobba I, et al. Antimicrobial activity of medicinal plant extracts.
Asian Pac J Trop Biomed. 2011;1(5):377-380.
39. Moghadamtousi SZ, Kadir HA, Hassandarvish P, et al. Anti-inflammatory effects of
Swietenia macrophylla. *Molecules*. 2014;19(7):10465-10483.
40. Prausnitz MR, Langer R. Transdermal drug delivery. *Nat Biotechnol*. 2008;26(11):1261-1268.
41. Gupta A, Mishra AK, Bansal P, et al. Stability studies of herbal formulations. *Int J Pharm Sci Rev Res*. 2010;5(3):67-72.
42. Ajazuddin, Alexander A, Khichariya A, et al. Recent expansions in emulgel technology. *J Control Release*. 2013;171(2):122-132.
43. Gannu R, Palem CR, Yamsani VV, et al. Enhanced bioavailability through nanoemulsion-based gels. *Int J Pharm*. 2010;388(1-2):231-241.
44. Singla V, Saini S, Joshi B, Rana AC. Emulgel: a new platform for topical drug delivery.
Int J Pharma Bio Sci. 2012;3(1):485-498.
45. Harborne JB. *Phytochemical Methods: A Guide to Modern Techniques of Plant Analysis*. 3rd ed. Chapman and Hall; 1998.
46. Shah P, Bhalodia D, Shelat P. Nanoemulsion: a pharmaceutical review. *Syst Rev Pharm*. 2010;1(1):24-32.
47. Stuart B. *Infrared Spectroscopy: Fundamentals and Applications*. John Wiley & Sons; 2004.
48. Shah P, Bhalodia D, Shelat P. Nanoemulsion: a pharmaceutical review. *Syst Rev Pharm*. 2010;1(1):24-32.
49. Anton N, Vandamme TF. Nano-emulsions and micro-emulsions: clarifications of the critical differences. *Pharm Res*. 2011;28(5):978-985.
50. Zhao Y, Wang C, Chow AH, et al. Self-nanoemulsifying drug delivery system for herbal oil delivery. *Int J Pharm*. 2010;383(1-2):170-177.
51. Eid AM, El-Enshasy HA, Aziz R, Elmarzugi NA. Preparation, characterization and anti-inflammatory activity of *Swietenia macrophylla* nanoemulgel. *J Nanomed Nanotechnol*. 2014;5:190.
52. Müller RH. Zeta potential and particle charge in laboratory practice. Stuttgart: Scientific Verlagsgesellschaft; 1996.
53. Ajazuddin, Alexander A, Khichariya A, et al. Recent expansions in emulgel technology. *J Control Release*. 2013;171(2):122-132.
54. Eid AM, El-Enshasy HA, Aziz R, Elmarzugi NA. Preparation, characterization and anti-inflammatory activity of *Swietenia macrophylla* nanoemulgel. *J Nanomed Nanotechnol*. 2014;5:190.