Journal of Molecular Science

Journal of Molecular Science
Volume 35 Issue 4, Year of Publication 2025, Page 1712-1720
DoI-10.004687/1000-9035.2025.222

Journal of Molecular Science
www.jmolecularsci.com ISSN:1000-9035

Formulation and Evaluation Nanoemulgel for Osteoarthritis using *Boswellia serrata* and *Withania somnifera*

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Article Information
Received: 21-10-2025
Revised: 11-11-2025
Accepted: 04-12-2025
Published: 25-12-2025

Keywords
Boswellia serrata; Withania somnifera; Nanoemulgel; Nanoemulsion; Osteoarthritis; Topical drug delivery; Franz diffusion cell; Encapsulation efficiency; Sustained release.

ABSTRACT
The present study was aimed to develop and evaluate a topical nanoemulgel formulation containing *Boswellia serrata* and *Withania somnifera* extracts for improved management of osteoarthritis. The plant materials were extracted using Soxhlet extraction and subjected to preliminary phytochemical screening. Extractive values, ash values, UV spectral analysis, and FTIR compatibility studies were performed to confirm extract quality and compatibility with excipients. Nanoemulgel formulations (F1–F4) were prepared using Tween 80 as surfactant, propylene glycol as co-surfactant, ethanol as co-solvent, and Carbopol 940 as gelling agent. The prepared formulations were evaluated for pH, viscosity, droplet size, polydispersity index (PDI), zeta potential, spreadability, gel strength, adhesiveness, drug content, and encapsulation efficiency. In-vitro drug release study was carried out using Franz diffusion cell, followed by kinetic modeling. The results showed that all formulations exhibited acceptable physicochemical characteristics and were suitable for topical application. Among all batches, formulation F3 showed optimized performance with droplet size of 140 ± 2 nm, PDI of 0.19 ± 0.01, zeta potential of -30.2 ± 0.35 mV, viscosity of 2003 ± 16.7 cP, and maximum encapsulation efficiency for *Boswellia serrata* (98.0 ± 0.5%) and *Withania somnifera* (96.4 ± 0.6%). The in-vitro drug release study indicated sustained release up to 24 h, with maximum cumulative release observed for F3 (93.5 ± 3.2%). Release kinetics revealed best fitting with Korsmeyer–Peppas model, indicating diffusion-controlled drug release. Overall, the developed herbal nanoemulgel formulation demonstrated promising characteristics for topical delivery with enhanced stability and sustained release, suggesting its potential as an effective alternative for osteoarthritis management.

1. INTRODUCTION:

Osteoarthritis (OA) is a chronic degenerative joint disorder characterized by progressive cartilage damage, inflammation, pain, stiffness, and reduced mobility, and it remains a major cause of disability worldwide [1]. Current pharmacological management mainly relies on NSAIDs and analgesics, which provide symptomatic relief but are associated with adverse effects such as gastrointestinal irritation, renal toxicity, and cardiovascular risks during long-term use. Hence, there is a growing need to develop safer and effective therapeutic alternatives with improved patient compliance [2]. Herbal medicines are gaining scientific interest due to their multi-target pharmacological action and comparatively better safety profile [3]. *Boswellia serrata* is a well-known anti-inflammatory medicinal plant containing

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boswellic acids, which inhibit inflammatory mediators and enzymes involved in arthritis progression. Similarly, *Withania somnifera* (Ashwagandha) contains withanolides that exhibit anti-inflammatory, antioxidant, and immunomodulatory activity. The combination of these two herbal extracts may provide enhanced therapeutic benefit in osteoarthritis through synergistic inhibition of inflammation and oxidative stress pathways [4].

However, the clinical effectiveness of herbal extracts is often limited due to poor solubility, instability, and reduced bioavailability. Topical drug delivery is a promising approach for osteoarthritis as it enables localized drug action with reduced systemic exposure. Nanoemulsions have emerged as advanced carriers capable of improving solubility, stability, and skin permeation due to their Nano sized droplets and large surface area [5]. Incorporation of nanoemulsion into a gel base results in nanoemulgel, which combines enhanced penetration with better viscosity, spreadability, and prolonged residence time on the skin [6]. Therefore, the present study aimed to develop and evaluate a topical nanoemulgel containing *Boswellia serrata* and *Withania somnifera* extracts for improved management of osteoarthritis. The prepared formulations were characterized for physicochemical properties, encapsulation efficiency, and in-vitro drug release behaviour to identify an optimized formulation with suitable topical performance and sustained release potential.

MATERIALS AND METHODS:

Materials:

Boswellia serrata extract and Withania somnifera extract were selected as herbal active pharmaceutical ingredients due to their reported anti-inflammatory and analgesic properties. Tween 80 was used as surfactant, propylene glycol as co-surfactant, ethanol as solvent/co-solvent, Carbopol 940 as gelling agent, and triethanolamine (TEA) as neutralizing agent. All chemicals and reagents used were of analytical grade and procured from certified suppliers. Distilled water was used throughout the study.

Collection, Processing and Extraction of Plant Material (Single Paragraph)

Boswellia serrata leaves were collected from dry and mountainous regions, while *Withania somnifera* plants were collected from semi-arid regions. Healthy and mature plant samples were selected, washed thoroughly to remove dirt and extraneous matter, shade dried to prevent degradation of thermolabile phytoconstituents, and pulverized into coarse powder using a grinder. The dried powdered plant materials were then subjected to Soxhlet extraction using ethanol, methanol, and water as solvents. A measured quantity of powder was loaded into the Soxhlet apparatus and extracted continuously until the siphon tube solvent became nearly colorless. The obtained extracts were concentrated by solvent evaporation and stored in airtight containers under suitable conditions until further analysis. The extraction process is illustrated in Figure 1.

Figure 1. Extraction Process

Preliminary Phytochemical Screening:

Test for Alkaloids: About 5 g of extract was mixed with 2% hydrochloric acid and heated. After cooling, the mixture was filtered and the filtrate was treated with Mayer's reagent. Formation of cream-colored precipitate indicated the presence of alkaloids [7].

Test for Saponins: About 5 g of extract was mixed with 20 mL distilled water and shaken vigorously for 30 seconds. Formation of stable froth indicated the presence of saponins [8].

Test for Tannins: About 0.5 g extract was mixed with 2 mL water and filtered. A few drops of 0.1% ferric chloride were added to the filtrate. Development of blue-black or green-black coloration confirmed the presence of tannins.

Test for Flavonoids: About 1 g extract was mixed with 10 mL ethyl acetate and heated for 3 minutes. After cooling and filtration, 4 mL dilute ammonia solution was added. Yellow coloration indicated flavonoids [9].

Test for Terpenoids: About 5 mL extract was mixed with 2 mL chloroform and 3 mL concentrated sulfuric acid. Appearance of reddish-brown coloration at the interface indicated terpenoids.

Test for Phenols: About 1 g extract was treated with ferric chloride solution. Development of blue or green coloration indicated the presence of phenols [10].

Test for Cardiac Glycoside: About 2 g extract was dissolved in 2 mL glacial acetic acid containing one drop of ferric chloride solution and underlaid with 1 mL concentrated sulfuric acid. Formation of a brown

ring at the interface indicated cardiac glycosides [11].

Determination of Extractive Values: Extractive values were determined using water, ethanol, and methanol to evaluate the solubility of phytoconstituents and to establish extract quality. About 5 g of powdered drug was separately macerated with 100 mL of distilled water, ethanol, and methanol for 24 hours with frequent shaking. After maceration, the mixtures were filtered and the respective filtrates were evaporated to dryness. The obtained residues were dried to constant weight and weighed, and the percentage extractive values were calculated for each solvent [12].

Determination of Ash Values: Ash values were determined to assess the inorganic content and purity of the plant materials. About 2–3 g of powdered drug was accurately weighed in a crucible and incinerated in a muffle furnace at 500–600°C until white ash was obtained. The crucible was cooled in a desiccator and weighed to calculate the total ash percentage. For acid-insoluble ash, the total ash was boiled with 25 mL of dilute hydrochloric acid for 5 minutes, filtered through ashless filter paper, washed with hot water, and the residue was incinerated, cooled, and weighed. For water-soluble ash, the total ash was boiled with 25 mL of water for 5 minutes, filtered, and the residue was incinerated to constant weight; the water-soluble ash was calculated by difference [13].

UV Spectroscopic Identification and Calibration Curve:
The identity and purity of Boswellia serrata and Withania somnifera extracts were confirmed using UV-visible spectroscopy. Sample solutions were prepared in suitable solvents and scanned between 200–400 nm to determine wavelength of maximum absorbance (λmax). Standard solutions of different concentrations were prepared and absorbance was recorded at respective λmax values. Calibration curves were plotted by taking concentration on X-axis and absorbance on Y-axis, and linear regression equations were obtained for quantitative analysis.

FTIR Compatibility Study:
Drug-excipient compatibility was evaluated using FTIR spectroscopy by KBr pellet method. About 1–2 mg of sample was mixed with 200–250 mg of dry potassium bromide and compressed into a transparent pellet. FTIR spectra were recorded in the range of 4000–400 cm^{-1}. Individual spectra of Boswellia serrata extract, Withania somnifera extract, Tween 80, propylene glycol, ethanol, and Carbopol 940 were obtained. A physical mixture containing all ingredients in formulation ratio was also analyzed. Spectral peak shifts, disappearance, or appearance of new peaks were evaluated to confirm compatibility [14].

Formulation Design of Nanoemulgel:
Four nanoemulgel formulations (F1–F4) were developed to investigate the effect of varying surfactant, co-surfactant, and solvent ratios on Nanoemulsion characteristics and gel consistency. The composition of formulations is presented in Table 1.

Table 1. Composition of Nanoemulgel Formulations (F1–F4)

Ingredient	F1 (% w/w)	F2 (% w/w)	F3 (% w/w)	F4 (% w/w)
Boswellia serrata Extract	1	1	1	1
Withania somnifera Extract	1	1	1	1
Tween 80	15	12	10	15
Propylene Glycol	3	5	5	3
Ethanol	5	5	10	5
Carbopol 940	1	1	1	1
Triethanolamine (TEA)	0.5	0.5	0.5	0.5
Distilled Water (q.s. to 100 g)	73.5	74.5	71.5	73.5

Preparation of Nanoemulsion, Gel Base and Nanoemulgel:
Boswellia serrata and *Withania somnifera* extracts were accurately weighed according to the formulation composition (Table 1). Tween 80, propylene glycol, and ethanol were mixed in a beaker and the extracts were gradually incorporated under continuous stirring. Moderate heating (40–45°C) was applied when required to ensure complete dissolution. The mixture was homogenized using a high-speed homogenizer at 35,000 rpm in cycles of 15 minutes and further subjected to ultrasonication for 5 minutes using pulse mode (30 seconds ON and 10 seconds OFF), repeated for 5 cycles. Distilled water was then added dropwise under continuous stirring to obtain a uniform Nanoemulsion [15]. Carbopol 940 (1% w/w) was dispersed in distilled water with gentle stirring and allowed to hydrate for 30 minutes until a lump-free dispersion was obtained, followed by dropwise addition of triethanolamine under continuous stirring until gel formation occurred and the pH was adjusted within the desired skin-compatible range. The prepared Nanoemulsion was then incorporated into the Carbopol gel base in small portions under slow continuous stirring to prevent air entrapment, and mixing was continued until a uniform nanoemulgel was obtained. The final weight of each formulation was adjusted to 100 g using distilled water, and the prepared nanoemulgel formulations were transferred into airtight containers and allowed to stabilize for 24 hours at room temperature prior to evaluation [14].

Evaluation of Nanoemulgel Formulations:
The prepared nanoemulgel formulations were evaluated for pH, viscosity, droplet size, polydispersity index (PDI), zeta potential, spreadability, gel strength, adhesiveness, and

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encapsulation efficiency. The pH of each formulation was measured using a calibrated digital pH meter at room temperature (25 ± 2°C) and readings were recorded in triplicate. Viscosity was determined using a Brookfield viscometer at 25 ± 1°C. Droplet size, PDI, and zeta potential were analyzed using Dynamic Light Scattering (DLS) and a zeta sizer after suitable dilution with distilled water. Spreadability was determined by placing a fixed quantity of nanoemulgel between two glass plates, applying a known weight for a specific time, and calculating spreadability in cm^2/sec. Gel strength and adhesiveness were evaluated using a texture analyzer by compression method, where maximum force required for deformation was recorded as gel strength and the negative area under the force-time curve was considered as adhesiveness [15]. Encapsulation efficiency was determined by dissolving 1 g of nanoemulgel in a suitable solvent, sonication for extraction, filtration, and UV spectrophotometric analysis at 245 nm for *Boswellia serrata* and 227 nm for *Withania somnifera*, and encapsulation efficiency was calculated using the equation:

$$\mathbf{EE}(\%) = \frac{\textbf{Actual drug content}}{\textbf{Theoretical drug content}} \times \mathbf{100}$$

In-vitro Drug Release Study and Release Kinetics

In-vitro drug release study was performed using a Franz diffusion cell in which a dialysis membrane was mounted between the donor and receptor compartments. Phosphate buffer pH 7.4 was used as the receptor medium and maintained at 32 ± 1°C throughout the study. Approximately 1 g of nanoemulgel was placed in the donor compartment, and samples were withdrawn at predetermined time intervals (0, 1, 2, 4, 6, 8, 12, and 24 h) with replacement of an equal volume of fresh receptor medium to maintain sink conditions. The collected samples were analyzed using UV spectroscopy at 245 nm for *Boswellia serrata* and 227 nm for *Withania somnifera*, and the cumulative percentage drug release was calculated. The obtained release data were further fitted into various kinetic models including zero-order, first-order, Higuchi, and Korsmeyer-Peppas models to determine the drug release pattern, and the best fit model was selected based on the highest correlation coefficient (R^2) value. The release exponent (n) obtained from the Korsmeyer-Peppas model was used to interpret the drug release mechanism, and the applied kinetic models [16].

RESULTS AND DISCUSSION:

Phytochemical Screening of Extracts:

Preliminary phytochemical screening was carried out for *Boswellia serrata* and *Withania somnifera* extracts prepared using water, ethanol, and methanol solvents. The results confirmed the presence of multiple bioactive phytoconstituents including alkaloids, flavonoids, phenols, terpenoids, tannins, saponins, and cardiac glycosides depending on the extraction solvent. In *Boswellia serrata*, the aqueous extract showed the presence of alkaloids, tannins, flavonoids, terpenoids, and phenols, whereas saponins and cardiac glycosides were absent. However, ethanol and methanol extracts showed the presence of all tested phytoconstituents, indicating their superior extraction efficiency. In *Withania somnifera*, the aqueous extract showed alkaloids, flavonoids, phenols, and saponins, while tannins, terpenoids, and cardiac glycosides were absent; in contrast, both ethanol and methanol extracts revealed the presence of all phytochemicals, confirming ethanol and methanol as effective solvents for extracting diverse active compounds. These findings support the therapeutic significance of both plants, as flavonoids and phenolic compounds contribute to antioxidant potential, while alkaloids and terpenoids are associated with anti-inflammatory and analgesic activity. The phytochemical test observations are shown in **Figure 2**, and the screening results are summarized in **Table 2.**

Figure 2. Alkaloids, Saponins, Tannins, Flavonoids, Terpenoids, Phenols & Cardiac Glycosides

Table 2. Phytochemical Screening of *Boswellia serrata* and *Withania somnifera* Extracts in Different Solvents

Phytochemicals	*Boswellia serrata*			*Withania somnifera*		
	Water	Ethanol	Methanol	Water	Ethanol	Methanol
Alkaloids	+	+	+	+	+	+
Saponins	–	+	+	+	+	+
Tannins	+	+	+	–	+	+
Flavonoids	+	+	+	+	+	+
Terpenoids	+	+	+	–	+	+
Phenols	+	+	+	+	+	+
Cardiac Glycosides	–	+	+	–	+	+

Note: (+) Present, (–) Absent

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Extractive Values

Extractive values were determined to estimate the quantity of active constituents extracted using different solvents. The extractive value of *Boswellia serrata* was found to be 12% (water), 18% (ethanol), and 20% (methanol), while *Withania somnifera* showed extractive values of 14% (water), 16% (ethanol), and 19% (methanol). Methanol exhibited the highest extractive values for both plants, indicating its superior efficiency in extracting polar and moderately non-polar phytoconstituents. Ethanol also showed good extraction capacity, particularly for *Boswellia serrata*. The comparative extractive values are represented in **Fig. 3** and summarized in **Table 3**.

Table 3. Extractive Values of *Boswellia serrata* and *Withania somnifera*

Solvent	*Boswellia serrata* (%)	*Withania somnifera* (%)
Water	12	14
Ethanol	18	16
Methanol	20	19

Figure 3. Extractive Values

Ash Values:

Ash values were determined as quality control parameters to assess the inorganic and mineral content present in the crude plant materials. *Boswellia serrata* showed total ash value of 8.5%, acid-insoluble ash of 1.2%, and water-soluble ash of 4.3%, while *Withania somnifera* showed slightly higher values including total ash 9.8%, acid-insoluble ash 1.5%, and water-soluble ash 5.6%. The comparatively higher total ash value of *Withania somnifera* indicates higher mineral content, whereas the low acid-insoluble ash values in both plants suggest minimal contamination with silica and earthy matter, confirming good sample purity. The ash values are represented in Figure 4 and summarized in Table 4.

Table 4. Ash Values of *Boswellia serrata* and *Withania somnifera*

Ash Type	*Boswellia serrata* (%)	*Withania somnifera* (%)
Total Ash	8.5	9.8
Acid-Insoluble Ash	1.2	1.5
Water-Soluble Ash	4.3	5.6

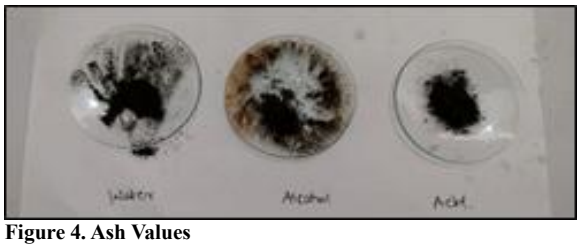

Figure 4. Ash Values

UV Spectral Analysis and Determination of λmax

UV spectroscopy was performed to confirm the identity and purity of *Boswellia serrata* and *Withania somnifera* extracts. The UV spectrum of *Boswellia serrata* extract exhibited prominent absorption peaks at 205 nm and 245 nm, confirming the presence of boswellic acid constituents, while *Withania somnifera* extract showed a broad absorption peak at 227 nm corresponding to withanolide compounds. Based on the spectral scan, λmax values were selected as 245 nm for *Boswellia serrata* and 227 nm for *Withania somnifera* for further quantitative estimations (Figure 5). Calibration curves were prepared for both extracts in the concentration range of 5–25 µg/mL and showed excellent linearity with high correlation coefficients, confirming compliance with Beer–Lambert's law and validating the suitability of UV spectrophotometry for accurate drug content estimation in the developed nanoemulgel formulations.

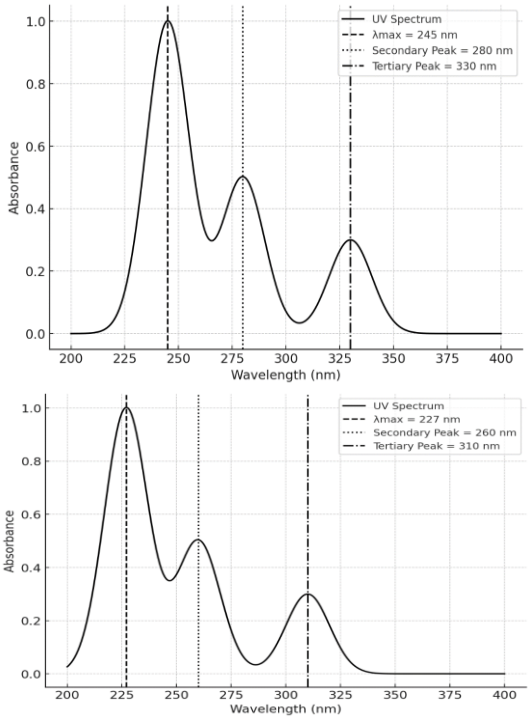

Figure 5. UV Spectral

FTIR Compatibility Study:

The individual FTIR spectra of *Boswellia serrata*, *Withania somnifera*, Tween 80, propylene glycol, ethanol, and Carbopol 940 showed characteristic

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peaks corresponding to their functional groups. *Boswellia serrata* exhibited O–H stretching peaks around 3400–3450 cm^{-1} and C=O stretching peaks at 1700–1730 cm^{-1}, confirming the presence of boswellic acid-related functional groups, while *Withania somnifera* showed broad O–H stretching peaks around 3300–3400 cm^{-1} and C=O stretching peaks around 1660–1700 cm^{-1}, consistent with withanolide constituents. The FTIR spectrum of the physical mixture (Fig. 11) showed only minor peak shifting and broadening, which may be attributed to hydrogen bonding, and no disappearance of major peaks or formation of new peaks was observed. This confirms the absence of significant chemical interaction and indicates good compatibility between the extracts and formulation excipients. The FTIR spectra of *Boswellia serrata* and *Withania somnifera* extracts are shown in **Figure 6 and Figure 7**, while the physical mixture spectrum is presented ii figure 8, confirming compatibility.

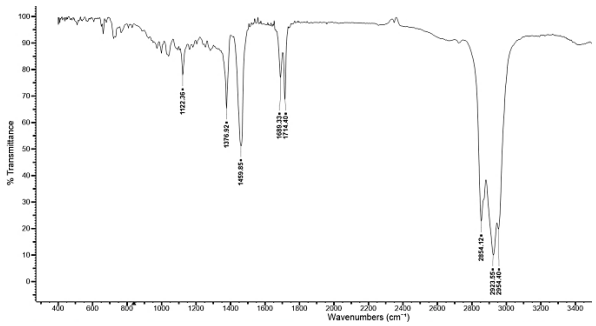

Figure 6. Boswellia serrate FTIR

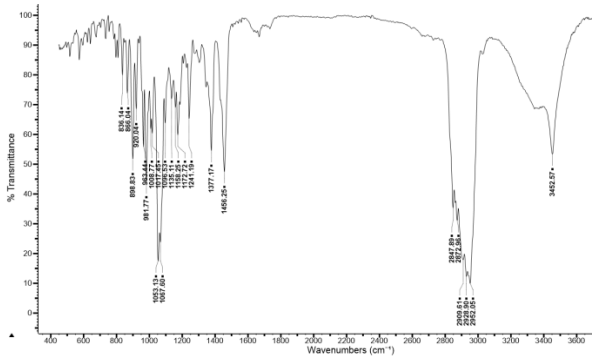

Figure 7. Withania somnifera FTIR

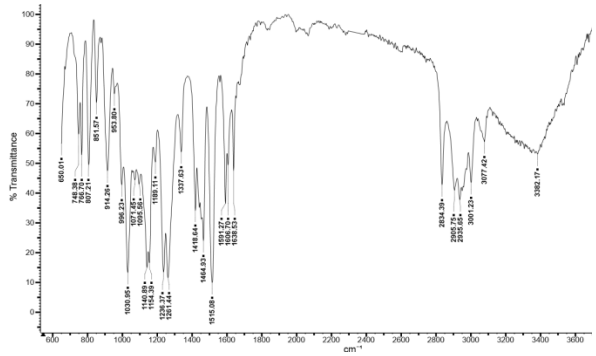

Figure 8. Physical Mixer of All ingredients FTIR

Evaluation of Nanoemulgel Formulations:

pH Determination: The pH of all formulations was found to be within the acceptable skin-compatible range of 5.5–6.5. Formulation F1 showed mean pH of 5.55 ± 0.03, F2 showed 5.67 ± 0.02, F3 showed 6.18 ± 0.03, and F4 showed 5.98 ± 0.02. These results (Table 5) indicate that the formulations are suitable for topical application with minimal irritation risk.

Viscosity Study: Viscosity is an important parameter influencing gel consistency, spreadability, and retention at the application site. The viscosity values ranged from 1505 ± 15 cP to 2003 ± 16.7 cP. Formulation F3 exhibited the highest viscosity, suggesting stronger gel structure and better retention, whereas F1 showed the lowest viscosity but remained within acceptable topical gel range (Table 5).

Zeta Potential: Zeta potential indicates the stability of nanoemulsion droplets. The formulations showed zeta potential values between -24.8 mV and -30.2 mV. Higher negative values suggest better stability due to electrostatic repulsion. Formulation F3 exhibited the highest negative zeta potential (-30.2 ± 0.35 mV), suggesting maximum stability (Table 5).

Polydispersity Index (PDI): PDI indicates droplet size distribution uniformity. All formulations showed PDI values below 0.3, confirming narrow distribution and homogeneity. F3 showed the lowest PDI (0.19 ± 0.01), indicating the most uniform nanoemulsion system (Table 5).

Droplet Size Analysis: Droplet size is a critical parameter affecting drug permeation and stability. All formulations were found to be within the Nano range (<200 nm). F3 showed the smallest droplet size (140 ± 2 nm), followed by F2 (160 ± 2 nm), F4 (168 ± 2.5 nm), and F1 (179 ± 3.6 nm). Smaller droplet size increases surface area and enhances drug release and skin penetration (Table 5).

Nanoemulgel Evaluation:

Spreadability:

Spreadability values ranged between 3.8 ± 0.1 and 4.5 ± 0.05 cm^2/sec, indicating easy application. F4 showed the highest spreadability, while F3 showed slightly lower spreadability due to its higher viscosity. However, all formulations were within acceptable limits for topical gels.

Gel Strength and Adhesiveness:

Gel strength and adhesiveness determine gel consistency and retention at the site of application. F3 exhibited the highest gel strength (50.2 ± 0.4 g) and adhesiveness (8.9 ± 0.1 g·s), which correlates with its highest viscosity. This suggests F3 may remain on the skin longer, improving residence time and therapeutic

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effect.

Encapsulation Efficiency:

Encapsulation efficiency indicates the ability of nanoemulgel to entrap and retain active constituents. Boswellia serrata showed high encapsulation efficiency ranging from 95.1% to 98.0%, whereas Withania somnifera showed 93.4% to 96.4%. Among all formulations, F3 showed the highest encapsulation efficiency for both extracts (Boswellia: 98.0 ± 0.5%; Withania: 96.4 ± 0.6%), suggesting optimal formulation composition (Table 5).

Table 5. Physicochemical and Performance Evaluation of Nanoemulgel Formulations (F1–F4)

Parameter	F1 (Mean ± SD)	F2 (Mean ± SD)	F3 (Mean ± SD)	F4 (Mean ± SD)
pH	5.55 ± 0.03	5.67 ± 0.02	6.18 ± 0.03	5.98 ± 0.02
Viscosity (cP)	1505 ± 15	1800 ± 10	2003 ± 16.7	1703 ± 12.5
Zeta Potential (mV)	-25.2 ± 0.78	-28.1 ± 0.30	-30.2 ± 0.35	-24.8 ± 0.25
PDI	0.25 ± 0.02	0.21 ± 0.01	0.19 ± 0.01	0.26 ± 0.02
Droplet Size (nm)	179 ± 3.6	160 ± 2.0	140 ± 2.0	168 ± 2.5
Spreadability (cm²/sec)	4.4 ± 0.1	4.1 ± 0.1	3.8 ± 0.1	4.5 ± 0.05
Gel Strength (g)	42.5 ± 0.7	46.0 ± 0.2	50.2 ± 0.4	44.6 ± 0.4
Adhesiveness (g·s)	7.5 ± 0.1	8.0 ± 0.2	8.9 ± 0.1	7.8 ± 0.2
Drug Content (*Boswellia serrata*) (mg)	9.53 ± 0.08	9.69 ± 0.04	9.80 ± 0.05	9.51 ± 0.04
Encapsulation Efficiency (*Boswellia serrata*) (%)	95.3 ± 0.8	96.9 ± 0.4	98.0 ± 0.5	95.1 ± 0.4
Drug Content (*Withania somnifera*) (mg)	9.34 ± 0.06	9.49 ± 0.03	9.64 ± 0.06	9.39 ± 0.03
Encapsulation Efficiency (*Withania somnifera*) (%)	93.4 ± 0.6	94.9 ± 0.3	96.4 ± 0.6	93.9 ± 0.3

In-vitro Drug Release Study:

In-vitro drug release study was performed using Franz diffusion cell to evaluate sustained release behaviour of nanoemulgel formulations. The cumulative drug release of Boswellia serrata after 24 hours was found to be 90.2 ± 3.1% (F1), 87.0 ± 2.9% (F2), 93.5 ± 3.2% (F3), and 89.2 ± 3.0% (F4). The drug release was gradual and sustained throughout 24 hours, indicating controlled release properties of the nanoemulgel system. Formulation F3 showed the highest cumulative drug release (93.5%), which may be attributed to its smallest droplet size and lowest PDI, providing higher surface area for drug diffusion. The cumulative release data are summarized in Table 6.

Table 6. Cumulative Drug Release (%)

Time (h)	F1 (Mean ± SD)	F2 (Mean ± SD)	F3 (Mean ± SD)	F4 (Mean ± SD)
0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0
1	12.5 ± 1.0	10.2 ± 0.8	13.5 ± 1.2	11.0 ± 0.7
2	25.6 ± 1.2	22.1 ± 1.1	28.2 ± 1.0	24.0 ± 1.3
4	40.3 ± 1.5	36.7 ± 1.6	42.8 ± 1.8	38.5 ± 1.5
6	55.1 ± 2.0	50.2 ± 2.1	59.5 ± 2.3	53.8 ± 2.0
8	66.4 ± 2.4	61.5 ± 2.2	71.5 ± 2.5	65.2 ± 2.3
12	78.3 ± 2.7	73.5 ± 2.6	82.1 ± 2.8	76.8 ± 2.7
24	90.2 ± 3.1	87.0 ± 2.9	93.5 ± 3.2	89.2 ± 3.0

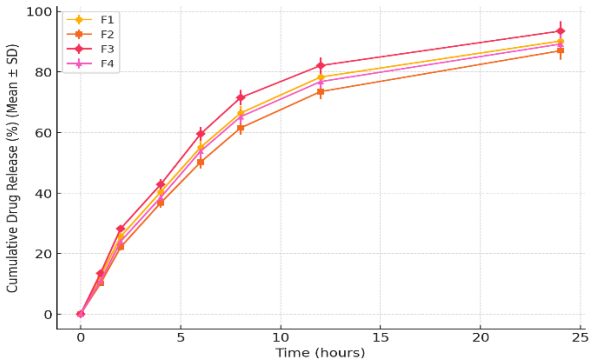

Figure 9. Cumulative Drug Release

Drug Release Kinetics:

To understand the release mechanism, drug release data were fitted into different kinetic models including zero order, first order, Higuchi, and Korsmeyer-Peppas models. The correlation coefficient (R^2) values indicated that the Korsmeyer-Peppas model showed the best fit for all formulations, with R^2 values ranging from 0.978 to 0.985. Higuchi model also showed good fit, confirming diffusion-based release behaviour. The release exponent (n) values ranged between 0.43 to 0.48, indicating Fickian diffusion or quasi-Fickian diffusion mechanism ($n < 0.5$). This suggests that the drug release from nanoemulgel occurs mainly through diffusion of drug molecules through the gel matrix. The kinetic analysis is summarized in Table 7.

Table 7. Release Kinetics Model Fitting (R^2 Values)

Formulation	Zero Order (R^2)	First Order (R^2)	Higuchi (R^2)	Korsmeyer-Peppas (R^2)	n Value
F1	0.93	0.92	0.965	0.978	0.45
F2	0.925	0.91	0.970	0.982	0.46
F3	0.94	0.916	0.972	0.985	0.48
F4	0.935	0.914	0.966	0.980	0.43

Selection of Optimized Formulation:

Among all prepared nanoemulgel formulations, F3 was found to be the most optimized formulation. It exhibited the smallest droplet size (138 nm), lowest PDI (0.19), highest viscosity (2003 cP), highest zeta potential (-30.2 mV), maximum gel strength (50.2 g), and highest encapsulation efficiency for both extracts. Additionally, F3 demonstrated the highest in-vitro drug release (93.5% at 24 hours). These results indicate that the formulation containing Tween 80 (10%), propylene glycol (5%), ethanol (10%), and

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Carbopol 940 (1%) provided the best balance between stability, consistency, drug loading, and controlled drug release. Thus, F3 was selected as the optimized nanoemulgel formulation suitable for topical anti-inflammatory and osteoarthritis applications.

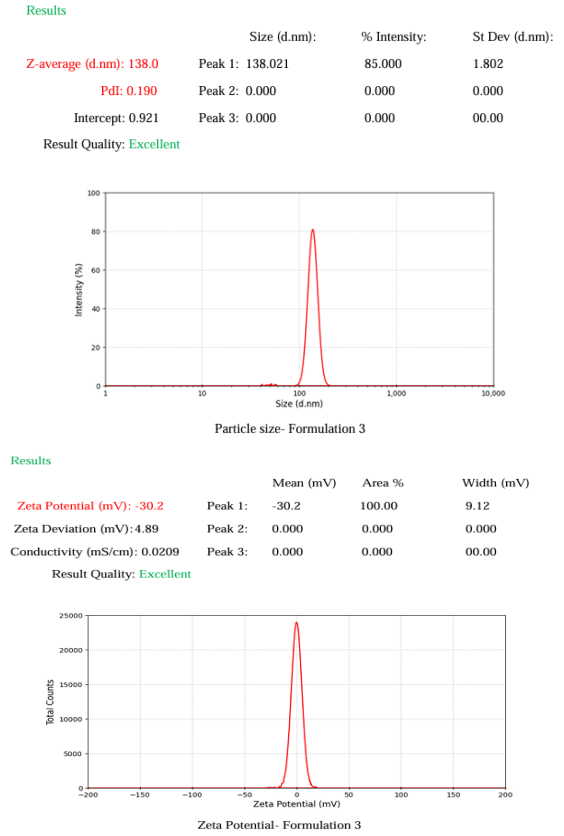

Figure 10. Optimized Formulation Particle Size and Zeta Potential

CONCLUSION:

In the present study, a topical nanoemulgel containing *Boswellia serrata* and *Withania somnifera* extracts was successfully formulated and evaluated for its suitability in osteoarthritis management. Phytochemical screening confirmed the presence of major bioactive constituents in the extracts, while extractive and ash value studies supported the quality of the crude drugs. UV and FTIR analysis confirmed the identity of the extracts and demonstrated compatibility with formulation excipients. Nanoemulgel formulations (F1–F4) showed acceptable physicochemical properties, including suitable pH, viscosity, droplet size, PDI, and zeta potential, indicating stability and skin compatibility. Among all formulations, F3 was identified as the optimized batch due to its smallest droplet size, lowest PDI, highest viscosity, maximum encapsulation efficiency, and superior gel strength and adhesiveness. In-vitro drug release studies demonstrated sustained release up to 24 hours, with maximum cumulative release observed for F3. Drug release kinetics suggested diffusion-controlled release behaviour and developed herbal nanoemulgel formulation demonstrated promising characteristics for enhanced topical delivery and sustained therapeutic action, indicating its potential as a safe and effective alternative for osteoarthritis treatment.

ACKNOWLEDGEMENT:

The authors are thankful to the Department of Pharmacy, Madhav University, Abu Road, Rajasthan, India, for providing the necessary facilities to carry out this work. The authors also express sincere gratitude to **Dr. Abhinay Kumar Dwivedi** (Guide) and **Dr. Sanjesh Kumar Rathi** (Co-guide) for their valuable guidance and support throughout the research work.

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