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Research

Development & Evaluation of Nanoemulsion Based Syrup of Poorly Soluble Curcumin for Enhanced Oral Bioavailability

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Abstract:
Turmeric contains curcumin, a naturally occurring polyphenolic compound that is well-known for its antimicrobial, anti-inflammatory, and antioxidant qualities. However, because of its poor water solubility, low gastrointestinal absorption, quick metabolism, and low bioavailability, its therapeutic efficacy following oral administration is severely restricted. The goal of the current study was to improve the oral bioavailability and therapeutic efficacy of poorly soluble curcumin by developing and assessing syrup based on nanoemulsion. Using an appropriate oil, surfactant, co-surfactant, and aqueous phase, the nanoemulsion formulation was created using a homogenization technique. It was then added to a syrup base to increase patient compliance and palatability. Physical appearance**,** pH (5), viscosity (0.145), drug content (98.36 %), and in vitro drug release (97%) in 240 minutes were all assessed for the prepared formulations. The optimized formulation demonstrated consistent drug distribution throughout the system and good stability with nanosized droplets. When compared to traditional formulations, better curcumin release and dissolution were noted. According to the study's findings, curcumin's solubility and oral bioavailability can be enhanced by using a syrup based on nanoemulsion. For oral drug delivery applications, this formulation may offer increased patient acceptability and therapeutic efficacy.

Keywords: drug release, poorly soluble drug, oral bioavailability, curcumin, and nanoemulsion

INTRODUCTION

Curcumin is a natural polyphenolic compound found in the rhizomes of turmeric (Curcuma longa). It has been extensively studied due to its diverse pharmacological activities, which include antioxidant, anti-inflammatory, antimicrobial, anticancer, and hepatoprotective properties. Curcumin's therapeutic properties have sparked significant interest in pharmaceutical and nutraceutical research for the prevention and treatment of a variety of chronic diseases, including cancer, cardiovascular disorders, arthritis, diabetes, and neurodegenerative diseases [1]. Despite its promising therapeutic potential, curcumin's clinical application is severely limited due to numerous physicochemical and pharmacokinetic issues. Curcumin is highly hydrophobic and has very low aqueous solubility. Furthermore, it is rapidly metabolized and degraded under physiological conditions, resulting in poor systemic absorption following oral administration. As a result, curcumin's oral bioavailability remains extremely low, with only a small portion of the administered dose reaching the systemic circulation [2].

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Figure 1 (Turmeric)

According to the Biopharmaceutics Classification System (BCS), curcumin is generally categorized as a poorly soluble compound, which makes its formulation development challenging. Poor dissolution in gastrointestinal fluids significantly reduces its absorption across the intestinal membrane. Furthermore, curcumin is unstable in alkaline pH and is rapidly metabolized into inactive metabolites such as glucuronides and sulfation the liver and intestinal mucosa. These factors collectively contribute to the low plasma concentration of curcumin after oral administration [3]. To overcome these limitations, various formulation approaches have been investigated to enhance the solubility and bioavailability of curcumin. These strategies include liposomes, polymeric nanoparticles, solid dispersions, micelles, phospholipid complexes, and nanoemulsion systems. Among these techniques, nanoemulsion-based drug delivery systems have gained considerable attention due to their ability to improve the solubility and stability of poorly water-soluble drugs [4]. Nanoemulsions are defined as thermodynamically or kinetically stable colloidal dispersions composed of oil, water, surfactant, and sometimes co-surfactant. The droplet size of nanoemulsions typically ranges from 20 to 200 nm. Due to their extremely small droplet size, nanoemulsions provide a large interfacial surface area, which enhances drug dissolution and improves absorption across biological membranes. These properties make nanoemulsions highly suitable for the delivery
of hydrophobic drugs such as curcumin (5).

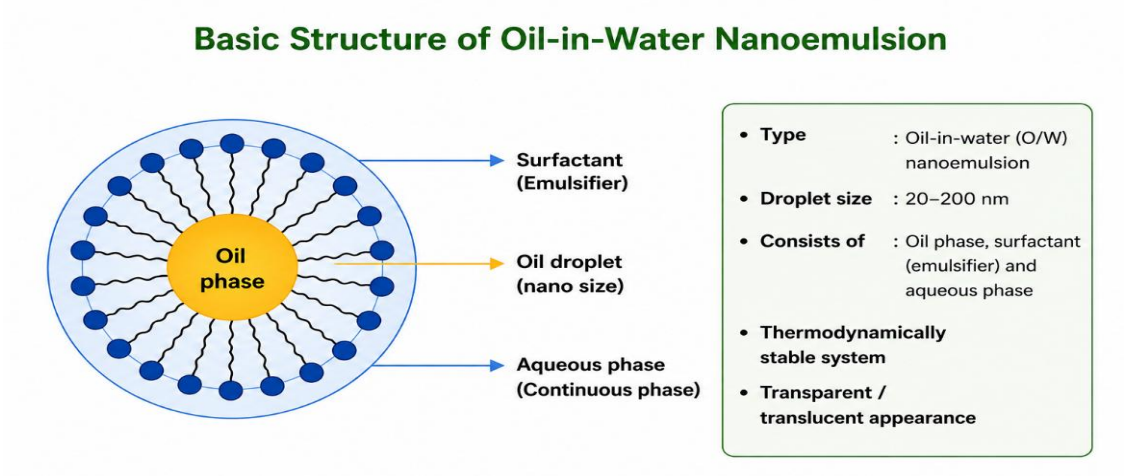

Figure 2 (Structure Oil-in Water Nanoemulsion)

Nanoemulsion systems provide several advantages for pharmaceutical drug delivery. These include improved drug solubility, stability, controlled release properties, and bioavailability. Nanoemulsions improve oral drug absorption by increasing the surface area available for digestion and speeding up drug transport through the gastrointestinal tract. Furthermore, nanoemulsions may enhance lymphatic transport of lipophilic drugs, reducing first-pass metabolism and increasing systemic availability [6].

Several research studies have demonstrated that nanoemulsion-based formulations significantly improve the bioavailability of curcumin compared to conventional formulations. For example, curcumin nanoemulsions prepared using appropriate surfactants and oils have shown improved dissolution rates and enhanced pharmacokinetic profiles in animal studies. In one study, nanoemulsion formulations exhibited significantly higher drug release and improved oral

bioavailability compared to crystalline curcumin formulations [7].

Another important advantage of nanoemulsion systems is their ability to protect curcumin from chemical degradation. Curcumin is known to be unstable in the presence of light, oxygen, and alkaline conditions. Encapsulation of curcumin within nano-sized oil droplets provides protection against environmental degradation and improves its chemical stability during storage and digestion [8].

The development of a stable nanoemulsion formulation requires careful selection of formulation components such as oil phase, surfactant, co-surfactant, and aqueous phase. The oil phase acts as a solvent for hydrophobic drugs, while surfactants reduce interfacial tension and stabilize the nanoemulsion droplets. Non-ionic surfactants such as Tween-80, Tween-20, and lecithin are commonly used in nanoemulsion formulations because of their biocompatibility and high emulsifying efficiency [9].

Incorporating nanoemulsions into oral liquid dosage forms such as syrups can provide additional advantages. Syrups are widely used for oral drug delivery because they offer improved patient compliance, especially in paediatric and geriatric populations. Liquid dosage forms are easier to swallow and allow accurate dose adjustment. When nanoemulsion systems are incorporated into syrup formulations, they combine the advantages of nanotechnology with the convenience of liquid dosage forms [10].

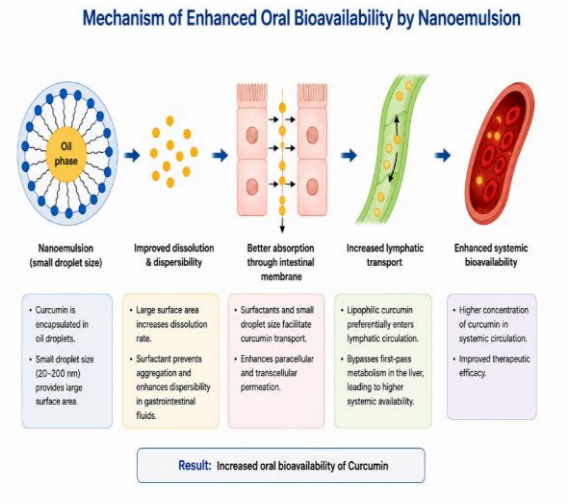

Figure 3 (Mechanism of Enhanced Oral Bioavailability by Nanoemulsion)

LITERATURE OF REVIEW

1. **Kaur et al. (2026)** reported that nanoemulsion-based oral systems protect curcumin from degradation in gastrointestinal conditions and improve therapeutic efficacy [11].
2. **Pino et al. (2026)** demonstrated that curcumin-loaded nanoemulsions significantly enhance solubility, dispersion, stability, and oral bioavailability in oil-in-water systems [12].
3. **Mehta et al. (2026)** reported that incorporation of stabilizers and polymers improves shelf-life and stability of nanoemulsion-based formulations [13].
4. **Ahmed et al. (2025)** reported that surfactants such as Tween 80 and co-surfactants like PEG 400 reduce interfacial tension and facilitate formation of stable nano-sized droplets [14].
5. **Singh et al. (2025**) demonstrated that nanoemulsions enhance lymphatic transport of lipophilic drugs, thereby bypassing hepatic first-pass metabolism and improving systemic bioavailability [15].
6. **Raee et al. (2025)** reported that nanoemulsion formulations improve antioxidant activity and enhance pharmacological response of curcumin through increased cellular uptake [16].
7. **Rajet al. (2025)** developed protein-stabilized nanoemulsions and reported improved encapsulation efficiency and controlled drug release behaviour [17].
8. **Gupta et al. (2025)** demonstrated that nanoemulsion syrups improve palatability and effectively mask the bitter taste of curcumin, enhancing patient acceptability [18].
9. **Iacia et al. (2024)** reported that curcumin nanoemulsions reduce oxidative stress and provide intestinal protection, thereby improving gastrointestinal stability and drug absorption [19].
10. **Sayyar and Malmiri (2024)** highlighted that optimization of surfactant and co-surfactant concentration is essential for

achieving stable nanoemulsion systems with desired characteristics [20].

11. **Puttegowda and Karki (2024)** demonstrated that pseudo-ternary phase diagrams are effective tools for selecting appropriate composition of oil, surfactant, and co-surfactant for nanoemulsion formulation [21].
12. **Rao et al. (2024)** reported that optimized nanoemulsions exhibit low polydispersity index and suitable zeta potential, indicating enhanced physical stability and uniform droplet distribution [22].
13. **Verma et al.(2024)** highlighted that nanoemulsion systems improve pharmacokinetic performance and reduce variability in drug absorption compared to conventional dosage forms [23].
14. **Jacob et al. (2024)** highlighted that liquid nanoemulsion formulations improve dosing accuracy and are particularly beneficial for pediatric and geriatric populations [24].
15. **Han et al. (2024)** concluded that nanoemulsion systems represent a highly effective approach for enhancing solubility and bioavailability of lipophilic drugs [25].
16. **Omidian et al. (2023)** reported that despite its therapeutic potential, curcumin suffers from poor aqueous solubility, low permeability, rapid metabolism, and extensive first-pass metabolism, resulting in extremely low oral bioavailability [26].
17. **Kumar et al. (2023**) highlighted that nanotechnology-based drug delivery systems have emerged as effective strategies to overcome solubility and bioavailability limitations associated with poorly water-soluble drugs [27].
18. **David Julian McClements (2023)** explained that nanoemulsions are isotropic dispersions consisting of oil, water, surfactant, and co-surfactant, with droplet sizes typically ranging from 20 to 200 nm, which contribute to improved drug delivery efficiency [28].
19. **Kumari and Nanda (2023)** demonstrated that curcumin nanoemulsions exhibit improved physicochemical stability and protect the drug from degradation in physiological environments [29].
20. **Sheng et al. (2023)** reported that nanoemulsion formulations significantly improve pharmacokinetic parameters such as Cmax and AUC, indicating enhanced systemic availability of curcumin [30].

MATERIAL & METHODOLOGY

1. Material

1.1 EQUIPMENT REQUIREMENT

S. No.	Equipment / Glassware	Application
1	Hot Plate	Used for uniform mixing of oil and aqueous phases along with controlled temperature conditions
2	Beakers (50 mL, 100 mL, 250 mL)	Used for preparation of oil phase and aqueous phase
3	Conical Flask	Used for mixing and temporary storage of the formulation
4	Measuring Cylinder	Used for accurate measurement of liquid components such as oil, water, and surfactants
5	Analytical Balance	Curcumin aur excipients ka accurate weighing
6	Glass Rod	Used for manual stirring and mixing
7	PH meter	Used to determine the pH of the final formulation
8	Thermometer	Used to monitor and maintain temperature during formulation
9	Storage Bottle (Amber)	Final formulation ko store karne ke liye

1.2 INGREDIENTS REQUIREMENTS

2. METHODOLOGY

2.1 SPONTANEOUS EMULSIFICATION METHOD.

S. No.	Ingredient	Quantity	Role in Formulation
1	Curcumin	1 gm	Active drug; provides anti-inflammatory & antioxidant activity
2	Coconut Oil	10 gm	Oil phase; enhances solubility of curcumin
3	PEG 400	40 gm	Co-surfactant; reduces interfacial tension and improves stability
4	Water	q.s. to 100 ml	Aqueous phase; adjusts final volume
5	Syrup Base	As required	Improves taste, viscosity, and patient acceptability

Step 1: Preparation of Oil Phase

- Curcumin (1 g) was added to coconut oil (10ml).

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- The mixture was stirred until completely dissolved.
- Mild heating (40–50°C) was applied.

Figure 4 (Oil Phase)

Step 2: Addition of Co-Surfactant

- PEG-400 (40ml) was added to the oil phase.
- The mixture was stirred continuously to obtain a clear and homogeneous solution.

Step 3: Preparation of Aqueous Phase

- Prepared 66.7% w/v simple syrup as per IP in a separate beaker.
- The solution was heated mildly to ensure complete dissolution of sugar and then cooled to room temperature.

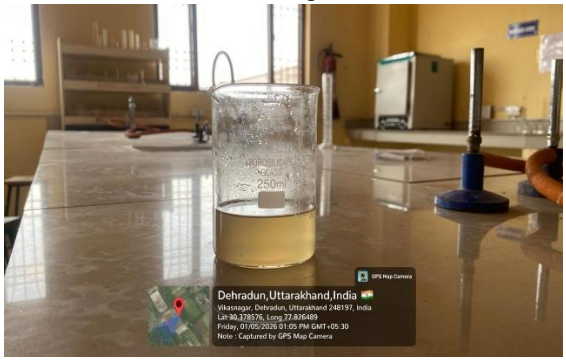

Figure 5 (Aqueous Phase)

Step 4: Volume Adjustment

- Final volume was adjusted to 100 ml using distilled water.

Step 5: Homogenization

- Homogenization was performed for 5–10 minutes.
- To improve stability and uniformity.

Step 6: Filtration and Storage

- The formulation was filtered.
- Stored in amber-colored bottles.

Figure 6 (Final Product)

RESULT AND DISCUSSION

1. **pH**

   The pH of final product was found to be **5**

2. **Viscosity**

S. No.	Liquid Sample	Time 1 (s)	Time 2 (s)	Time 3 (s)	Mean Time (s)	Density (g/cm³)	Viscosity (cP)
1	Water	4.13	3.51	4.00	3.88	0.998	0.270
2	Curcumin Nanoemulsion Syrup	4.50	4.24	4.31	4.35	1.25	0.38

Result - The viscosity of the developed Curcumin Nanoemulsion Syrup was found to be **0.38 cP** using an Ostwald viscometer. The formulation exhibited good flow characteristics, indicating its suitability for oral administration.

3. **Drug Content Uniformity Test**

   The drug content of the Curcumin Nanoemulsion Syrup was found to be 98.36%, indicating uniform distribution of curcumin and satisfactory content uniformity within acceptable limits.

Sample No.	Drug Content%
1	98.2
2	99.1
3	97.8
4	98.5
5	98.2

4. **In-vitro Drug Release Study**

The Curcumin Nanoemulsion Syrup showed a gradual and sustained release of curcumin over the study period. A maximum cumulative drug release

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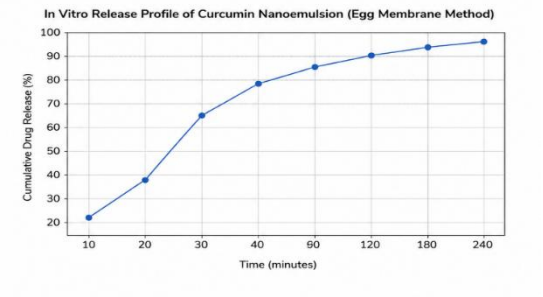
of **97 %** was observed at **240 minutes**, indicating efficient drug.

In Vitro Drug Release Study

Sample: Curcumin Nanoemulsion Syrup
Method: Egg Membrane Diffusion Method

Time (min)	Cumulative Drug Release (%)
10	22
20	38
30	57
40	73
60	82
90	88
120	92
180	95
240	97



5. Organoleptic Properties

The prepared Curcumin Nanoemulsion Syrup exhibited a yellowish-orange color, pleasant odor, and sweet taste. The formulation was homogeneous and showed no visible phase separation, indicating good physical stability and acceptability.

Observation Table

S. No.	Parameter	Observation
1	Color	Yellowish Orange
2	Odor	Characteristic Pleasant Odor
3	Taste	Sweet and Slightly Bitter
4	Appearance	Smooth and Uniform
5	Homogeneity	Homogeneous, No Phase Separation

6. Clarity Test

The prepared Curcumin Nanoemulsion Syrup was clear and transparent, with no visible suspended particles or phase separation. This indicated successful nanoemulsion formation and uniform dispersion of curcumin.

Observation Table

S. No.	Parameter	Observation
1	Transparency	Clear
2	Turbidity	Absent
3	Suspended Particles	Not Observed
4	Precipitation	Absent
5	Phase Separation	Absent

CONCLUSION

The present study successfully demonstrated the development and evaluation of a nanoemulsion-based syrup of poorly soluble curcumin for enhanced oral bioavailability. Curcumin possesses significant pharmacological activities such as antioxidants, anti-inflammatory, and therapeutic effects; however, its clinical application is restricted due to poor aqueous solubility, low absorption, and rapid metabolism. To overcome these limitations, a stable nanoemulsion formulation was prepared using suitable oil, surfactant, and co-surfactant systems. The developed nanoemulsion showed nanosized globule distribution, good physical stability, acceptable pH, viscosity, and satisfactory drug content, indicating the suitability of the formulation for oral administration. Incorporation of nanoemulsion into syrup dosage form improved palatability, patient compliance, and ease of administration. In-vitro drug release studies demonstrated enhanced dissolution and improved release profile of curcumin when compared with conventional formulations. The increased surface area and reduced droplet size of the nanoemulsion system contributed significantly to enhanced solubility and drug availability. Stability studies confirmed that the optimized formulation remained stable without phase separation or significant changes in physicochemical properties during storage. Overall, the nanoemulsion-based syrup proved to be an effective and promising drug delivery approach for improving the oral bioavailability and therapeutic performance of poorly soluble curcumin. The study suggests that nanoemulsion technology can be successfully utilized for the formulation of other poorly water-soluble drugs to achieve better therapeutic outcomes.

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