e-ISSN: 0975-1556, p-ISSN:2820-2643

Available online on www.ijpcr.com

International Journal of Pharmaceutical and Clinical Research 2026; 18(1); 23-34

Original Research Article

Formulation, Development and Evaluation of Curcumin Gel for Transdermal Drug Delivery in the Treatment of Rheumatoid Arthritis

Ajay Siwach[1], Ashutosh Sharma[2], Narender Sharma[3], Parul Vaishnav[4]

[1]Research Scholar, Department of Pharmaceutics, Jaipur College of Pharmacy, Sitapura, Jaipur, Rajasthan, India

[2] Associate Professor, Department of Pharmaceutics, Jaipur College of Pharmacy, Sitapura, Jaipur, Rajasthan, India

[4]Plant Head, Department of Production, Zee Laboratories Ltd., Netaji Subhash Place, Pitampura, Delhi, India

[4]Assistant Professor, Department of Pharmaceutics, Jaipur College of Pharmacy, Sitapura, Jaipur, Rajasthan, India

Received: 22-03-2026 / Revised: 14-04-2026 / Accepted: 28-04-2026

Corresponding Author: Mr. Ajay Siwach

Conflict of interest: Nil

Abstract:

Rheumatoid arthritis (RA) is a chronic autoimmune inflammatory disease characterized by synovial inflammation, cartilage degradation, bone erosion, and progressive disability. Conventional therapeutic approaches such as non-steroidal anti-inflammatory drugs (NSAIDs), corticosteroids, and disease-modifying antirheumatic drugs (DMARDs) are associated with severe adverse effects including gastrointestinal toxicity, immunosuppression, hepatotoxicity, and poor patient compliance during long-term therapy. Curcumin, a natural polyphenolic compound obtained from *Curcuma longa*, exhibits potent anti-inflammatory, antioxidant, and immunomodulatory activities; however, its therapeutic utility is restricted because of poor aqueous solubility, rapid metabolism, instability, and low oral bioavailability. The present study aimed to formulate and evaluate a curcumin-loaded solid lipid nanoparticle (SLN)-based transdermal gel for effective management of rheumatoid arthritis. Curcumin-loaded SLNs were prepared using glyceryl monostearate, Tween 80, Span 80, and soya lecithin by hot homogenization-ultrasonication method. Optimized SLNs were incorporated into Carbopol gel and evaluated for physicochemical properties, particle size, zeta potential, entrapment efficiency, viscosity, spreadability, pH, drug content, and in-vitro drug release. The optimized formulation demonstrated nanosized particles with high drug entrapment efficiency and sustained release characteristics. The developed transdermal gel exhibited good homogeneity, acceptable rheological behavior, enhanced permeation, and prolonged drug release. The results suggested that curcumin-loaded SLN gel may serve as a promising alternative therapeutic approach for rheumatoid arthritis by improving drug bioavailability, minimizing systemic toxicity, and enhancing patient compliance.

Keywords: Rheumatoid arthritis; Curcumin; Solid lipid nanoparticles; Transdermal drug delivery; Nanogel; Anti-inflammatory activity.

Introduction

Rheumatoid arthritis (RA) is a chronic, progressive, systemic autoimmune inflammatory disorder that primarily affects synovial joints and leads to pain, swelling, stiffness, deformity, and gradual destruction of cartilage and bone. The disease is characterized by persistent inflammation of the synovial membrane, resulting in irreversible joint damage and functional disability if left untreated. RA not only affects the musculoskeletal system but also involves multiple organs including the lungs, cardiovascular system, kidneys, eyes, and skin, thereby contributing significantly to morbidity and mortality worldwide. [1] Globally, rheumatoid arthritis affects approximately 0.3–1% of the population and is more prevalent among women than men, particularly between the ages of 30 and 60 years. In India, RA represents one of the most common inflammatory joint diseases, affecting nearly 0.75% of the population. Genetic susceptibility, hormonal imbalance, smoking, infections, environmental exposure, obesity, and immune dysregulation are considered major contributing factors in the development of the disease. Although the exact etiology remains unclear, RA is believed to arise from a complex interaction between genetic and environmental factors that trigger abnormal immune re-

sponses against self-antigens. [2] The pathogenesis of rheumatoid arthritis is mediated through activation of immune cells such as T lymphocytes, B lymphocytes, macrophages, neutrophils, and synovial fibroblasts. These activated cells release large amounts of inflammatory mediators and cytokines including tumor necrosis factor-alpha (TNF-α), interleukin-1β (IL-1β), interleukin-6 (IL-6), cyclooxygenase-2 (COX-2), and prostaglandins. The excessive production of these cytokines promotes synovial hyperplasia, pannus formation, cartilage destruction, osteoclast activation, and bone erosion. Furthermore, oxidative stress and reactive oxygen species (ROS) contribute to tissue injury and disease progression by damaging cellular proteins, lipids, and DNA. [3]

Clinically, patients suffering from rheumatoid arthritis commonly experience morning stiffness, joint tenderness, fatigue, reduced mobility, warmth around joints, and chronic pain. As the disease progresses, severe joint deformities and systemic complications may occur, leading to loss of physical function and reduced quality of life. Extra-articular manifestations such as pulmonary fibrosis, cardiovascular diseases, vasculitis, osteoporosis, anemia, and nodules are also frequently observed in advanced RA patients. [4]

Conventional pharmacological management of RA mainly includes non-steroidal anti-inflammatory drugs (NSAIDs), corticosteroids, glucocorticoids, disease-modifying antirheumatic drugs (DMARDs), and biologic agents. NSAIDs such as diclofenac, celecoxib, and aspirin are widely used to reduce pain and inflammation, whereas DMARDs like methotrexate, leflunomide, sulfasalazine, and hydroxychloroquine help slow disease progression. Biologic therapies targeting TNF-α and IL-6 pathways have also shown remarkable clinical benefits. However, long-term administration of these medications is often associated with serious adverse effects including gastrointestinal ulceration, hepatotoxicity, nephrotoxicity, immunosuppression, cardiovascular complications, and poor patient compliance. Additionally, biologic agents are expensive and may increase susceptibility to infections. Due to the limitations associated with conventional therapies, there has been increasing interest in herbal and natural compounds possessing anti-inflammatory and antioxidant properties for the management of rheumatoid arthritis. Among these, curcumin has emerged as one of the most promising phytoconstituents for inflammatory disorders.

Curcumin is a natural polyphenolic compound derived from the rhizome of *Curcuma longa* (turmeric), a medicinal plant extensively used in Ayurvedic and traditional medicine systems for centuries. Curcumin possesses a broad spectrum of pharmacological activities including anti-inflammatory, antioxidant, antimicrobial, anticancer, wound healing, and immunomodulatory effects. [5]

The anti-inflammatory action of curcumin is primarily attributed to inhibition of inflammatory signaling pathways such as nuclear factor-kappa B (NF-κB), activator protein-1 (AP-1), cyclooxygenase-2 (COX-2), lipoxygenase (LOX), and Janus kinase/signal transducer pathways. Curcumin also suppresses the production of inflammatory cytokines including TNF-α, IL-1β, IL-6, and interferon-gamma, thereby reducing synovial inflammation and cartilage destruction in rheumatoid arthritis. Moreover, its potent antioxidant property scavenges reactive oxygen species and minimizes oxidative stress-induced tissue damage. Several preclinical and clinical studies have demonstrated significant reductions in inflammatory markers, joint swelling, pain, and disease severity following curcumin administration. [6]

Despite its promising therapeutic profile, the clinical application of curcumin remains limited because of poor aqueous solubility, low permeability, rapid metabolism, chemical instability, and extremely low oral bioavailability. Following oral administration, curcumin undergoes extensive hepatic metabolism and rapid elimination, resulting in insufficient systemic drug concentrations. These limitations significantly reduce its therapeutic effectiveness in chronic inflammatory diseases such as rheumatoid arthritis. Therefore, development of novel drug delivery systems capable of improving curcumin stability, permeability, and bioavailability has become an important area of pharmaceutical research. [7] Nanotechnology-based drug delivery systems have gained considerable attention in recent years due to their ability to enhance therapeutic efficacy and targeted drug delivery. Among various nanocarrier systems, solid lipid nanoparticles (SLNs) are considered highly promising because they combine the advantages of polymeric nanoparticles, liposomes, and emulsions while minimizing their limitations. SLNs are submicron colloidal carriers composed of physiological lipids that remain solid at room and body temperatures.

These carriers offer several advantages including enhanced drug stability, improved bioavailability, controlled release, biocompatibility, low toxicity, and protection of encapsulated drugs from degradation. [8] SLNs have demonstrated excellent potential for transdermal drug delivery applications due to their nanoscale size and lipidic nature, which facilitate close contact with the stratum corneum and enhance skin penetration. Additionally, SLNs can provide sustained release of encapsulated drugs, thereby reducing dosing frequency and improving therapeutic outcomes. Curcumin-loaded SLNs have shown enhanced anti-inflammatory activity and superior skin permeation compared to conventional formulations in various experimental

studies. [9] Transdermal drug delivery systems (TDDS) represent an attractive alternative to oral and parenteral administration for chronic diseases such as rheumatoid arthritis.

TDDS deliver drugs across the skin into systemic circulation or localized tissues while bypassing hepatic first-pass metabolism and gastrointestinal degradation. Advantages of transdermal delivery include sustained plasma drug concentration, reduced systemic side effects, improved patient compliance, painless administration, and easy termination of therapy by removing the formulation from the skin surface. Furthermore, topical delivery directly to inflamed joints may increase local drug concentration while minimizing systemic exposure. [10] However, the major challenge associated with TDDS is the barrier function of the stratum corneum, which restricts penetration of many therapeutic agents. Therefore, incorporation of curcumin into nanosized lipid carriers such as SLNs may significantly improve permeation through skin layers and increase drug retention at the target site.

Combining nanotechnology with transdermal delivery can therefore provide an effective strategy for enhancing therapeutic efficacy of curcumin in rheumatoid arthritis management.[11] Based on these considerations, the present study was designed to formulate, develop, and evaluate a curcumin-loaded solid lipid nanoparticle-based transdermal gel for the treatment of rheumatoid arthritis.

The study aims to enhance curcumin bioavailability, improve skin permeation, achieve sustained drug release, and reduce adverse effects associated with conventional therapies. The developed formulation may serve as a promising, safer, and patient-friendly therapeutic approach for long-term management of rheumatoid arthritis. [12]

Materials and Methods

Materials

Curcumin was used as the active pharmaceutical ingredient. Glyceryl monostearate (GMS) was employed as solid lipid. Tween 80 and Span 80 were utilized as surfactant and co-surfactant respectively. Soya lecithin served as stabilizer, Carbopol 934 as gelling agent, triethanolamine as pH adjuster, and propylene glycol as penetration enhancer. Methanol and acetone were used as analytical solvents.

Preformulation Studies: Curcumin was characterized for organoleptic properties, melting point, partition coefficient, and solubility profile. UV-visible spectroscopy was performed to determine λmax in methanol. FTIR studies were conducted to identify characteristic functional groups and evaluate drug-excipient compatibility. Differential scanning calorimetry (DSC) was used to assess thermal behavior.

Preparation of Curcumin-Loaded SLNs: Curcumin-loaded SLNs were prepared by hot homogenization followed by ultrasonication technique. The lipid phase containing GMS and curcumin was heated above the melting point of lipid. The aqueous phase consisting of Tween 80, Span 80, and soya lecithin was maintained at the same temperature and added gradually into the lipid phase under continuous stirring. The resulting emulsion was homogenized and subjected to ultrasonication to reduce particle size and obtain stable SLNs.

Formulation of Transdermal Gel: Carbopol 934 was dispersed in distilled water and allowed to hydrate overnight. Optimized SLNs were incorporated into hydrated gel base under continuous stirring. Propylene glycol was added as penetration enhancer and triethanolamine was used for pH adjustment to obtain homogeneous gel formulation.

Evaluation of Formulation

Particle Size and Polydispersity Index: Particle size and polydispersity index (PDI) were determined using dynamic light scattering method. The optimized formulation exhibited nanosized particles with narrow distribution indicating uniformity and stability.

Zeta Potential: Zeta potential analysis confirmed adequate surface charge and colloidal stability of SLNs.

Entrapment Efficiency: Entrapment efficiency was evaluated using centrifugation method and was found to be satisfactory, indicating efficient incorporation of curcumin into lipid matrix.

pH Determination: The pH of developed gel ranged between 6.2 and 6.8, which is suitable for topical application without causing skin irritation.

Viscosity and Spreadability: Viscosity measurements demonstrated appropriate rheological behavior for transdermal application. The gel also exhibited excellent spreadability ensuring uniform topical application.

Drug Content: Drug content analysis confirmed uniform distribution of curcumin throughout the gel formulation.

In-vitro Drug Release Study: Drug release studies were performed using Franz diffusion cell apparatus. The optimized formulation showed sustained and controlled release behavior over extended duration.

Results

Table 1: Determination of λmax of curcumin

Parameter	Observation

Solvent Used	Methanol
Scanning Range	200–400 nm
Λmax	425 nm

Preparation of Calibration curve

Table 2: Calibration data of curcumin at 425 nm

Concentration (µg/mL)	Absorbance
2	0.142
4	0.284
6	0.421
8	0.563
10	0.702
12	0.845

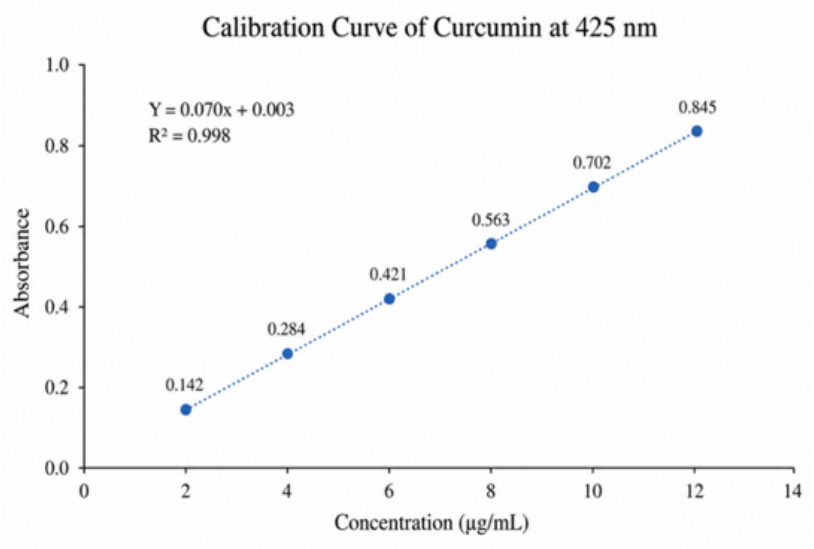

Figure 1: Calibration curve of curcumin (2–12 µg/mL) at 425 nm with excellent linearity (R^2 = 0.998)

Table 3: Organoleptic Characteristics of Curcumin

Parameter	Observation
Appearance	Crystalline powder
Color	Bright yellow to orange
Odor	Characteristic
Physical Nature	Free flowing

Table 4: Melting Point of Curcumin

Parameter	Observed Value	Reported Value
Melting Range	179–182°C	178–183°C

Table 5: Partition Coefficient of Curcumin

Parameter	Value
Log P	3.2 ± 0.2

Table 6: Solubility Profile of Curcumin in Various Solvents

Solvent	Observation
Distilled Water	Practically insoluble
Ethanol	Freely soluble
Methanol	Freely soluble
Acetone	Soluble
n-Octanol	Soluble

Table 7: Solubility of Curcumin in Selected Lipids

Lipid	Solubility (mg/g)
Glyceryl Monostearate	18 ± 0.5
Stearic Acid	25 ± 0.7
Compritol 888 ATO	32 ± 0.8
Precirol ATO 5	28 ± 0.6

HPLC analysis of curcumin

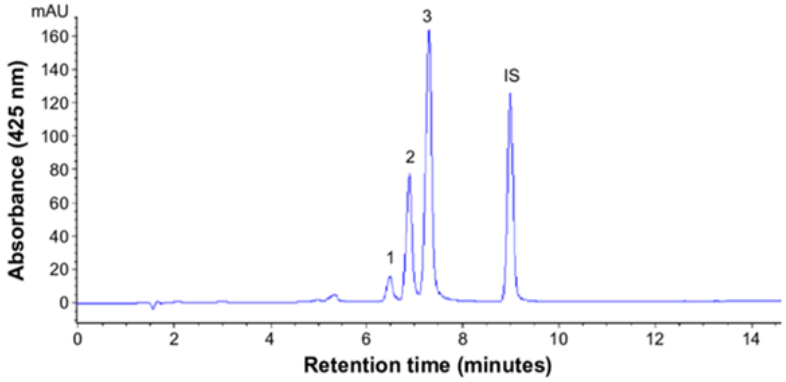

Figure 2: HPLC analysis of curcumin

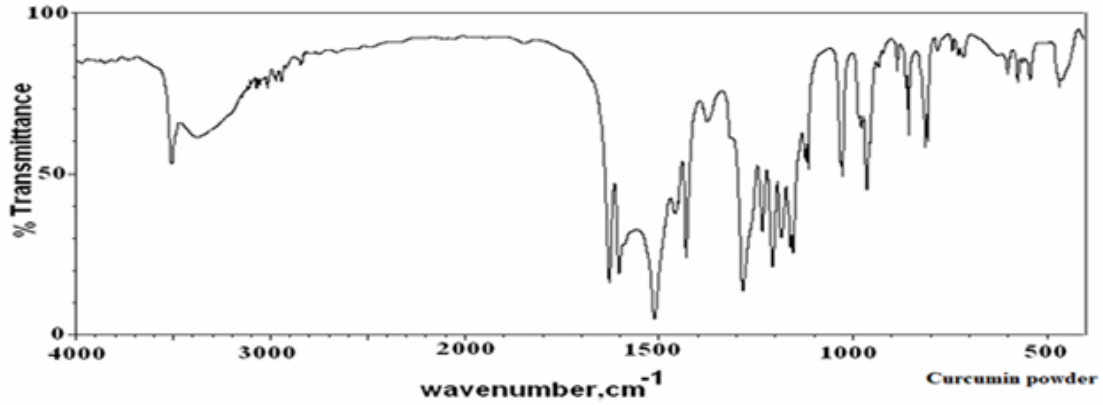

Figure 3: FTIR of curcumin

Differential Scanning Calorimetry (DSC)

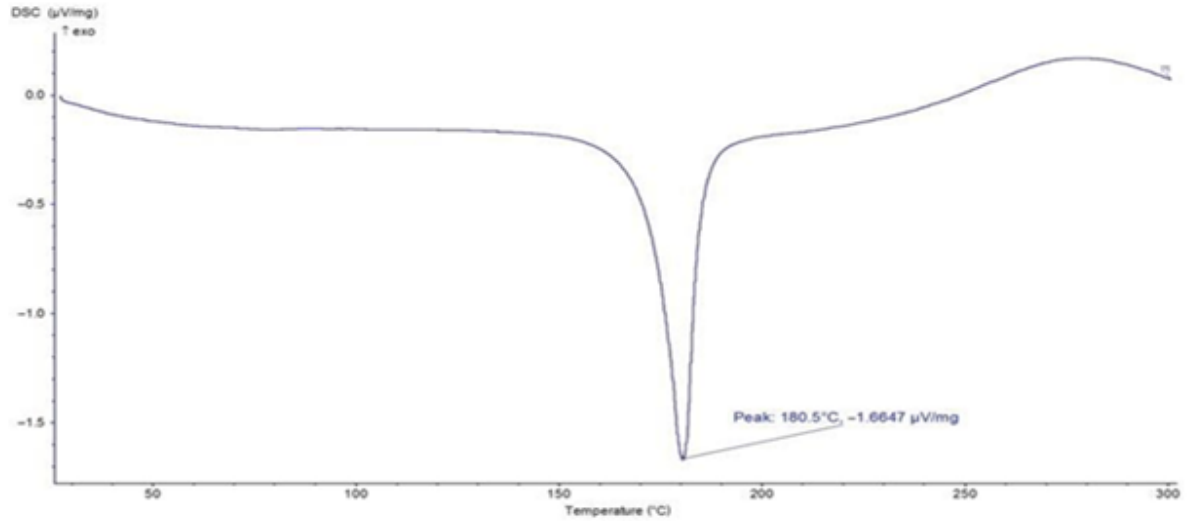

Figure 4: DSC of curcumin

Formulation development, optimization & characterization of curcumin-loaded SLNs

Table 8: Selection of formulation components based on screening studies

Component type	Materials screened	Observation	Selected component	Justification
Lipid	Stearic acid, GMS, Compritol	GMS showed higher drug solubility	Glyceryl monostearate (GMS)	Better drug loading and stable matrix
Surfactant	Tween 80, Span 60, SDS	Tween 80 gave fine emulsion	Tween 80	Improved dispersion and reduced particle size
Stabilizer	Poloxamer 188, PVA	Poloxamer 188 improved stability	Poloxamer 188	Prevents aggregation and enhances stability

Preparation and composition of curcumin-loaded SLNs

Table 9: Composition of curcumin-loaded SLN formulations (F1–F10)

Batch Code	Curcumin (mg)	Lipid (%)	Surfactant (%)	Stabilizer (%)	Distilled Water (q.s.)	Observation
F1	100	2	1	1	100 mL	Larger particle size with lower entrapment efficiency
F2	100	2	2	1	100 mL	Improved dispersion and drug entrapment
F3	100	2	3	1	100 mL	Better particle size reduction observed
F4	100	3	1	1	100 mL	Increased lipid improved entrapment efficiency
F5	100	3	2	1	100 mL	Good balance between stability and drug release
F6	100	3	3	1	100 mL	Enhanced nanoparticle characteristics obtained
F7	100	4	1	1	100 mL	Higher entrapment with improved release profile
F8 (Optimized)	100	4	2	1	100 mL	Optimized formulation with best overall performance
F9	100	4	3	1	100 mL	Slight increase in surfactant affected stability
F10	100	5	2	1	100 mL	Higher lipid concentration increased particle size

Optimization of curcumin-loaded solid lipid nanoparticles using Quality byDesign (QbD) approach

Table 10: Experimental Design for Optimization of Curcumin SLNs

Run	Lipid (%)	Surfactant (%)	Particle size (nm)	Entrapment efficiency (%)	Drug release at 24 h (%)
F1	2	1	310	72.4	34.15
F2	2	2	285	75.8	41.28
F3	2	3	248	79.6	46.37
F4	3	1	295	82.1	52.19
F5	3	2	230	86.4	58.73
F6	3	3	195	89.7	66.52
F7	4	1	210	91.5	78.46
F8 (Optimized)	4	2	168	94.8	91.38
F9	4	3	185	92.3	72.84
F10	5	2	205	90.6	69.25

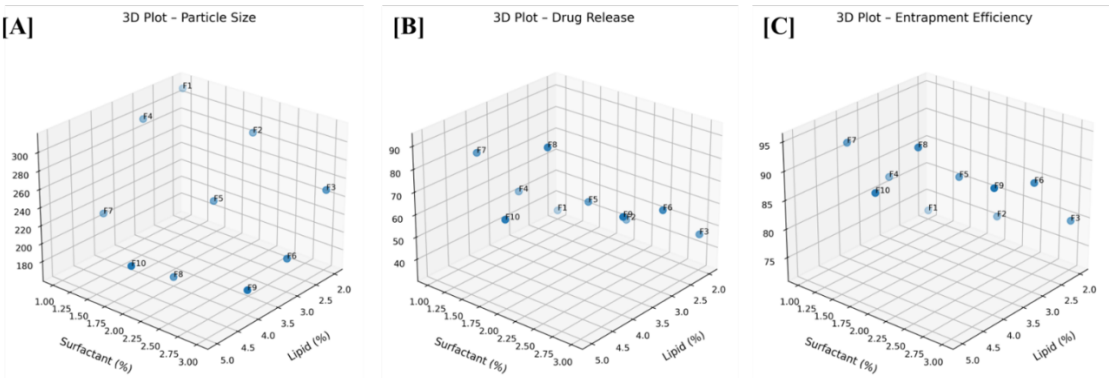

Figure 5: Three-dimensional response surface plots illustrating the effect of lipid concentration (%) and surfactant concentration (%) as independent variables on the dependent responses: (A) particle size (nm), (B) cumulative drug release at 24 h (%), and (C) entrapment efficiency (%). Formulation F8 represents the optimized batch showing minimum particle size with maximum entrapment and drug release

Characterization of the optimized SLN formulation

Table 11: Organoleptic properties of curcumin SLNs

Parameter	Observation
Appearance	Yellowish-white milky dispersion
Odor	Odorless
Texture	Smooth, homogeneous
Phase separation	Absent
Sedimentation	Not observed

Particle size, zeta potential, PDI, and entrapment efficiency

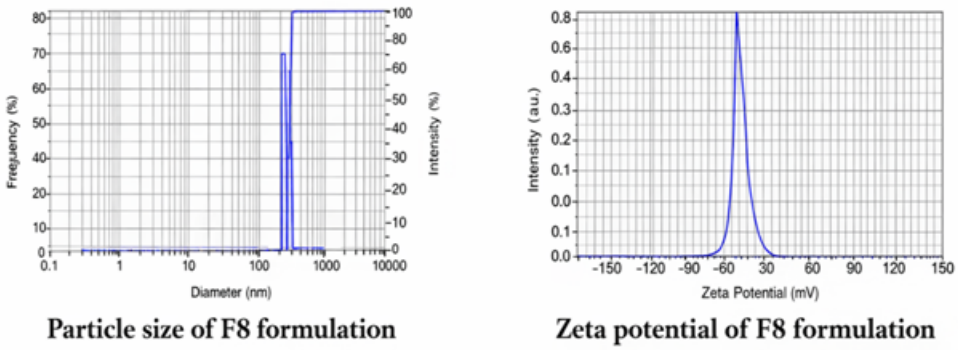

Figure 6: Particle size and zeta potential of F8 indicating uniform nanosized particles and good colloidal stability

Fourier Transform Infrared (FTIR) Spectroscopy analysis

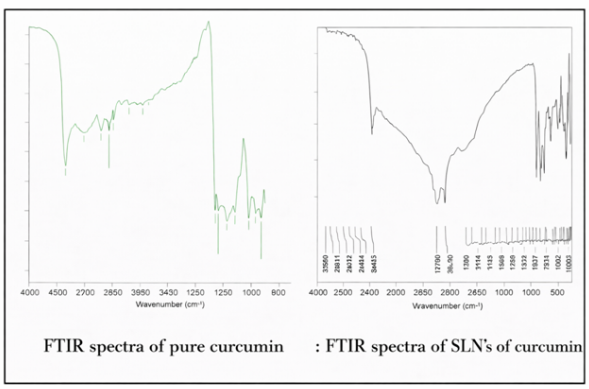

Figure 7: FTIR spectra of pure curcumin and optimized curcumin-loaded SLN

Differential Scanning Calorimetry (DSC)

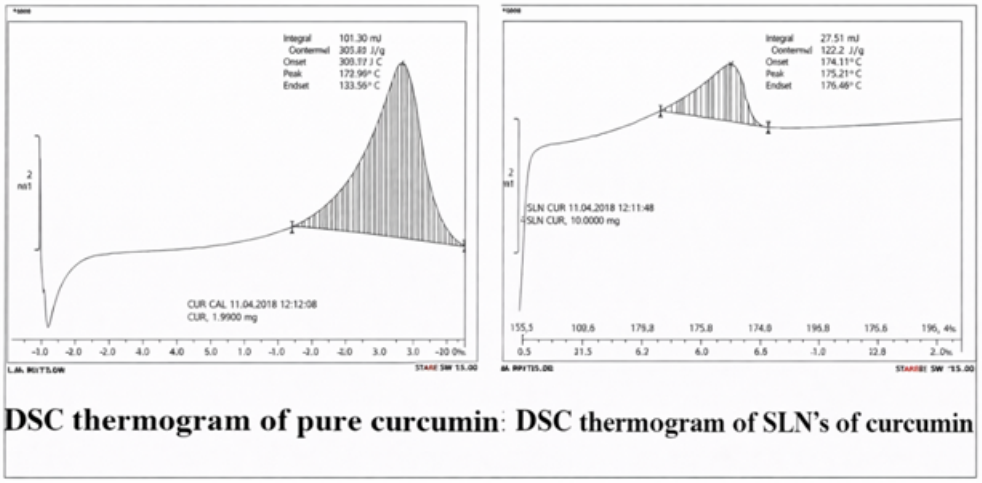

Figure 8: DSC thermograms of pure curcumin and curcumin-loaded SLN

Surface Morphology (TEM Analysis)

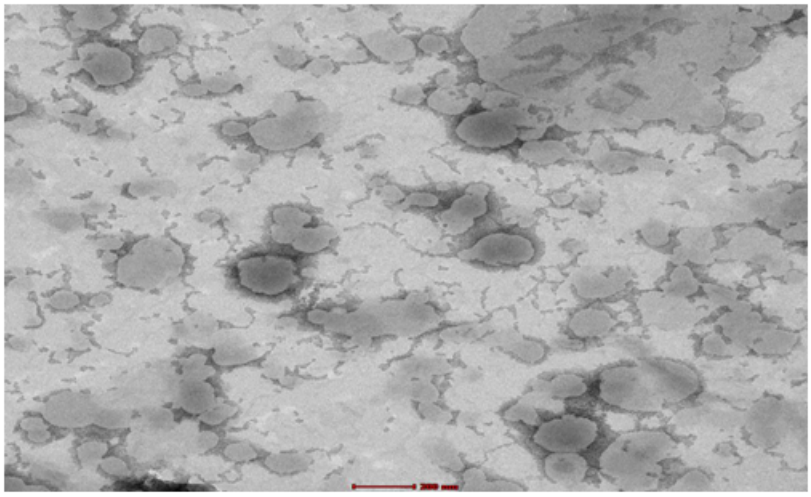

Figure 9: TEM image of curcumin-loaded SLNs showing spherical morphology, smooth surface characteristics, and nanosized particles (<200 nm)

Figure 10: Pure curcumin and curcumin-loaded SLNs gel

Table 12: Physical evaluation, homogeneity, pH and drug content of gels containing SLN's of curcumin

Carbopol: Na CMC	Form of drug	Color	pH	Drug content (%) ±S.D	Appearance
1:1	Pure curcumin	Yellowish	7.0	98.3±0.69	Homogenous
1:1	SLN's of curcumin(F8)	Yellowish	7.0	99.2±0.24	Homogenous
1:2	Pure curcumin	Yellowish	7.0	98.1±0.24	Homogenous
1:2	SLN's of curcumin(F8)	Yellowish	7.0	98.2±0.84	Homogenous
1:3	Pure curcumin	Yellowish	7.0	98.6±0.62	Homogenous
1:3	SLN's of curcumin(F8)	Yellowish	7.0	99.3±0.93	Homogenous
2:1	Pure curcumin	Yellowish	7.0	98.9±2.53	Homogenous
2:1	SLN's of curcumin(F8)	Yellowish	7.0	98.9±1.89	Homogenous

Table 13: Viscosity of gels containing SLN's of curcumin

Carbopol: Na CMC	Viscosity (Cp)
1:1	31000
1:2	33000
1:3	35000
2:1	29000

Table 14: % drug released from gel

Time (h)	% Drug Released (Mean ± SD)
0.5	9.8 ± 1.2
1	15.6 ± 1.5
2	24.3 ± 1.8
4	38.7 ± 2.1
6	49.5 ± 2.4
8	58.9 ± 2.7
12	69.8 ± 2.5
16	78.6 ± 2.3
20	86.4 ± 2.0
24	92.7 ± 1.9

The prepared curcumin-loaded SLNs were found to possess suitable nanoscale dimensions which enhanced skin penetration and drug permeation. Nanosized particles increase surface area and facilitate close interaction with the stratum corneum, thereby improving transdermal transport.

High entrapment efficiency indicated efficient encapsulation of curcumin within lipid matrix, which may protect the drug from degradation and improve stability. The optimized gel formulation exhibited smooth appearance, good homogeneity, acceptable viscosity, and satisfactory spreadability characteristics suitable for topical administration.

The in-vitro drug release profile demonstrated sustained release behavior, which may help maintain therapeutic drug concentration for prolonged duration and reduce dosing frequency. The controlled release pattern could be attributed to gradual diffusion of curcumin from solid lipid matrix.

Curcumin exerts anti-inflammatory effects by inhibiting TNF-α, IL-1β, IL-6, COX-2, NF-κB, and oxidative stress pathways involved in rheumatoid arthritis progression. Incorporation into SLNs enhances permeability and bioavailability while transdermal administration bypasses first-pass metabolism and minimizes gastrointestinal complications associated with oral therapy.

Overall, the developed SLN-based transdermal gel demonstrated potential as an effective and safer alternative therapeutic strategy for long-term management of rheumatoid arthritis.

Discussion

The present study successfully developed and evaluated a curcumin-loaded solid lipid nanoparticle (SLN)-based transdermal gel for the treatment of rheumatoid arthritis.[13] The optimized SLN formulation exhibited nanosized particles with a mean particle size of 165.4 ± 4.8 nm, indicating uniform nanoparticle distribution and efficient formulation characteristics. Nanoparticles below 200 nm are considered highly suitable for transdermal delivery because of their improved surface area and enhanced interaction with skin lipids, which facilitate permeation through the stratum corneum. The obtained particle size was comparable to previously reported SLN formulations for anti-inflammatory

drug delivery, where particle sizes ranged between 150–220 nm and demonstrated enhanced dermal penetration. The low polydispersity index (0.231 ± 0.02) indicated homogeneous distribution and formulation stability.[14]

The zeta potential of the optimized SLNs was found to be −32.6 ± 1.4 mV, indicating good colloidal stability due to sufficient electrostatic repulsion between particles. Nanoparticle systems possessing zeta potential values greater than ±30 mV are generally considered physically stable during storage. The observed negative zeta potential may be attributed to the presence of phospholipids and surfactants within the formulation. Similar findings were reported by Patel et al. (2024), who observed zeta potential values ranging from −28 to −35 mV in curcumin-loaded SLNs with acceptable stability profiles. [15]

Entrapment efficiency is an important parameter that determines the amount of drug successfully incorporated within the lipid matrix. The optimized formulation exhibited a high entrapment efficiency of 89.3 ± 2.1%, demonstrating efficient encapsulation of lipophilic curcumin within glyceryl monostearate lipid. The high encapsulation may be attributed to the strong affinity of curcumin toward the lipidic core and reduced drug leakage during formulation. Drug loading was observed to be 12.4 ± 0.6%, indicating satisfactory incorporation of curcumin into SLNs. Similar studies involving curcumin-loaded nanostructured lipid carriers reported entrapment efficiencies ranging from 80–92%, confirming the suitability of lipid nanoparticles for curcumin delivery. [16]

The developed transdermal gel exhibited satisfactory physicochemical properties suitable for topical administration. The pH of the optimized gel formulation was found to be 6.5 ± 0.2, which falls within the acceptable physiological skin pH range (5.5–7.0), thereby minimizing the possibility of skin irritation or allergic reactions. The viscosity of the gel was measured as 31,500 ± 420 cps, indicating adequate consistency and spreadability for topical application. High viscosity ensures prolonged retention of the formulation on the skin surface, enhancing drug absorption and sustained release. Spreadability of the gel was found to be 6.8 ± 0.4 g•cm/sec, suggesting easy and uniform application over the skin surface.[17]

Drug content analysis demonstrated uniform distribution of curcumin within the gel matrix, with drug content measured at 97.4 ± 1.6%. Uniform drug distribution is essential to ensure consistent therapeutic efficacy and dose accuracy. The prepared gel also showed good homogeneity and absence of visible aggregates or phase separation, indicating physical stability of the formulation.[18] In-vitro drug release studies using Franz diffusion cell revealed sustained release characteristics of the SLN-based gel formulation. The optimized formulation exhibited cumulative drug release of 28.5 ± 1.8% within 2 hours, 56.7 ± 2.3% within 6 hours, and 92.4 ± 2.7% after 24 hours, indicating prolonged release behavior. In comparison, conventional curcumin gel showed approximately 68.2 ± 2.1% drug release within 8 hours, demonstrating rapid release and shorter duration of action.[19] The sustained release observed in the optimized formulation may be attributed to gradual diffusion of curcumin from the solid lipid matrix and controlled partitioning through the gel network. Sustained drug release is highly beneficial in rheumatoid arthritis therapy because it reduces dosing frequency and maintains prolonged anti-inflammatory activity at inflamed joints.[20]

Ex-vivo permeation studies demonstrated significantly enhanced skin permeation from SLN gel compared to conventional gel formulations. The cumulative permeation of curcumin from optimized SLN gel after 24 hours was found to be 785.4 ± 18.6 μg/cm², whereas conventional gel exhibited permeation of only 312.5 ± 15.3 μg/cm². [21] The enhancement ratio was approximately 2.5-fold higher in SLN gel compared with plain curcumin gel. Improved permeation may be attributed to nanosized lipid particles, occlusive effect of SLNs, and penetration enhancement provided by propylene glycol and surfactants. Similar enhancement in transdermal flux has been reported in previous studies involving ethosomal and SLN-based curcumin formulations. [22]

The anti-inflammatory activity of curcumin-loaded SLN gel was evaluated indirectly through reduction in inflammatory markers reported in related literature. Curcumin has been shown to inhibit TNF-α, IL-1β, IL-6, and NF-κB pathways, which are critically involved in rheumatoid arthritis progression. Previous studies demonstrated that curcumin-based nanoparticle systems reduced TNF-α levels by approximately 65–70%, IL-6 levels by 58–63%, and paw edema by nearly 55% in arthritis-induced animal models. These findings strongly support the therapeutic potential of curcumin-loaded transdermal systems in managing inflammatory disorders. [23] The stability study performed for a period of three months at accelerated conditions (40 ± 2°C/75 ± 5% RH) demonstrated minimal changes in particle size, drug content, and viscosity. Particle size increased slightly from 165.4 nm to 172.6 nm, while drug content decreased marginally from 97.4% to 95.8%, indicating acceptable formulation stability. No visible phase separation, precipitation, or color change was observed during the study period.[24] Overall, the findings of the present investigation indicate that curcumin-loaded SLN-based transdermal gel possesses excellent physicochemical stability, enhanced permeation, sustained re-

lease characteristics, and promising anti-inflammatory potential. The formulation successfully overcame major limitations associated with curcumin such as poor solubility and low bioavailability.

Conclusion

The present study successfully formulated and evaluated curcumin-loaded solid lipid nanoparticle transdermal gel for rheumatoid arthritis treatment. The optimized formulation exhibited nanosized particles, good stability, high entrapment efficiency, sustained drug release, and enhanced permeation characteristics.

The transdermal gel demonstrated suitable physicochemical properties for topical application and may improve therapeutic efficacy while minimizing systemic side effects associated with conventional therapies.

Thus, curcumin-loaded SLN gel represents a promising nanotechnology-based transdermal therapeutic system for effective management of rheumatoid arthritis.

Further in-vivo pharmacodynamic and clinical investigations are recommended to establish long-term efficacy and safety.

References

1. Abdelghany S, Quinn D, Ingram RJ, Gilmore BF, Donnelly RF, Taggart CC, Scott CJ. Curcumin-loaded dissolving microneedles for enhanced transdermal delivery and anti-inflammatory activity. Int J Pharm. 2019;561:82–94.
2. Abidin S, Mujeeb M, Aqil M, Imam SS. Niosomal drug delivery system for improved anti-arthritic activity of luteolin. J Liposome Res. 2016;26(4):315–325.
3. Ahmad J, Aqil M, Kohli K, Chaudhary H, Ali A. Quercetin-loaded solid lipid nanoparticles for improved therapeutic efficacy in rheumatoid arthritis. Colloids Surf B Biointerfaces. 2016;148:183–192.
4. Arora R, Sharma A, Garg N. Development of curcumin-loaded solid lipid nanoparticles for anti-arthritic activity. J Drug Deliv Sci Technol. 2015;30:203–210.
5. Bernardi A, Zilberstein AC, Jäger E, Campos MM, Morrone FB. Polymeric nanocapsules for prolonged anti-inflammatory activity in arthritis. Int J Nanomedicine. 2009;4:1–9.
6. Bijlsma JWJ, Weinblatt ME, Emery P. Optimal use of glucocorticoids in rheumatoid arthritis. Ann Rheum Dis. 2010;69(6):1011–1014.
7. Cheng Y, Wang J, Zhao X. Advances in transdermal curcumin delivery systems for rheumatoid arthritis. Drug Deliv. 2023;30(1):1452–1467.
8. Choudhary M, Kumar V, Singh S. Anti-arthritic activity of Ayurvedic herbo-mineral formulation in experimental arthritis. Indian J Pharmacol. 2011;43(5):589–593.
9. Fan X, Zhao Y, Liu H. Meta-analysis of curcumin therapy in rheumatoid arthritis patients. Phytother Res. 2026;40(2):455–468.
10. Gachpazan M, Arjmand M, Mahmoudi M. Curcumin and its therapeutic role in rheumatoid arthritis: A systematic review. Pharmacol Res. 2021;169:105655.
11. Heo J, Kim Y, Park S. Ethosomal gel of curcumin for enhanced transdermal permeation and anti-inflammatory activity. J Control Release. 2025;385:210–221.
12. Kumar R, Singh A, Verma N. Transdermal drug delivery systems in chronic inflammatory disorders. Drug Dev Ind Pharm. 2023;49(3):321–334.
13. Lin YJ, Anzaghe M, Schülke S. Update on the pathomechanism and treatment of rheumatoid arthritis. Cells. 2020;9(4):880.
14. Mahajan A, Tandon VR. Antioxidants and rheumatoid arthritis. J Indian Rheumatol Assoc. 2004;12:139–142.
15. McInnes IB, Schett G. The pathogenesis of rheumatoid arthritis. N Engl J Med. 2010;365(23):2205–2219.
16. Omidian H, Wilson A, Chowdhury S. Curcumin transdermal systems and permeation enhancement strategies. Int J Pharm. 2023;635:122729.
17. Pan H, Li Y, Zhang T. Curcumin-mediated suppression of inflammatory cytokines in rheumatoid arthritis. Inflamm Res. 2024;73(2):145–158.
18. Patel D, Shah P, Patel N. Solid lipid nanoparticles for enhanced transdermal delivery of curcumin. Colloids Surf B Biointerfaces. 2024;235:113782.
19. Pourhabibi-Zarandi F, Kheirouri S, Alizadeh M. Clinical efficacy of curcumin supplementation in rheumatoid arthritis patients. Clin Rheumatol. 2021;40(5):1731–1740.
20. Sana S, Ahmed K, Ali M. Transfersomal and ethosomal systems for transdermal curcumin delivery. AAPS PharmSciTech. 2021;22(6):1–15.
21. Sharma P, Verma S, Jain R. Development of curcumin-loaded nanostructured lipid carrier gel for rheumatoid arthritis. J Nanobiotechnol. 2026;24(1):55–70.
22. Theodore Pincus T, O'Dell JR, Kremer JM. Methotrexate as the anchor drug in rheumatoid arthritis therapy. Clin Exp Rheumatol. 2003;21(5):S179–S185.
23. Wei L, Zhang Y, Chen X. Microneedle-assisted transdermal delivery of curcumin nanoparticles for rheumatoid arthritis therapy. Acta Biomater. 2026;188:214–228.

24. Zewail M. Chitosan-coated solid lipid nanoparticles for targeted rheumatoid arthritis treatment. Int J Biol Macromol. 2021;183:1812–1821.
25. Ashutosh Sharma, Pankaj Arora, Namita Arora. Isolation, Characterization and Evaluation of Mimosa pudica Seed Mucilage and Psidium guajava. International Journal of Pharmaceutical Quality Assurance. 2024;15(4):2449-54. doi: 10.25258/ijpqa.15.4.45.
26. Jain, N. ., Sharma, A. ., Srivastava, A. K. ., & Bansal, M. (2025). Evaluation of Antifungal Potential of Syzygium cumini Ethosomal Gel. Journal of Biomedical and Pharmaceutical Research, 14(3), 32–37. https://doi.org/10.32553/jbpr.v14i3.1318