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Research Article

Development and Characterization of a Ginger-Boswellic Acid Nanoemulgel for Enhanced Topical Delivery in Osteoarthritis Therapy

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A B S T R A C T

Osteoarthritis is a prevalent degenerative joint disorder characterized by chronic inflammation and cartilage breakdown, for which conventional oral therapies often suffer from low bioavailability and systemic side effects. In this study, a novel nanoemulgel delivery system was developed to co-deliver boswellic acid (from *Boswellia serrata*) and 6-gingerol (from *Zingiber officinale*) topically for localized anti-inflammatory therapy. Nanoemulsions were formulated using oil, surfactant/co-surfactant (Smix), and water, optimized via pseudo-ternary phase diagrams, and then incorporated into a Carbopol 940 gel base. Physicochemical characterization revealed nanosized droplets (145–185 nm) with low polydispersity (PDI ~0.18–0.28), negative zeta potential (up to –26.7 mV), skin-compatible pH (5.2–5.8), suitable viscosity, and good spreadability (~23 g·cm/s for optimal batch). Drug content was high (96–99%) for both active compounds, suggesting efficient encapsulation. In vitro release studies using Franz diffusion cells demonstrated sustained release over 12 hours, with the optimized formulation (G-F3-1.0) showing the best performance. Stability testing under accelerated and long-term conditions confirmed no phase separation, minimal size increase, and maintained drug content. FTIR analysis indicated no significant interaction between the actives and excipients. The developed nanoemulgel offers an effective topical strategy for delivering anti-inflammatory phytoconstituents directly to arthritic tissue, potentially reducing systemic exposure and improving patient compliance. This approach presents promising therapeutic potential for managing chronic joint inflammation in osteoarthritis.

Key words: Nanoemulgel, Boswellic Acid, Topical Drug Delivery, Osteoarthritis, Skin Permeability, Anti-inflammatory

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INTRODUCTION

Topical Drug delivery

Topical drug delivery is a non-invasive and effective method to administer therapeutic agents directly to the skin for localized treatment. This route offers significant advantages such as bypassing the gastrointestinal tract and avoiding first-pass hepatic metabolism, which can reduce systemic side effects and improve drug bioavailability at the target site. A unique property of dermatological pharmacology is the direct accessibility of the skin as a target organ for diagnosis and treatment [1].

Overview of Nanoemulgel

Nanoemulgel is a type of topical delivery system that combines the benefits of nanoemulsions and gels, designed to enhance the effectiveness and patient acceptability of topical applications. It consists of oil droplets dispersed at the nanoscale within a gel matrix, which improves the stability and delivery of the active components.

Advantages of Using Nanoeemulgels as a Drug Delivery system: [2,3]

1. The drug's affinity for oil dictates stability, and the distribution of oil droplets in the gel foundation enhances the stability of the nanoemulsion.
2. Compared to previous topical formulations that have

been explored, the nanoemulgel has several advantages, such as the preference to avoid first-pass metabolism. Incorporation of Lipophilic drugs.

3. Better skin permeability and drug disposition.
4. The drug release is controlled by the nanoemulgel.
5. Patients always prefer the topical use of nanoemulgel, which improves patient compliance.
6. Patients of all ages can accept topical treatment, which is always preferred over oral and parenteral drug delivery.
7. The nanoemulgels can be stopped or cleaned off at any moment in the event of any negative effects or localized skin irritation.
8. Additionally, a strong concentration gradient caused by good skin adherence with high solubilizing strength increases medication penetration as it descends.

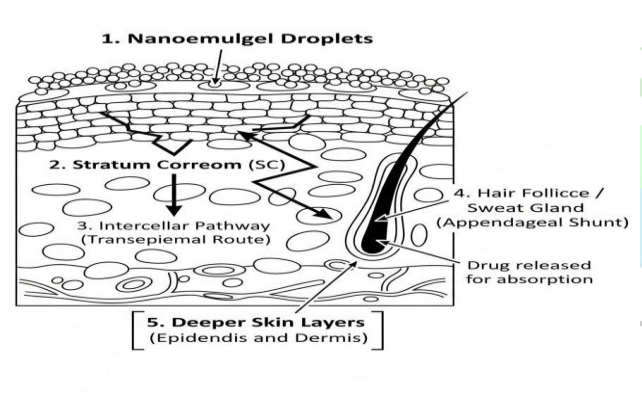

Figure: 1 Nanoemulgel Penetration through the skin

Arthritis

Arthritis is a medical condition characterized by inflammation of one or more joints in the body, causing pain, swelling, stiffness, and reduced movement. It is a common disorder that can affect people of all ages but is more prevalent in older adults. Arthritis may result from various causes, including autoimmune diseases, wear and tear of cartilage, infections, or injury. The inflammation leads to damage in the joint tissues, impairing normal joint function and causing discomfort, here are different types of arthritis, with osteoarthritis and rheumatoid arthritis being the most common.

Osteoarthritis

Osteoarthritis (OA) is a progressive, degenerative joint disease and the most prevalent form of arthritis worldwide. It results from the gradual breakdown of the cartilage that cushions the ends of bones within a joint, leading to bones rubbing directly against each other during movement. There is currently no cure, but symptom management and lifestyle adaptations can help maintain function and reduce discomfort. Osteoarthritis (OA) affects hundreds of millions globally and imposes a substantial socioeconomic burden. In 2020, approximately 595 million people around 7.6% of the global population were living with OA, marking a 132% increase since 1990. More recently, prevalence estimates rose to

606 million cases in 2021. The majority of affected individuals are older than 55 years**,** and 60% are female. OA is most frequently seen in the knee, followed by the hip and hand, with more than 344 million people experiencing moderate to severe symptoms that could benefit from rehabilitation.

METHODOLOGY

Collection of Materials

The *Boswellia serrata* resin and dried rhizomes of *Zingiber officinale* (ginger) were procured from online an authenticated herbal raw material supplier. All chemicals, solvents, and reagents used were of analytical grade and obtained from Merck, Sigma-Aldrich, and Hi Media Laboratories.

Preformulation Studies

FTIR Study

Fourier Transform Infrared (FTIR) spectroscopy was employed to identify characteristic functional groups present in the extracts and to assess any possible drug–excipient interactions. The analysis was carried out using a Shimadzu IRTracer-100 FTIR spectrophotometer. Samples of pure *Boswellia serrata* extract, pure *Zingiber officinale* extract, individual excipients (Carbopol 940, surfactants, co-surfactants), and their physical mixtures (1:1 ratio by weight) were prepared for testing. For each sample, approximately 2 mg of dried material was triturated with 200 mg of spectroscopic grade potassium bromide (KBr) until a fine, homogeneous mixture was obtained. The mixture was then compressed into a transparent disc (pellet) under a pressure of 10,000–15,000 psi using a hydraulic press. Each KBr pellet was placed in the sample holder, and the spectra were recorded in the range of 4000–400 cm^{-1} at a resolution of 4 cm^{-1}, using air as the background reference.

The obtained spectra were analyzed to identify characteristic peaks corresponding to various functional groups such as O–H, C–H, C=O, C–O, and aromatic ring vibrations. The spectra of physical mixtures were compared with those of pure extracts and individual excipients to detect any significant peak shifts, disappearance, or appearance of new peaks, which could indicate potential chemical interactions. [4]

Determination of λmax by UV–Vis Spectrophotometer

The maximum wavelength of absorption (λmax) for boswellic acid and 6-gingerol was determined using a Shimadzu UV-1800 double-beam UV–Visible spectrophotometer. Standard stock solutions of each extract

were prepared separately by dissolving an accurately weighed quantity (10 mg) of the dried extract in 10 mL of ethanol to obtain a concentration of 1 mg/mL. From these stock solutions, suitable dilutions were prepared with ethanol to achieve a final concentration range of 5–20 µg/mL for spectral scanning.

The prepared solutions were transferred into clean quartz cuvettes of 1 cm path length, and ethanol was used as the blank reference. Each sample was scanned over the wavelength range of 200–400 nm at a scanning speed of 600 nm/min, with the instrument baseline corrected prior to measurement. The λmax was identified as the wavelength corresponding to the highest absorbance peak on the obtained spectrum. The λmax values obtained for boswellic acid and 6-gingerol were used for subsequent quantitative estimations, including drug content determination and in vitro release studies. All measurements were performed in triplicate to ensure reproducibility, and mean values were reported. [5]

Formulation of Nanoemulsion and Nanoemulgel

A nanoemulsion containing boswellic acid and 6-gingerol was formulated by optimizing the ratios of oil, Smix (surfactant: co-surfactant mixture), and water using pseudo-ternary phase diagrams. The phase diagrams were constructed using the aqueous titration method, where mixtures of oil and Smix at varying weight ratios were titrated with distilled water under gentle stirring until turbidity or phase separation occurred. The clear and isotropic regions of the diagrams indicated nanoemulsion formation zones, and suitable compositions were selected for further study. From the identified region, five trial formulations (F1–F5) were prepared by varying the oil: Smix: water ratios to evaluate the effect of composition on droplet size, stability, and drug-loading capacity. The oil phase was selected based on solubility studies (Section 3.3.3), while Tween 80 (surfactant) and propylene glycol (co-surfactant) were used to form the Smix.

Each formulation was prepared by dissolving the weighed quantities of boswellic acid and 6- gingerol in the oil phase, followed by the gradual addition of Smix under magnetic stirring at 1000 rpm. The pre-emulsion obtained was subjected to high-energy ultrasonication using a probe sonicator (VCX 750, Sonics & Materials Inc., USA) at 40% amplitude for 5 min with intermittent cooling in an ice bath to prevent thermal degradation. The optimized nanoemulsion was then incorporated into a Carbopol 940 gel base (0.5–1% w/w), neutralized with triethanolamine, and mixed gently to form a smooth, homogeneous nanoemulgel. [6].

Table: 1 Composition of Ginger–Boswellic Acid Nanoemulsions (F1–F5)

Formulation Code	Drug (Boswellic acid + 6-Gingerol) (% w/w)	Coconut Oil (% w/w)	Tween 80 (% w/w)	Propylene Glycol (% w/w)	Purified Water (% w/w)	Total
F1	2.0	5.0	30.0	15.0	48.0	100
F2	2.0	5.0	25.0	12.5	55.5	100
F3	2.0	5.0	20.0	10.0	63.0	100
F4	2.0	5.0	15.0	7.5	70.5	100
F5	2.0	5.0	10.0	5.0	78.0	100

"Various trial formulations (F1–F5) of nanoemulsion were prepared using different Smix ratios (Tween 80: Propylene glycol = 2:1) with fixed drug and oil concentration, and water as the continuous phase."

Table: 2 Composition of Ginger–Boswellic Acid Nanoemulgels (F1–F5) Incorporated into Carbopol 940 Gel Base (1% w/w)

Nanoemulgel Code	Nanoemulsion	Nanoemulsion (% w/w)	Carbopol 940 (% w/w)	TEA	Purified Water (% w/w)	Total
G-F1-1.0	F1	94.0	1.0	q.s. (pH 6–7)	5.0	100
G-F2-1.0	F2	94.0	1.0	q.s. (pH 6–7)	5.0	100
G-F3-1.0	F3	94.0	1.0	q.s. (pH 6–7)	5.0	100
G-F4-1.0	F4	94.0	1.0	q.s. (pH 6–7)	5.0	100
G-F5-1.0	F5	94.0	1.0	q.s. (pH 6–7)	5.0	100

"The optimized nanoemulsion batches (F1–F5) were further incorporated into a Carbopol 940 gel base (1% w/w), neutralized with triethanolamine, to obtain nanoemulgel formulations."

Note:

- **G** → stands for Gel (nanoemulgel formulation).
- **F1** → Refers to the source nanoemulsion batch used (F1 from above Table).
- → Refers to the Carbopol 940 concentration (% w/w) used in the gel (here 1%).

Physicochemical Characterization

Zeta potential

The surface charge (zeta potential) of the nanoemulsion and nanoemulgel formulations was determined using the electrophoretic light scattering technique with a Malvern Zetasizer Nano ZS (Malvern Instruments, UK). Prior to analysis, samples were diluted with 1 mM potassium chloride (KCl) solution to regulate ionic strength and achieve appropriate conductivity. The diluted samples were transferred into clean reusable or disposable zeta cells, ensuring that the electrodes were thoroughly cleaned between successive measurements. All measurements were carried out at 25 °C. Each sample was analyzed in triplicate, with every replicate representing an average of multiple subruns automatically recorded by the instrument. Zeta potential values are expressed as mean ± standard deviation (SD) in millivolts (mV).[8].

2.4.1 Droplet size & Polydispersity Index (PDI) — Dynamic Light Scattering (DLS)

Dynamic light scattering (DLS) was employed to determine the droplet size (hydrodynamic diameter) and polydispersity index (PDI) of the prepared nanoemulsion and nanoemulgel formulations using a Malvern Zetasizer Nano ZS (Malvern Instruments, UK). Prior to measurement, samples were suitably diluted (1:50–1:200) with filtered Milli-Q water or the corresponding aqueous phase to obtain an optimal scattering intensity within the recommended instrument range (approximately 0.1–1.0 McFarland equivalent). Measurements were carried out in quartz or disposable cuvettes at 25 ± 0.5 °C after an equilibration period of 120 seconds. Each formulation was analyzed in triplicate, with each measurement comprising three runs and at least 10–15 subruns per run. The intensity-weighted mean droplet size (Z-average) and PDI were calculated using the instrument software. Results are reported as mean ± standard deviation (SD) (n = 3). [7]

pH

The pH of the nanoemulsion and nanoemulgel formulations was measured using a calibrated digital pH meter at 25 ± 1 °C. Prior to analysis, the pH meter was standardized using buffer solutions of pH 4.00, 7.00, and 10.00. For nanoemulsion samples, a stable pH reading was obtained by diluting an aliquot of the formulation with distilled water in a 1:1 ratio. In the case of nanoemulgels, approximately 0.5 g of gel was dispersed in 10 mL of distilled water and allowed to equilibrate for 10 minutes under gentle stirring before measurement. [9]

Viscosity

The viscosity of the nanoemulgel was measured using a Brookfield rotational viscometer at 25 ± 0.5 °C. About 10–20 g of gel was placed in the sample cup, and measurements were performed using a suitable spindle (e.g., spindle No. 64) with constant immersion depth. Viscosity was recorded at different rotational speeds (5, 10, 20, and 50 rpm) and expressed as apparent viscosity (cP or mPa·s). All measurements were carried out in triplicate (n = 3).

Spreadability

Spreadability was evaluated using the glass slide method. A fixed quantity of formulation (e.g., 0.5 g) was placed between two glass slides, and a standard weight (e.g., 500 g) was applied for 1 min to obtain a uniform film. The upper slide was then allowed to move under a known weight, and the time (t) required to travel a specified distance (l, e.g., 7 cm) was recorded. Each formulation was analyzed in triplicate, and results were expressed as mean ± SD. Higher spreadability values indicate better ease of application.

Drug content

The drug content (%) of 6-gingerol and boswellic acid in the nanoemulgel was determined by UV–visible spectrophotometry. An accurately weighed quantity of nanoemulsion or nanoemulgel equivalent to a known amount of drug (e.g., 10 mg) was dissolved or extracted in ethanol using sonication for 15 minutes and made up to volume in a volumetric flask. The solution was centrifuged at 5000 rpm for 10 minutes and filtered through a 0.45 µm membrane filter.

Absorbance was measured using a UV–Vis spectrophotometer (Shimadzu UV-1800) at the predetermined λmax for each drug after suitable dilution. Drug concentrations were calculated from calibration curves prepared in the same solvent within the linear range. Drug content (%) was calculated by comparing the measured drug amount with the theoretical content and expressed as mean ± SD (n = 3). Acceptance for content uniformity was considered within 95–105% of the theoretical value. [12]

In Vitro Release Study

In vitro drug release from the nanoemulgel was evaluated using a Franz diffusion cell with an effective diffusion area of 3.14 cm^2. A dialysis membrane (MWCO 12,000–14,000 Da), pre-soaked overnight in phosphate buffer (pH 7.4), was placed between the donor and receptor compartments. The receptor compartment was filled with 20 mL of phosphate

buffer (pH 7.4), maintained at 37 ± 0.5 °C, and stirred continuously at 300 rpm.

An accurately weighed amount of nanoemulgel equivalent to the required drug content was placed in the donor compartment. At predetermined time intervals (0.5, 1, 2, 3, 4, 6, 8, and 12 h), 1 mL samples were withdrawn from the receptor medium and immediately replaced with fresh buffer to maintain sink conditions. The samples were filtered through a 0.45 µm membrane filter, and drug content was analyzed using a UV–Vis spectrophotometer at the respective λmax of boswellic acid and 6-gingerol. Cumulative drug release (%) was plotted against time.

Stability study

Stability testing of the optimized nanoemulgel formulation was performed in accordance with ICH Q1A (R2) guidelines. The formulation was packed in suitable containers (amber glass vials and collapsible tubes) and stored for three months under long-term conditions (25 ± 2 °C/60 ± 5% RH) and accelerated conditions (40 ± 2 °C/75 ± 5% RH). Samples were withdrawn at 0, 1, 2, and 3 months and evaluated for physical appearance, phase separation, droplet size and PDI, zeta potential, pH, viscosity, and drug content.

The acceptance criteria included absence of phase separation or significant creaming, droplet size variation of less than 20% from the initial value, PDI within acceptable limits (≤ 0.3), drug content within 90–110% of the theoretical value (research stage), and maintenance of pH and viscosity within ±10–20% of initial values.

Results

Obtained Extract for Bio-compound

Yield of Boswellic Acid

Extraction of boswellic acid from *Boswellia serrata* resin using ethanol yielded approximately 8.6% of a purified fraction. Defatting with *n*-hexane effectively removed non-polar impurities, while subsequent recrystallization from methanol improved the purity of boswellic acid. Although minor losses occurred during purification, the yield indicates efficient isolation of triterpenoids by Soxhlet extraction. These findings are consistent with earlier reports identifying ethanol as a suitable solvent for extracting resin-based phytoconstituents.

Yield of Gingerol Extract

Extraction of 6-gingerol from *Zingiber officinale* rhizomes using ethanol resulted in a purified yield of approximately 9.1%. The higher solubility of phenolic compounds in ethanol facilitated efficient extraction, while liquid–liquid partitioning effectively removed lipids and waxes, thereby enhancing the purity of the gingerol-rich fraction.

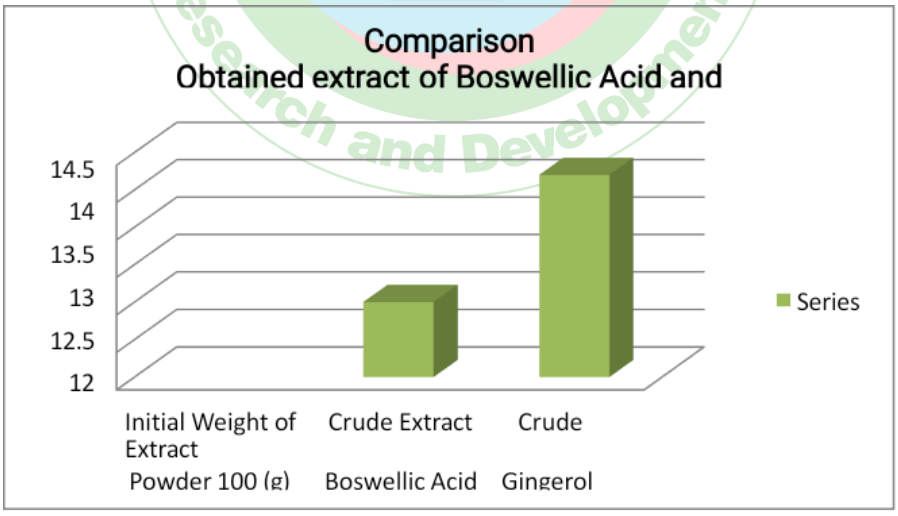

Figure: 2 Schematic representation of Obtained extract of both bio compound

FTIR Spectroscopic Determination

FTIR study of extracts Boswellia serrata

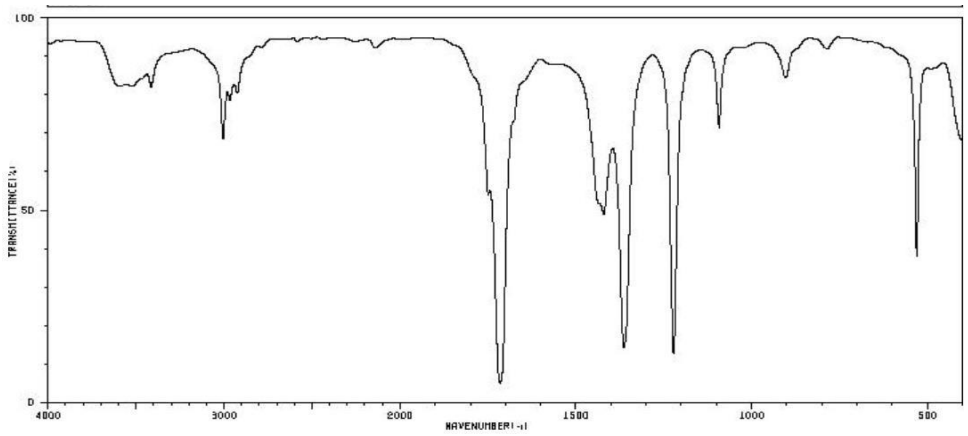

Figure: 3 FTIR Characterization of Boswellia serrata Extract

FTIR study of extracts Zingiber officinale

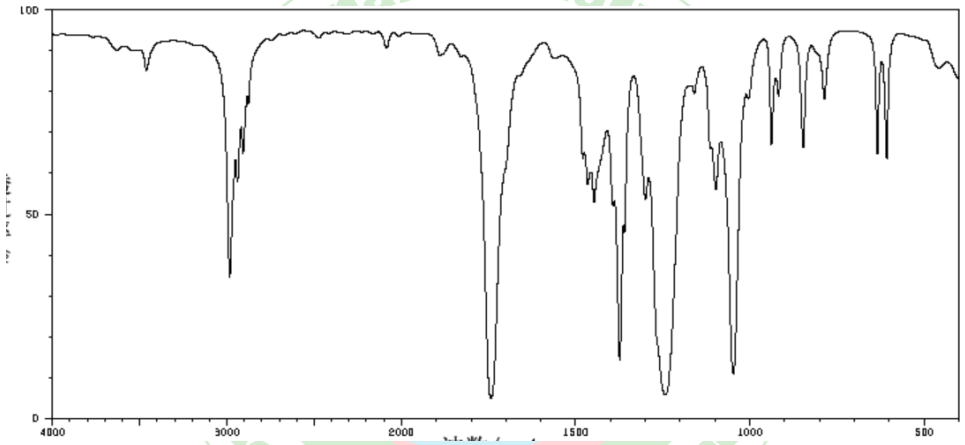

Figure: 4 FTIR Spectrum of Zingiber officinale Extract

FTIR study of extracts and excipients used in nanoemulgel

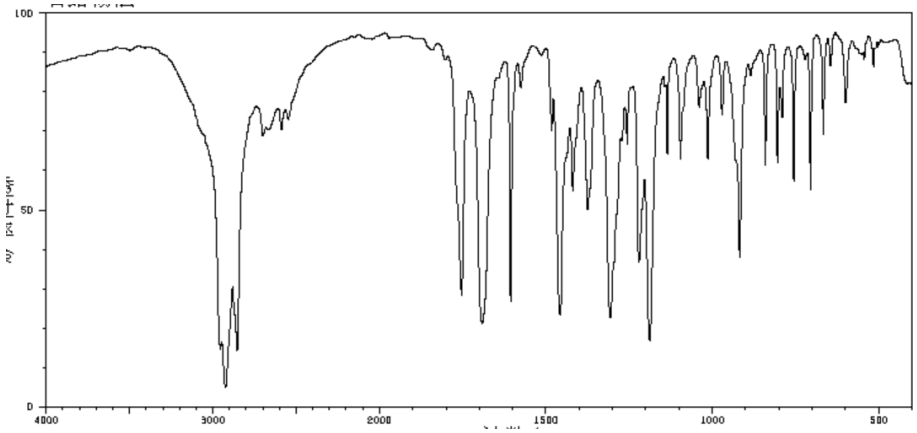

Figure: 5 FTIR Compatibility Study of Extracts with Excipients

The compatibility analysis confirmed that both Boswellic acid and Gingerol retained their characteristic peaks in the presence of Carbopol 940, Tween 80, and Propylene glycol. The absence of significant shifts or disappearance of peaks suggests no chemical interaction**,** indicating that these

excipients are safe and suitable carriers for the formulation of nanoemulgel systems.

Determination of λmax by UV–Vis Spectrophotometer

The UV–Vis spectral analysis of the extracts revealed that Boswellic acid exhibited a λmax at around 247 nm, which corresponds to the presence of conjugated carbonyl and terpenoid Functional groups. In contrast, 6-Gingerol showed a λmax at approximately 282 nm, attributed to aromatic phenolic structures and conjugated ketone groups. The sharp and well-defined absorption peaks confirmed the suitability of ethanol as a solvent system for both extracts. The reproducibility of results (triplicate analysis with ±2 nm variation) ensures reliability for further quantitative estimations such as drug content and release studies.

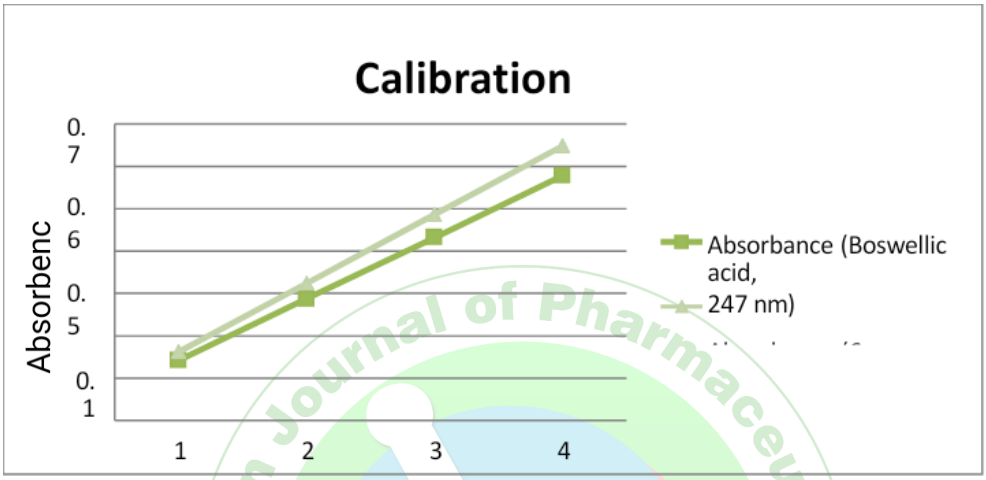

Figure: 6 Calibration curves of Boswellic Acid and 6-Gingerol

Solubility study of both extracts in various oils, surfactant and co-surfactant Table: 2 Solubility of Boswellic Acid in Different Vehicles

Vehicle Type	Vehicle Name	Solubility (mg/mL, mean ± SD, n=3)
Oil	Castor oil	2.18 ± 0.08
	Sesame oil	3.42 ± 0.11
	Coconut oil	4.05 ± 0.09
Surfactant	Tween 80	6.72 ± 0.14
	Span 80	5.48 ± 0.12
Co-surfactant	Propylene glycol	8.34 ± 0.16
	PEG 400	7.95 ± 0.13

Table: 3 Solubility of 6-Gingerol in Different Vehicles

Vehicle Type	Vehicle Name	Solubility (mg/mL, mean ± SD, n=3)
Oil	Castor oil	2.75 ± 0.07
	Sesame oil	3.91 ± 0.10
	Coconut oil	4.62 ± 0.08
Surfactant	Tween 80	7.12 ± 0.15
	Span 80	6.03 ± 0.11
Co-surfactant	Propylene glycol	9.15 ± 0.18
	PEG 400	8.56 ± 0.14

Characterization of Nanoemulgel

Droplet Size and Polydispersity Index (PDI)

Table: 4 Droplet Size and Polydispersity Index (PDI) of Nanoemulgels

Formulation	Droplet Size (nm, mean ± SD)	PDI (mean ± SD)
F1	185 ± 4.2	0.28 ± 0.01
F2	172 ± 3.8	0.26 ± 0.01
F3	145 ± 3.5	0.18 ± 0.01
F4	160 ± 4.0	0.22 ± 0.02
F5	155 ± 3.9	0.20 ± 0.01

The droplet size of all formulations ranged from 145–185 nm, with F3 showing the smallest size (145 nm) and lowest PDI (0.18), indicating a uniform and narrow size distribution. Smaller droplet size enhances surface area and improves stability, while low PDI suggests homogeneity in the formulation.

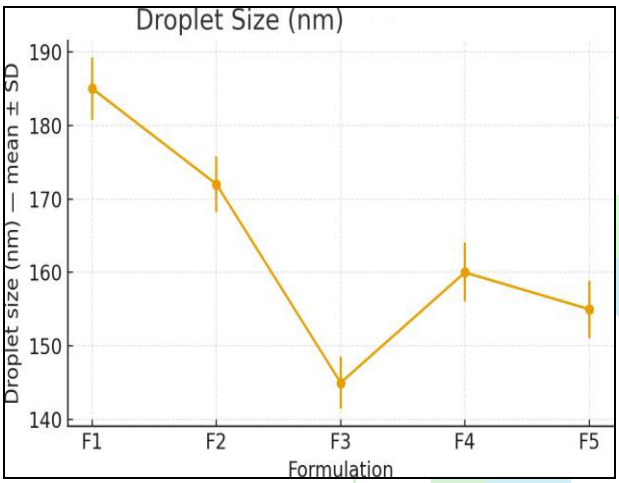

Figure: 7 Droplet Size of Nanoemulgels

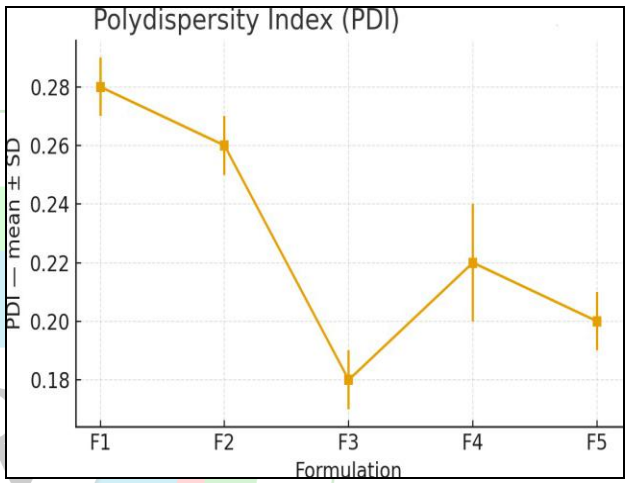

Figure: 8 Polydispersity Index of Nanoemulgel

Zeta Potential and pH of Nanoemulgel

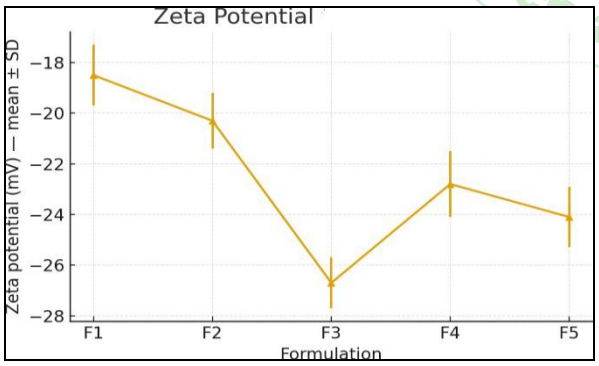

Figure: 9 Zeta Potential of Nanoemulgel

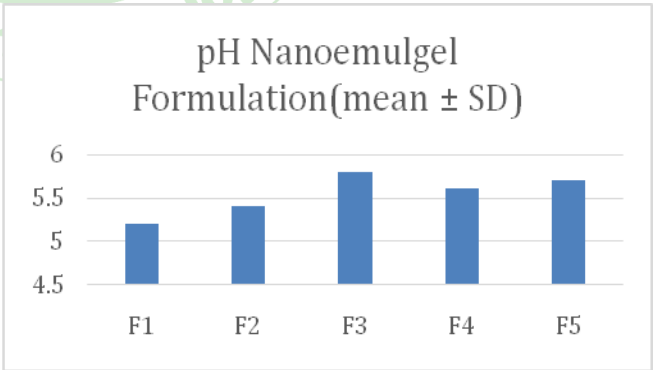

Figure: 10 Graphical representation of pH of Nanoemulgel

All formulations exhibited negative zeta potential, reflecting electrostatic stabilization. F3 had the highest absolute value (−26.7 mV), suggesting stronger repulsion between droplets and better stability against aggregation. Non-ionic surfactants contribute steric stabilization; hence, even moderate zeta potential values support overall stability.

The pH of nanoemulgels ranged from 5.2 to 5.8, within the normal skin pH range (4.5–6.5). F3 had a pH of 5.8, indicating minimal risk of skin irritation and suitability for topical application.

Viscosity of Nanoemulgels (Brookfield Viscometer)

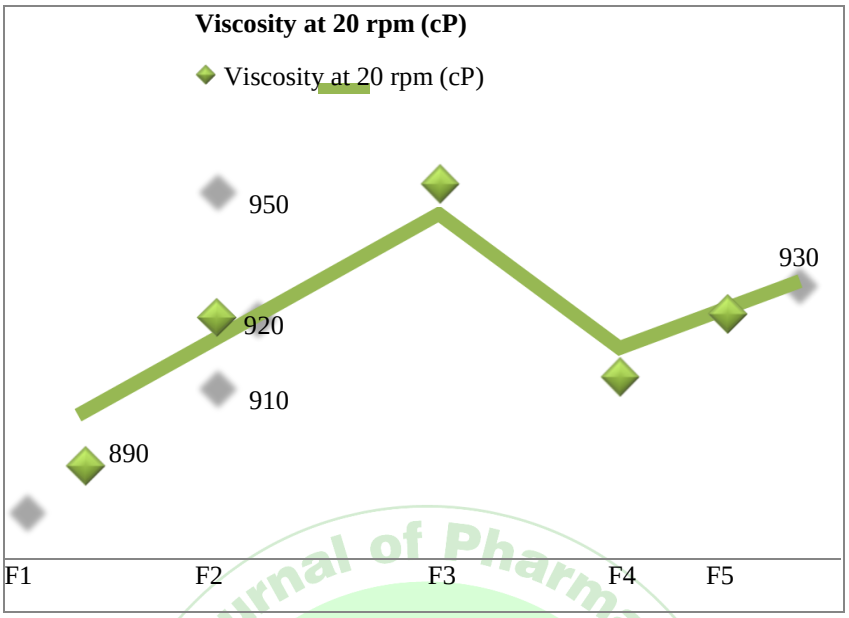

Figure: 11 Graphical representation of Viscosity of Nanoemulgels

Table: 5 Spreadability of Nanoemulgels

Formulation	Spreadability (g·cm/s, mean ± SD)
F1	19.8 ± 0.6
F2	20.5 ± 0.5
F3	23.4 ± 0.7
F4	21.2 ± 0.6
F5	22.0 ± 0.5

F3 exhibited the highest spreadability (23.4 g·cm/s), indicating that the gel can easily cover the application area with minimal effort. Higher spreadability enhances user experience and ensures uniform drug distribution over the skin surface.

Drug Content of Boswellic Acid and 6-Gingerol

Table: 6 Drug Content of Boswellic Acid and 6-Gingerol in Nanoemulgels

Formulation	Boswellic Acid (%)	6-Gingerol (%)
F1	96.5 ± 1.2	95.8 ± 1.1
F2	97.2 ± 1.0	96.4 ± 1.0
F3	98.6 ± 0.8	97.9 ± 0.9
F4	97.0 ± 1.1	96.7 ± 1.0
F5	97.8 ± 0.9	97.3 ± 0.8

Drug content for both boswellic acid and 6-gingerol is found to be between (96.5 ± 1.2 to98.6 ± 0.8) and (95.8 ± 1.1 to 97.9 ± 0.9) for Boswellic Acid and 6-Gingerol respectively, reflecting excellent incorporation efficiency. Consistent drug content ensures reproducibility and therapeutic effectiveness of the nanoemulgel.

In Vitro Cumulative Drug Release study

The drug release profile shows that all formulations provided sustained release over 12 hours. Among them, G-F3-1.0 achieved the highest cumulative release**,** suggesting that the optimized composition (oil:Smix:water ratio + 1% Carbopol gel) provides the best control over diffusion and release. The other formulations showed slightly lower or faster release, indicating less efficient drug retention. Therefore, G-F3-1.0 is confirmed as the optimized nanoemulgel for topical delivery of both extracts.

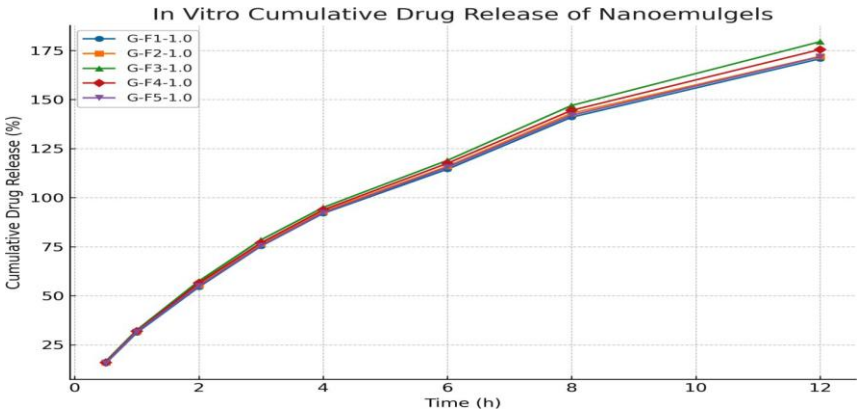

Figure: 12 Graph of in Vitro Cumulative Drug Release

Stability study

The F3 formulation of nanoemulgel demonstrated excellent stability under short-term accelerated (40 °C/75% RH) and long-term (25 °C/60% RH) conditions for 3 months. No phase separation, creaming, or significant color change was observed. Droplet size increased slightly (<5%), PDI remained low (<0.25), and zeta potential, pH, viscosity, and drug content stayed within acceptable limits, indicating that the formulation is physicochemically stable. Stress tests (centrifugation, freeze–thaw cycles, and dilution robustness) also showed no instability, confirming the robustness of F3 nanoemulgel**.**

CONCLUSION:

The present study successfully developed and characterized a ginger–boswellic acid nanoemulgel as a novel topical delivery system for the management of osteoarthritis. Both ginger and boswellic acid have well-documented anti-inflammatory and antioxidant activities, but their clinical utility has been limited by poor solubility, low permeability, and reduced systemic bioavailability when administered orally. By incorporating these phytoconstituents into a nanoemulgel system, their physicochemical barriers were overcome, resulting in nanosized droplets with uniform distribution, stable zeta potential, and improved dermal penetration.

The optimized formulation containing Boswellic acid and 6-Gingerol exhibited desirable topical characteristics, including smooth texture, good spreadability, and adequate viscosity for patient- friendly application. FTIR analysis confirmed no drug–excipient incompatibilities, while in vitro release studies demonstrated sustained and enhanced drug release compared with conventional formulations.

This formulation addresses key challenges in osteoarthritis management by offering targeted local delivery, minimizing systemic side effects, and improving patient compliance, thus establishing itself as a promising therapeutic option for chronic joint disorders.

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