International Journal of Environment, Agriculture and Biotechnology
Vol-11, Issue-1; Jan-Feb, 2026
Peer-Reviewed International Journal
Journal Home Page Available: https://ijeab.com/
Journal DOI: 10.22161/ijeab

A comprehensive Review on Formulation, Characterization, Composition, Stability & Preparation, of Nanoemulsions

Leila Mahmoud Mokhtar

Applied College in Afif, Shaqra University, P.O. Box 33, Shaqra 11961, Kingdom of Saudi Arabia

Received: 29 Dec 2025; Received in revised form: 31 Jan 2026; Accepted: 05 Feb 2025; Available online: 15 Feb 2026

Abstract— *The use of Essential Oils (Eos) alone is limited due to their disadvantages such as high volatility, low stability, bioavailability and solubility. Therefore, Essential Oils are generally use in the form of nanoemulsions. The food and pharmaceutical sectors have shown a great deal of interest in essential oil-based nanoemulsions (EO-NEs) because of their improved stability, bioavailability, and functional properties. Nano-based emulsions havereceived considerable attention recently due to their physico-chemical properties and kinetic stability , attractive appearance. Furthermore, their rheological properties make them superior over counter parts. The ability of nanoemulsion to improve the solubility, bioavailability and stability of weakly water-soluble drugs has emerged their roles as promising drug delivery systems, drug administration and vaccine formulation, cosmetics, and food, it also has numerous applications in the field of agriculture. Nevertheless, their benefits, some concerns may represent obstacles that hinder their applications such as formulation complexity, stability issues and industrial production scale-up. To get beyond these hurdles and completely realize the potential of nanoemulsion in commercial and therapeutic applications, more research and innovation are need. This review intends to offer an overview of the formulation, Characterization, Composition, Stability & Preparation, of nanoemul sions specifically, recent literature has been examined in order to define the most common practices adopted (materials and fabrication methods), highlighting their suitability and effectiveness. Finally, relevant to some points such as advantages disadvantages, and applications of nanoemulsions.*

Keywords*— *Characterization, Essential Oils, Formulation, Nanoemulsions, Preparation.

I. INTRODUCTION

Essential oils (EOs) are secondary metabolites from aromatic plants. Moreover, they are plant-derived oily bioactive compounds from various parts like roots, leaves, flowers, and seeds. Through methods such as steam distillation, cold pressing, steam distillation, microwave or ultrasound assisted extraction etc [1, 2]. Essential oils are a complex mixture of various bioactive chemical molecules, they are typically use in small quantities due to their potent aroma and flavor, they are recognised as safe by both the US Food and Drug Administration (FDA) , applications and can used as alternatives to chemical preservatives [3 - 6]. Due to these diverse, complex bio-structures, essential oils have been widely used in the traditional medicine as essential oil posse various biological activities like antimicrobial, antiviral, fungicidal, insecticidal and herbicidal, antioxidant, anti-inflammatory, anti-allergic, anticancer agents, expectorant, digestive, diuretic agents [7, 8]. The biggest challenges of modern botany is to move towards the replacement of synthetic compounds with natural ones, including EOs, in order to exploit their promote sustainable development based on a circular economy [8]. Interest in these kinds of plant based secondary metabolites is increasing day by day [9, 10]. Essential oils have poor physico-chemical properties, such as water insolubility [11]. However, these problems can be preventing through the encapsulation of EO within appropriate delivery systems, thereby amplifying their biological efficacy, [12].Therefore; nanoemulsification technology offers a good alternative for encapsulating these bioactive compounds, making them hydrophilic [13].

Recently, medical studies showed a possible anticancer activity of some EOs, attributable to an antimutagenic (i.e., *Salvia officinalis* L., *Origanum onites* L. and *compactum*, *Lavandula angustifolia* EOs [14, 15] and prooxidant activity (i.e., *Origanum compactum*, *Artemisia herba-alba* and *Cinnamomum camphora*, *Glandora rosmarinifolia* EOs [16, 17]. This latter is a fundamental property to reduce local tumor volume and cell proliferation [18]. The studies was confirmed that the main components of Cinnamon essential oils (CEO), such as limonene and Cinnamaldehyde, have strong antimicrobial effects on foodborne pathogens like Escherichia coli and Listeria monocytogenes [19]. In addition, encapsulating extracts from graviola leaves [20], garlic [21], pep-permint [22], basil oil [23], and CEO in nanocapsules enhances their antimicrobial andantioxidant properties, thereby optimizing growth, gastrointestinal health [21]. The interest in nanoemulsions has experienced a continuous increase in the last years, emulsification is the process of dispersing two or more immiscible liquids together to form a semi stable mixture ([24- 26]. Nanoemulsions are three main components used in the preparation of nanoemulsions are oil, surfactant and cosurfactants have unique physicochemical properties [27-32]. Emulsions (liquid droplets and/or liquid crystals dispersed in a liquid) are prepared using nanotechnology (1-100 nm) by reducing the surface tension between the dispersed and dispersed phases. This is usually achieved through vacuum and electrostatic repulsion between the emulsions, is preferred, the stability of emulsions, which ranges from a few hours to several years, is influenced by important characteristics related to the preparation procedures and the ingredients used. Mollet and Groppenmann emphasize that emulsification requires both chemical and physical energy [33- 38]. Nanoemulsion is a nonequilibrium mechanism that is create with the aid of an external or internal energy source. This is accomplish by a variety of methods that are grade as either high-energy or low-energy by using mechanical devices [39]. Emulsions, which are prepared using nanotechnology, characterized by; exhibit excellent skin penetration and long-lasting effects. In contemporary times, nano-drug delivery systems have emerged as a highly effective approach for delivering drugs within the human body [40-44]. Nanoencapsulation based nanoemulsions, play a pioneering role in encapsulating herbal, Tween-20 and 80 are nonionic, biocompatible, and non-toxic surfactants and widely implicated in medicine, cosmetic, food industries products as used as emulsion surfactants [45-50]. The nanoencapsulation approach could improve the essential oils' physico-chemical properties and stability, by enabling their water dispersability, and by protect them from the interaction with the environment [51].

This work will endow with new information about nanoemulsions based on essential oils in different areas such as food, cosmetic, and pharmaceutical drug delivery systems. In addition, offer a technical overview on the formulation, preparation and stability parameters of Molecular extracts and Nano-extracts when used as vehicle and delivery systems for essential oils, based on the most relevant works reported in the literature in the last years. Moreover, it aims to provide a formulation guide for researchers that need to encapsulate essential oils in such Nano systems.

II. NANOEMULSIONS FORMULATION

An understanding of the physics of nanoemulsion formation is critical for the control of nanoemulsion droplet size. Nanoemulsions are typically prepared in a two-step process where a macroemulsion is first prepared, and is then converted to a nanoemulsion in a second step [52]**.** There are a number of techniques for preparing nanoemulsions, such as high-pressure homogenization, microfludization, phase inversion, spontaneous emulsification, solvent evaporation and hydrogel formation. Multiple emulsions are usually prepared using the double emulsion-solvent evaporation technique. [53]**.**

Theories of Nanoemulsions Formulation

1. **Solubilization Theories**

it is believed that the nano emulsion is getting closer to thermodynamically stable monophasic solutions of spherical micelles that are swelled in water (w/o) or oil (o/w) [54].

2. Interfacial theory

It is also called as mixed film,the surfactant and co-surfactant form a complex layer at the oil-water interface, which is what cause the spontaneous creation of nanoemulsion droplets. According to the general provisions of the theory, an increase in the degree of dispersion of micro droplets can be achieved by lowering the interfacial tension at the water–oil interface to reaching extremely low values (from almost zero to negative). As Shulman's work [55]. This is represent by the equation below:

$$yi = y0/w - \pi i \quad \text{(equation 1)}$$

Where, y0/w: Oil-water interfacial tension, πi:Spreading pressure, yi= interfacial tension [56]**.**

3. Thermodynamic theory

When interfacial tension between two immiscible phases reduces to zero, causes spontaneous formation of micro emulsions and formed negative free energy helps to make emulsion thermodynamically stable [57]. T. P. Hoar and J. H. the term microemulsion when they used this term to describe multiphase system . Discovery of microemulsions confirms well before use in the form liquid waxes., there are four types of micro emulsion phases exists in equilibrium, these phases are referred as Winsor phases [58, 59].

III. PHYSICOCHEMICAL CHARACTERIZATION ON NANOEMULSIONS

3.1. Droplet size & distribution

The normal range of droplet sizes for nanoemulsion is 20-500 nanometers. area-to-volume ratio produced by the small droplet size improves the interaction between the nanoemulsion and biological membranes, enhancing the absorption and bioavailability of the materials that are entrapped [60, 61]. As the droplet size is significantly smaller than the wavelength of visible light, nanoemulsions are often transparent in appearance [62]. Nano-emulsions size distribution is the most important parameters of nano-emulsions since it is relate to applicative properties [63, 64]. Methods used for size characterization include photon correlation spectroscopy (PCS) (i.e., dynamic light scattering, DLS), fluorescence correlation spectroscopy (FCS), electron microscop [65, 66].

3.2. Zeta potential analysis

The liquid layer surrounding the particle exists as two parts; an inner region (Stern layer) where the ions are strongly bound and an outer (diffuse) region where they are less firmly associated. Within the diffuse layer, the ions and particles form a stable entity inside a notional boundary. When a particle moves (e.g. due to gravity), ions within the boundary move it. Those ions beyond the boundary stay with the bulk dispersant. The potential at this boundary is the zeta potential [67, 68]**.** Sakhalin et al. designed the first zeta potential changing nanoemulsion exhibiting a zeta potential change from just -1 mV to +1 mV [69]. Up to date, all zeta potential changing nanoemulsions contain a cationic surfactant being responsible for a positive zeta potential [70]. Concept of zeta potential is rooted in the examination of electro kinetic phenomena, which describe the relative motion between a charged surface and a liquid under the effect of an electric field. The most frequently encountered electro kinetic phenomena used to measure zeta potential are Electrophoresis, Electro osmosis [71, 72].

3.3. Viscosity

The viscosity of freshly prepared nanoemulsion samples usually measured using a Brookfield DV-ETM viscometer. [73]. The proportions of water, oil, and surfactant in a nanoemulsion determine its viscosity, Lowering the content of cosurfactants and surfactants raises viscosity by raising the interfacial tension between the water and oil, whereas raising the water content lowers viscosity [74, 75].

3.4. Encapsulation efficiency (EE)

Encapsulation of essential oils in nanoemulsions systems represents a viable and efficient approach to increase the physical stability of bioactive compounds. Thus protecting them from loss and undesirable changes [76]. Indeed, the use of this technology gains special relevance when it comes to the formulation of biopharmaceuticals [77]. Encapsulation Efficiency (EE) was regarded as a bulk property and was measured as the average of all DDS particles in a solution. Recent technical advances however, allowed the monitoring of single particles [78, 79], to unique information on heterogeneous properties that were lost due to averaging [80]. Encapsulation Efficiency is calculated by following equation:

$$(EE)\,\% = \frac{\text{Total oil} - \text{Free oil}}{\text{Total oil}} \times 100$$ **(equation 2)** [81 - 83]

The encapsulation efficiency of the micro particle or microcapsule or microsphere will be affect by different parameters. Figure 1 illustrates the factors influencing encapsulation efficiency [84].

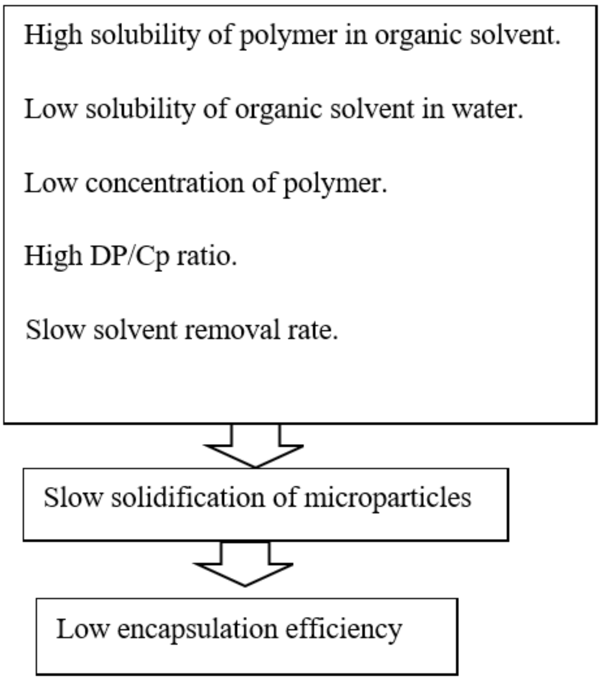

Fig.1: factors influencing encapsulation efficiency [85].

3.5. Surface tension

Surface tension usually measured using a thermostatically controlled processor tensiometer K10 PST at 22 °C [86].

3.6. Rheological measurements

The rheological properties of Nano-emulsions can be turn from flowing fluid to a solely relaxing fluid or to a gel-like system by controlling the dispersed phase volume fraction and droplet size, or by adding additives in the bulk [87].the study of interfacial properties, surface tension and dilatational rheology is getting more and more attention in recent years [88]. Rheological measurements usually done perform at 25±0.1°C using a Bohlen remoter equipped with a cone/plate apparatus 40 mm per 4°. For each sample, continuous variation of shear rate γ will applied and the resulting shear stress σ will measured. Viscosity of dispersions with Newtonian flow properties calculated according to the relation: $\eta=\sigma/\gamma$ (equation 3) [89].

IV. COMPOSITION OF NANO EMULSIONS

4.1. Emulsifier

An emulsifier has the ability that mixes two immiscible liquids (oil and water) to form a homogeneous dispersion. It plays a significant role in the food industry and it could prevent phase separation. [90]. Food colloids emulsions and foams have their origins in nature, Milk, for example, has a naturally occurring membrane, which allows solid fat to be disperse into an aqueous phase [91].

Table 1: Properties of emulsions [92, 93].

Emulsion	Droplet Size	Thermodynamic Stability	Appearance
Nanoemulsion	5-200 nm	Unstable	Transparent
Microemulsion	5-100 nm	Stable	Transparent
Macroemulsion	0.1-100 µm	Unstable	Turbid

4.2. Oil phase

The oil phase could consist in a carrier oil in which the lipophilic bioactive compound dissolved [97]. Oil-in-water miniemulsions are prepared at slow agitation by an emulsification process that involves the use of mixed emulsifier solutions of an ionic surfactant [98]. Penetrating the tail group region of the surfactant monolayer and causing it to swell, the oil components also affect curvature [99]. Because short chain oils, penetrate the lipophilic group more [100]. Nano-emulsions are thermodynamically unfavorable systems [101], the chemical stability is also important for quality control of the drug-loaded Nano-emulsions [102, 103]. Some plant oils (corn, olive, sunflower, sesame, oils) defined as "ripening inhibitors" is needed [104-107]. Plant oils less water-soluble, they are able on positively influence their partitioning between the lipid droplets and the aqueous phase, for these reasons, several works in the literature reported the mixing of essential Oils, acting as active ingredient, and ripening inhibitor oils, in order to guarantee the long-term stability of the system [108, 109].

4.3. Surfactant

A surfactant molecule consists of two parts. One part is hydrophobic and the other one is hydrophilic. These molecules are highly active in the interfaces between air and water or oil and water. There are four main classifications of surfactants: anionic, nonionic, cationic and amphoteric surfactants, therefore, proper selection of surfactants becomes a crucial criterion. [110, 111]. Surfactants are essential for stabilizing nanoemulsions [112]. These amphiphilic molecules form a protective layer around droplets, offering steric, electrostatic, or dual electro-steric stabilization [113]. The selection of surfactants depends on the desired droplet size, stability, and application. Cosurfactants are often added to strengthen the interfacial and further stabilize the emulsion. Examples include polyethylene glycol [114, 115].

Table 2: Types of surfactant [116 - 119]

Sr. No	**Types of surfactant**	**Examples**
1	**Non-ionic**	Sorbitan monooleate (Span 80), Tween 80
2	**Cationic**	Ecithin , soybean egg,. Quaternary ammonium alkyl salts
3	**Anionic**	Sodium bis-2-ethylhexylsulphosuccinate (AOT)
4	**Ampholytic**	Phospholipids (Lecithin, Ndodycylalanine**)**

4.4. Co-surfactant

Drugs that are not water-soluble usually made into emulsion preparations. Emulsion preparations have poor stability; surfactants are ingredients that affect nanoemulsions to reduce surface tension [120]. Surfactants have unique molecular characteristics; a short to medium hydrophobic chain, weak amphiphilic nature, and terminal small hydrophilic group (such as hydroxyl group characteristic of low molecular weight alcohols and diols). These properties increase the tendency of cosurfactants to interact with surfactant monolayers at interfaces, perturbing the packing and long-range order of surfactant molecules and promoting better interface fluidity and curvature in favor of NE formation [121]. Furthermore, the balanced amphiphile nature of these molecules promotes their selective partitioning between phases, changing their composition and thereby their relative hydro/lipophilicity of the immiscible phases to improve better miscibility [122].

Table 3: List of co-surfactant used in nanoemulsions [123]

Sr. NO	Co-surfactant
1	TranscutolP
2	Glycerin,Ethylene glycol
3	Propylene glycol
4	Ethanol
5	Propanol

V. STABILITY

5.1. Centrifugal stability

The stability of nanoemulsions under centrifugation reflects the emulsion resistance and the integrity of the interfacial film [123,124].use varying speeds (3000, 5000, and 8000 r/min) for 30 min, the absorbance of the non-layered emulsion is then measured at 210 nm before and after centrifugation, using distilled water as a reference sample. The permeability calculated using the following equation:

Transmittance formula: $T (\%) = A1/A2 \times 100$ **(equation 4)**

Where: T: transmittance; A1: absorbance of nanoemulsion before centrifugation; A2: absorbance of nanoemulsion after centrifugation [99].

5.2. Thermal stability

Increased temperatures can cause droplets to absorb energy in the Nano-emulsion, resulting in the emulsification, coalescence and flocculation of the Nano-emulsion [125]. Over time, they evolve into two distinct liquid phases, an irreversible process driven by the lower free energy level of the phase-separated state compared to the emulsion state [126]. The kinetics of Nano emulsion breakdown follow a first-order rate law, where the rate is exponentially proportional to $\exp(-\Delta E/kBT)$, with ΔE denoting the energy barrier, representing the Boltzmann constant, and T indicating the temperature [127]. The irreversible breakdown poses significant constraints on the utility of Nano emulsions, especially in scenarios where exposure to high temperatures during production, storage, or application is inevitable, such as in food processing, formulations, and pharmaceutical [128].

5.3. PH stability

The pH value of the Nano emulsion systems adjust by adding Hydrochloric acid or Potassium hydroxide to the system, which monitor by using a Sartorius basic pH [129].To pH testing conduct use the methodology described by Shoviantari et al. [130].Before evaluating the preparation's pH, the pH meter will be calibrate using buffer solutions (pH 4.00, 7.00, and 10.00). To guarantee its correct functioning. [131].

5.4. Storage stability

There are few studies have investigated the storage stability of Nano emulsion droplets; Environmental conditions that effect on the stability of emulsions include temperature, pH, and ionic strength [132- 134].The emulsion stored at higher temperatures increases the thermal energy of the droplets and therefore increases the frequency of droplet collisions. It also reduces interface viscosity, which results in a faster film-drainage rate and faster droplet coalescence [135]. Nano-emulsions have a long kinetic stability that can be maintaining for months because of their small size and low dispersion index. When the Nano-emulsion droplet size is less than 200 nm, the Nano-emulsion is highly resistant to gravitational separation, which is ideal for the development of products with a long shelf life [136]. The shelf of Nano emulsions is tested by storing a sample of fresh emulsion (5 ml) in a sealed container at 25°C for 2, 4, 6, 12, and 24 days respectively. The droplet size, dispersion index (PDI), and zeta potential are then measured at each storage period [125].

VI. NANO EMULSIONS PREPARATION

Nano emulsions can be prepared by using high and low energy methods. In high-energy methods, mechanical devices deliver required large disruptive forces. On the other hand, in low energy methods, there is no need for an external force [137]. Production of Nano emulsions achieved by using the intrinsic physiological properties of the system. [138].The most extensively used methods for the preparation of Nano emulsions: are Spontaneous Emulsification Method (SE), Phase inversion Temperature method (PIT), Emulsion phase inversion (EPI) method/ catastrophic phase, Emulsion inversion point (EIP) method, High-pressure homogenization (HPH) method, Micro fluidizers, High-Intensity Ultrasound (HIU), and Rotor stator mixer [139].

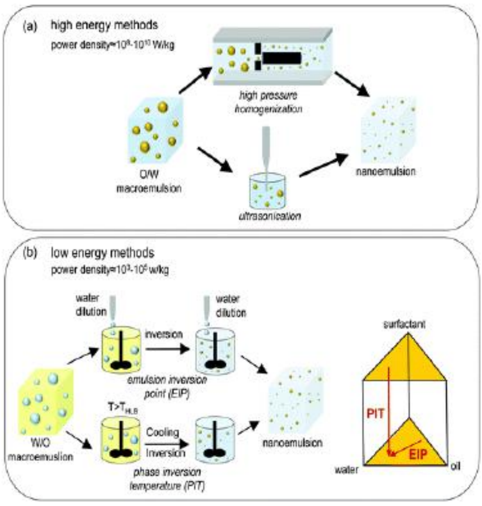

Fig.2: Nano emulsions Preparation

6.1. Low-energy methods

Low-energy approaches rely on the spontaneous for-mation of tiny oil droplets within oil-water-emulsifier mixtures when either their composition or the environment conditions are altered [140]. A number of different Nano emulsion preparation methods based on this principle, including: [141].

6.1.1. Spontaneous emulsification method (SE)

The spontaneous formation of an O/W Nano emulsion facilitated by specific temperatures relies on the chemical compounds present in both phases, as well as the utilized emulsifier [142]. Solvents can facilitate this spontaneous process [143]. It benefits from the chemical energy replacement based upon dilution process with the continuous phase, which occurs usually at constant temperature [144]. This method can produce Nano emulsions at room temperatures and no special devices are required. It subjected to interfacial tension, viscosity of interfacial and bulk, phase transition region, surfactant structure, and surfactant concentration. [145].

6.1.2. Phase inversion temperature method (PIT)

In the PIT method, Nano emulsions prepared by the formation of micro emulsions at its PIT followed by immediate cooling to room temperature, which can be divided into 3 main steps:

1. Non-ionic surfactant, oil and water stirred at room temperature to form a coarse emulsion [146].

2. The mixture gradually heated up to around PIT [147].

3. The solution rapidly cooled to the room temperature with continuous stirring, resulting in the formation of o/w Nano emulsions, mixture is rapid cooled either by immersing into an ice bath or by diluting with cold water [148]. Inversion Temperature method (PIT) has the advantage over SE method in that its composition is without organic solvent which is an integral component of the SE method. The PIT method also has superiority over the PIC method in that the nanoemulsion droplets have lower diameter and polydispersity index (PDI). The emulsification efficiency of PIT method has also been found higher (1) than that of PIC method (0.35)40 [149, 150].

6.1.3. Emulsion phase inversion (EPI) method/ catastrophic phase

Nano emulsions can be fabricate using either low-energy emulsification (e.g., transitional phase inversion) [151,152]. Although low energy emulsification methods use higher amounts of surfactants, it requires only a simple stirring to produce an emulsion with desirable characteristics [153,154]. Which makes them more energy efficient opposed to high-energy methods, which require the use of mechanical devices [154]. The Emulsion Phase Inversion (EPI) method, is a low-energy technique for creating fine emulsions, by agitated water-in-oil (O/W), emulsion inverts into an oil-in-water (W/O) emulsion and vice versa. There are two types of phase inversion; transitional phase inversion and catastrophic phase inversion (CPI) [155]. Emulsification via phase inversion is widely used in fabrication of cosmetic products, pharmaceutical products (e.g., vesicles for drug delivery), foodstuff and detergents. Emulsification process strongly affected by preparation method; very different droplet size distribution could be achieved, which is strictly linked to the product stability [156]. The phase inversion of a W/O emulsion can be achieved not only through changes in thermodynamic state variables but also by the imposition of ultra-high deformation rates under constant thermodynamic conditions. Phase inversion carried out using a model static mixer, which is essentially a series of short capillaries with flow dividers. His degree of phase inversion is dependent on the rate of deformation and number of mixer units. The properties of the emulsions produce by FIPI-emulsification are evaluated through particle size and viscosity measurements and optical and electron microscopy studies [157]. **6.1.4. Emulsion inversion point (EIP) method**

In the emulsion inversion point (EIP) methods the change from one type of an emulsion to another (e.g., W/O to O/W or vice versa) is through a catastrophic phase inversion (CPI), rather than a transitional phase inversion (TPI) as with the PIC or PIT methods [158]. In this case, a W/O emulsion with a high oil-to-water ratio is formed using a particular surfactant, and then increasing amounts of water are added to the system with continuous stirring. Above a critical water content, the water droplet concentration is so high that they are packed very tightly together, and the emulsion reaches a phase inversion point where it changes from a W/O to an O/W system. The size of the droplets formed depends on the process variables, such as the stirring speed and the rate of water addition [159]. Recently, it has been shown that the emulsion inversion point (CPI) method can be used to produce Nano emulsions (r< 100 nm) from food-grade ingredients [160, 161].

6.2. High energy methods

6.2.1. High-pressure homogenization (HPH) method

High pressure homogenization (HPH) was first introduced in the early 20th century by Auguste Gaulin, the basic operational principle of HPH remains unchanged since and it involves using a high-pressure pump to force the fluid through a small orifice. [162]. In the emulsion fabrication, a mixture of essential oil and Tween 80 (as surfactant) is disperse in distilled water, using a magnetic stirrer at 1500 rpm for 15 min, to form a primary emulsion. Subsequently, the primary emulsions subjected to a high-pressure homogenization [163].

Table 4: Preparation of nanoemulsions using Spontaneous Emulsification Method (SE) with different oils

Method	Bioactive Compound Encapsulated	Optimal Processing Conditions	Droplet Diameter (nm)	Ref
Spontaneous Emulsification Method (SE)	Peppermint oil	(1) titration of organic phase into aqueous phase, (2) constant stirring, 600 rpm, (3) room temperature	50	[164, 165]
	Eugenol oil	(1) deprotonated Eugenol in hot alkaline added to surfactant mixtures, (2) the mixtures acidic to pH 7.0, stirred, 600 rpm	109–139	[166]
	Black Cumin oil	Mix cumin essential oil with Tween 80 and distilled water using a magnetic blender for five minutes.	122.7	[167]
	mustard oil	1-Blends of Tween 20 and SDBS in a range of 1:1–1:6 ratios. 2-Mustard oil (5% w/w) add drop wise into different blends of emulsifier with slow mixing by magnetic stirrer at 50–60°C for final preparation of oily phase. 3- Aqueous phase form by adding two co-surfactants, in de-ionized water.	23	[168]
	pine oil	The method: Mix pine oil +Tween 80 + ethanol in + water with total cumulative value of all components not more than 100% v/v	633	[169]

Table 5: Preparation of nanoemulsions using Phase inversion &Emulsion inversion point Methods with different oils

Phase inversion Temperature method (PIT)	Curcuminoids	1. Non-ionic surfactant, oil and water are stirred at room temperature to form a coarse emulsion 2. The mixture is then gradually heated up to around or above the PIT. 3. The solution is rapidly cooled to the room temperature with continuous stirring..	20-100	[170]
	Lemon oil		100	[171]
	coconut oil		20-100	[146]
	ginger oil		100	[147] [148]
	Harmal oil	combining the essential oil with surfactants (like Tween 80/Span 20) and water, then mixing and homogenizing to create stable, nanometer-sized droplets	There is no study	
Emulsion phase inversion (EPI) method/ catastrophic phase	coconut oil	80 or Tween 20 & oil are prepare and add to it different amounts of water and the mixture was mixed using a vortex, for two minutes.	20-100	[172]
	Oregano Essential Oil		170-180	[173]
	Fenugreek oil		< 100	[174
	canola oil		156.13 ± 2.3	[175]

	orange oil		146-200	[176]
	sesame oil		100	[177]
	Mexican Tea essential oil		Suggested:	
Emulsion inversion point (EIP) method	Castor oil	slowly adding water to an oil-surfactant(tween 80) mix, which suddenly transforms the system into tiny droplets at low interfacial tension.	35 ± 45	[178]
	coconut oil (VCO)		<300	[179]
	paraffin wax		<200	[180]

Table 6: Preparation of nanoemulsions using High-pressure homogenization (HPH) method with different oils

Method	Essential oil	Surfactant	Aqueous Phase	Size (nm)	Ref
High-pressure homogenization (HPH) method	fish oil	Tween80	sodium Caseinate	369.4 ± 3.8	[181]
	clove essential oil	Tween 80	Distilled water	90	[163, 182]
	lemon essential oil	Tween 80	Distilled water	100-140	[163]
	Saccocalyx satureioides Coss. essential oil	Tween 20	Distilled water	106,000	[183]
	Cinnamon essential oil	Tween 80	Lauric arginate	100	[184]
	cardamom oil	Tween 80	grape seed oil		[185]
	bergamot essential oil	xanthan gum	Distilled water	63.6 - 85.3	[186]
	groundnut oil	Tween 80	Distilled water	20-200	[187]
	borage oil	Tween® 80	Distilled water	334.4 ± 5.2	[188]
	Cellulose derivatives	Tween 20, 60, or 80	Distilled water	100-126	[189]

Table 7: Preparation of nanoemulsions using microfluidizers and high-intensity ultrasonic (HIU) devices with different oils

Method	Essential oil	Surfactant	Aqueous Phase	Size (nm)	Ref
Microfluidizers	Corn oil	quillaja saponin and soy lecithin	Whey protein isolate (WPI)	20-200	[190]
	linseed oil	lecithin	Distilled water	70.8	[191]
	Mineral oil	lecithin	Distilled water	<200	[192]
	Chia Oil	NaCas	Distilled water	< 200	[193]
	orange oil	gum Arabic and modified starch	Distilled water	77	[194]
High-Intensity Ultrasound (HIU)	olive oil	Tween 80, Span 60, or sucrose esters	Distilled water	< 200	[195]
	Castor Oil	Tween 80	deionized water	174.6	[196]
	Cady oil	Tween 80	deionized water	< 200	[196]
	Neem oil	Tween 20	Distilled water	< 100	[197, 198]
	Almond Oil	Tween 20	Distilled water	< 100	[199]
	juniper berry essential oil	Tween 20	deionized water	182-250	[200]

	Curcumin	soybean lecithin	glycerol in the aqueous phase	108	[201]
	Thyme Essential Oil	Tween 80	deionized water	54.6	[202]
	ginger oil	Tween 80	buffer or distilled water, ethanol	< 100	[203, 204]
	grapeseed oil	Tween 80	Distilled water	144.2 - 162.6	[205]
	Moringa Oil	whey proteins	Distilled water		[206]
	Garlic essential oil	Tween 80	Distilled water	215-820	[207]
	Aloe vera oil	Span® 85	Distilled water	< 200	[208]
	safflower oil	polysorbate 80	Distilled water	88.14 ± 1.52	[209]
	Basil oil	Saponins extracted from Quillaja lancifolia	Distilled water	174.1	[188]
	celery seed oil	Tween 80	Distilled water	23.4 ± 1.80	[210]
	lavender oil	Tween-80, Span-80, ethanol	Distilled water	-----	[211]
	Qassum oil	Tween 80/Span 80	Distilled water	Suggested: There is no study	

Table 8: Preparation of nanoemulsions using Phase inversion composition (PIC) &Spontaneous emulsification methods (SE) with different oils

Method	Essential oil	Surfactant	Aqueous Phase	Size (nm)	Ref
Phase inversion composition (PIC)	Neem oil	Tween 80	Distilled water	194	198]
	Ginger oil	Tween 80	Distilled water	20–75	[212]
	coconut oil	Tween 80/Span 80 or lecithin	Distilled water	48.63	[179]
	Origanum Essential Oil	linseed mucilage	Distilled water	170-180	[173]
Spontaneous emulsification method (SE)	Lime Essential oil	Tween 80	Distilled water	20–60	[163]
	Cinnamon oil	Tween 80	Distilled water	100	[184]
	Peppermint Essential oil	Tween 20, 40, 60	Distilled water	70–170	[164]
	Clove oil				[182]
Phase Inversion Temperature (PIT)	oregano essential oil	Cremophor RH 40, Span 80	Millipore water	30–60	[213]
dynamic light scattering	Elongate oil	deionized water	non-heated water	115	[214]

6.2.2. Micro fluidizers

Two solutions (aqueous phase and oily phase) are united together and processed in an in-line homogenizer to create a coarse emulsion, which allowed into a Microfluidizer where it is further developed to obtain a steady Nano emulsion. [215]. It is most widely employed in the pharmaceutical industry [216]. In nanoparticle production, this process facilitates the size reduction and uniform dispersion of materials. For example, in the production of liposomes and lipid nanoparticles (LNPs), [217, 218].

6.2.3. High-intensity ultrasound (HIU)

Industrial scale emulsion formation typically takes place in highpressure homogenizers (HPHs) [219]. HPHs used widely in many branches of chemical engineering, ranging from traditional dairy applications to Nano emulsification in pharmaceutical production and more [220]. Advantages of these devices high-energy efficiency, and Good emulsion stability - HIU devices are easy to operate and clean [221]. Ultrasound devices can produce acoustic cavitation, releasing of reactive radicals promoting chemical reactions [222]. The physical effects of ultrasound induced by acoustic cavitation can boost the disruption of oil droplets, facilitating the formation of stable O/W [223]. High power ultrasound has mechanical, chemical and/or biochemical effects, which are used to modify the and enhance the quality of various food systems during processing [224].

VII. ADVANTAGES OF NANO EMULSIONS [225 - 230]

Nanoelums have a number of advantages due to the small size of their droplets (100 nanometers), most notably low cost, transparent appearance, no clumping or settling, and a large surface area, Non-toxic and non-irritating, therefore it can be taken via the digestive system. It has a superior ability to improve the solubility of hydrophobic substances, it can also be given topically, intravenously, by inhalation, nasally, intramuscularly, or orally, the metallic and bitter flavors of medicines that may cause unwanted side effects such as nausea and vomiting can be successfully masked using nanoemulsifiers. Nanoemulsifier formulations protect the active ingredients from degradation, oxidation, or reactions with external factors, such as light or heat, and the possibility of altering their rheological properties.

VIII. DISADVANTAGES OF NANO EMULSIONS [231- 237]

The stability of nanoemulsions is affected by environmental factors such as temperature and pH, and these factors change when nanoemulsions are given to patients, the homogenization apparatus (the tool needed to prepare nanoemulsions) is also an expensive process, and Ostwald maturation is the main problem associated with the non-acceptance of nanoemulsion formulations. Additionally, stabilizing nanodroplets requires the use of a high concentration of surfactants and auxiliary materials.

IX. APPLICATIONS OF NANO EMULSIONS [238-244]

Nanomulants appear highly attractive from an industrial perspective, given their ease of large-scale production and the absence of complex manufacturing techniques. Nanoemulsions have potential applications in the food industry for delivering pharmaceutical nutrients, coloring and flavoring agents, and antibiotics. Delivery systems made from smart materials with adjustable physical and biological properties also enhance current treatment methods. The development of nanosystems has shown a significant impact in many agricultural fields, including pesticide formulations, food coatings, fungicides, and antiparasitics. Recently, nanoemulsions have gained increasing importance as potential means of delivering cosmetics in a controlled manner, and of optimally distributing active ingredients in different layers of the skin.

X. RECOMMENDATIONS

The most important recommendations for developing nanoemulsions include improving their physical stability by using surfactants (non-toxic, safe, environmentally friendly), adopting high-energy production methods (ultrasonic homogenization), integrating artificial intelligence to improve formulations, and applying packaging techniques (drug loading and release), using Metal-organic frameworks in the preparation of crystalline nanocomposites because they have a large surface area, and have high porosity.

XI. CONCLUSION

To date Nano emulsions have been shown to be able to protect labile drug, control drug release, increase drug solubility,. The main thing is that it contain small particle size reduced to the nonmetric scale shows various physical properties. Nano emulsion can be used in various disciplines including cosmetics, biotechnology, food, agriculture and, and pharmaceuticals.

REFERENCES

[1] Qiaobin, H.; Gerhard, H.; Upadhyaya, I.; Venkitanarayanan, K.; Luo, Y. (2016), Antimicrobial eugenol nanoemulsion prepared by gum arabic and lecithin and evaluation of drying technologies, *International Journal of Biological Macromolecules*, Vol. 87, 130–140.

[2] Kumar, A.; Kanwar, R.; Mehta, S.; K. (2025), Nanoemulsion as an effective delivery vehicle for essential oils: Properties, formulation methods, destabilizing mechanisms and applications in agri-food sector, *Next Nanotechnology*, Vol. 7 (100096), 1–18.

[3] Bachir, R.; Benali, M. (2012), Antibacterial activity of the essential oils from the leaves of *Eucalyptus globulus* against *Escherichia coli* and *Staphylococcus aureus*, *Asian Pacific Journal of Tropical Biomedicine*, Vol. 2(9), 739–742.

[4] Natrajan, D.; Srinivasan, S.; Sundar, K.; Ravindran, A. (2015), Formulation of essential oil-loaded chitosan–alginate nanocapsules, *Journal of Food and Drug Analysis*, Vol. 23, 560–568.

[5] Turek, C.; Stintzing, F. (2013), Stability of Essential Oils: A Review, *Comprehensive Reviews in Food Science and Food Safety*, Vol. 12(1), 40–53. https://doi.org/10.1111/1541-4337.12006.

[6] Miresmailli, S.; Isman, M. (2014), Botanical insecticides inspired by plant–herbivore chemical interactions, *Trends in Plant Science*, Vol. 19, 29–35.

[7] Sharifi-Rad, J.; et al. (2017), Biological Activities of Essential Oils: From Plant Chemoecology to Traditional Healing Systems, *Molecules*, Vol. 22(1), 70.

[8] Pavela, R.; Benelli, G. (2016), Essential oils as ecofriendly biopesticides: Challenges and constraints, *Trends in Plant Science*, Vol. 21, 1000–1007.

[9] Tajkarimi, M.; Ibrahim, S.; Cliver, D. (2010), Antimicrobial herb and spice compounds in food, *Food Control*, Vol. 21, 1199–1218.

[10] Goodger, J.; Senaratne, S.; Nicolle, D.; Woodrow, I. (2016), Correction: Foliar Essential Oil Glands of *Eucalyptus* Subgenus *Eucalyptus* (Myrtaceae) Are a Rich Source of Flavonoids and Related Non-Volatile Constituents, *PLoS One*, Vol. 11(5), e0155568.

[11] Pavoni, L.; Benelli, G.; Maggi, F.; Bonacucina, G. (2019), Green nanoemulsion interventions for biopesticide formulations. In: *Nano-Biopesticides Today and Future Perspectives*; Academic Press: Cambridge, MA, USA; 133–160. ISBN 978-0-12-815829-6.

[12] Zhang, X.; Wang, Y.; Li, Z.; Li, Y.; Qi, B. (2024), Effects of polysaccharide type on the structure, interface behavior, and foam properties of soybean protein isolate hydrolysate–polysaccharide Maillard conjugates, *Food Hydrocolloids*, Vol. 151, 109801.

[13] Sharma, A.; Farmaha, M.; Kau, I. (2020), Preparation and characterization of O/W nanoemulsion with eucalyptus essential oil and study of in vitro antibacterial activity, *Nanomedicine Research Journal*, Vol. 5(4), 347–354.

[14] Gacic, B.; Nikcevic, S.; Bjedov, T.; Vukcevic, J.; Simic, D. (2006), Antimutagenic effect of essential oil of sage (*Salvia officinalis* L.) and its monoterpenes against UV-induced mutations in *Escherichia coli* and *Saccharomyces cerevisiae*, *Food and Chemical Toxicology*, Vol. 44(10), 1730.

[15] Evandri, M.; Battinelli, L.; Daniele, C.; Mastrangelo, S.; Bolle, P.; Mazzanti, G. (2005), The antimutagenic activity of *Lavandula angustifolia* (lavender) essential oil in the bacterial reverse mutation assay, *Food and Chemical Toxicology*, Vol. 43, 1381–1387.

[16] Bakkali, F.; Averbeck, S.; Averbeck, D.; Zhiri, A.; Baudoux, D.; Idaomar, M. (2006), Antigenotoxic effects of three essential oils in diploid yeast (*Saccharomyces cerevisiae*) after treatments with UVC radiation, 8-MOP plus UVA and MMS, *Mutation Research*, Vol. 606, 27–38.

[17] Poma, P.; Labbozzetta, M.; Notarbartolo, M.; Bruno, M.; Maggio, A.; Rosselli, S.; Sajeva, M.; Zito, P. (2018), Chemical composition, in vitro antitumor and pro-oxidant activities of *Glandora rosmarinifolia* (Boraginaceae) essential oil, *PLoS One*, Vol. 13, e0196947.

[18] Bakkali, F.; Averbeck, S.; Averbeck, D.; Idaomar, M. (2008), Biological effects of essential oils – a review, *Food and Chemical Toxicology*, Vol. 46, 446–475.

[19] Hilbig, J.; Ma, Q.; Davidson, P.; Weiss, J.; Zhong, Q. (2016), Physical and antimicrobial properties of cinnamon bark oil co-nanoemulsified by lauric arginate and Tween 80, *International Journal of Food Microbiology*, Vol. 233, 52–59.

[20] Maesaroh, U.; Dono, N. (2022), Performance, microbial populations, and jejunal morphology of broilers supplemented with nano-encapsulated graviola leaf extract, *Tropical Animal Science Journal*, Vol. 45, 64–72.

[21] Ibrahim, D.; Ismail, T. A.; Khalifa, E.; Abd El-Kader, S. A.; Mohamed, D. I.; Mohamed, D. T.; Abd El-Hamid, M. I. (2021), Supplementing garlic nanohydrogel optimized growth, gastrointestinal integrity and economics and ameliorated necrotic enteritis in broiler chickens using a *Clostridium perfringens* challenge model, *Animals*, Vol. 11, 2027.

[22] Yarmohammadi, B. S.; Samadi, F.; Hassani, S.; Asadi, G. (2017), Effects of encapsulated nano- and microparticles of peppermint (*Mentha piperita*) alcoholic extract on the growth performance, blood parameters and immune function of broilers under heat stress condition, *Iranian Journal of Applied Animal Science*, Vol. 7, 669–677.

[23] Thuekeaw, S.; Angkanaporn, K.; Chirachanchai, S.; Nuengjamnong, C. (2021), Dual pH responsive double-layered microencapsulation for controlled release of active ingredients in simulated gastrointestinal tract: A model case of chitosan-alginate microcapsules containing basil oil (*Ocimum basilicum* Linn.), *Polymer Degradation and Stability*, Vol. 191, 109660.

[24] Dahiya, P.; Sambhakar, Sh.; Malik, R.; Bhatia, S. (2023), Nanoemulsion: An Emerging Novel Technology for Improving the Bioavailability of Drugs, *Scientifica*, Vol. 4, 1–25.

[25] Fryd, M.; Mason, T. G. (2012), Advanced Nanoemulsions, *Annual Review of Physical Chemistry*, Vol. 63, 493–518.

[26] Gutiérrez, J. M.; González, C.; Maestro, A.; Solè, I.; Pey, C. M.; Nolla, J. (2008), Nano-emulsions: New applications and optimization of their preparation, *Current Opinion in Colloid & Interface Science*, Vol. 13(4), 245–251.

[27] Al-Edresi, S.; Baie, S. (2009), Formulation and stability of whitening VCO-in-water nano-cream, *International Journal of Pharmaceutics*, Vol. 373(1–2), 174–178.

[28] Anton, N.; Benoit, J. P.; Saulnier, P. (2008), Nanoemulsion formation by low-energy methods: A review, *Journal of Pharmacy and Pharmaceutical Sciences*, Vol. 128, 185–199.

[29] Mishra, S.; Srivastava, V. (2025), Advancement of Nanoemulsion Formulation in Drug Delivery System for

Anticancer Drug, *Journal of Emerging Technologies and Innovative Research*, Vol. 12(6), 866–872.

[30] Bai, L.; Huan, S.; Gu, J.; McClements, D. J. (2016), Fabrication of oil-in-water nanoemulsions by dual-channel microfluidization using natural emulsifiers: Saponins, phospholipids, proteins, and polysaccharides, *Food Hydrocolloids*, Vol. 61, 703–711.

[31] Solans, C.; Solè, I.; Fernández-Arteaga, A.; et al. (2009), Nano-emulsion formation by low-energy methods and functional properties, In: Hidalgo-Álvarez, R. (Ed.), *Structure and Functional Properties of Colloidal Systems*, Taylor & Francis Group, 457–482.

[32] Taylor, P. (1998), Ostwald ripening in emulsions, *Advances in Colloid and Interface Science*, Vol. 75(2), 107–163.

[33] Jabbar, M.; Baboo, I.; Majeed, H.; Farooq, Z.; Palangi, V. (2024), Preparation and characterization of cumin essential oil nanoemulsion (CEONE) as an antibacterial agent and growth promoter in broilers: A study on efficacy, safety, and health impact, *Animals*, Vol. 14, 2860. https://doi.org/10.3390/ani14192860

[34] Fitri, I. A.; Suryani, C. L.; Murtisari, A. (2025), The effects of heat treatment on the stability of oil-in-water nanoemulsions stabilized by nanocellulose, *International Symposium on Food and Agro-Biodiversity*, Vol. 1460, 1–9.

[35] Ghani, Sh.; Barzegar, H.; Noshad, M.; Hojjati, M. (2019), Development of nanoemulsion-based antimicrobial activity of cinnamon prepared with soy protein isolate-lecithin, *Journal of Food and Bioprocess Engineering*, Vol. 2(2), 147–154.

[36] Changediya, V. (2024), Nanoemulsions: A Recent Drug Delivery Tool, *Open Science Journals*, 1–10.

[37] Mollet, H.; Grubenmann, A.; Payne, H. (2001), *Formulation Technology: Emulsions, Suspensions, Solid Forms*, Wiley-VCH Verlag GmbH, 445 pages.

[38] Ocampo-Salinas, I. O.; Tellez-Medina, D. I.; Jimenez-Martinez, C.; Davila-Ortiz, G. (2016), Application of high-pressure homogenization to improve stability and decrease droplet size in emulsion-flavor systems, *International Journal of Environment, Agriculture and Biotechnology*, Vol. 1(4), 646–662.

[39] Sneha, K.; Kumar, A. (2022), Nanoemulsions: Techniques for the preparation and recent advances in food applications, *Innovative Food Science & Emerging Technologies*, Vol. 76.

[40] Iskandar, B.; et al. (2024), Herbal nanoemulsions in cosmetic science: A comprehensive review of design, preparation, formulation, and characterization, *Journal of Food and Drug Analysis*, Vol. 32(4), 429–458. https://doi.org/10.38212/2224-6614.3526

[41] Sohail, M.; Rabbi, F.; Younas, A.; Hussain, A.; Yu, B.; Li, Y. (2022), Herbal bioactive-based nano drug delivery systems, In: Bakshi, I. S.; Bala, R.; Madaan, R.; Sindhu, R. K. (Eds.), *Herbal Bioactive-Based Drug Delivery Systems*, Academic Press, 169–193.

[42] Arundina, I.; Diyatri, I.; Juliastuti, W. S.; Budhy, T. I.; Surboyo, M.; Iskandar, B.; et al. (2022), Osteoblast viability of liquid smoke rice hull and nanoparticles form as periodontitis treatment, *European Journal of Dermatology*, Vol. 17, 450–455.

[43] Kolling, C.; Ribeiro, J. L. D.; de Medeiros, J. F. (2022), Performance of the cosmetics industry from the perspective of corporate social responsibility and design for sustainability, *Sustainable Production and Consumption*, Vol. 30(1), 171–185.

[44] Ren, G.; Sun, Z.; Wang, Z.; Zheng, X.; Xu, Z.; Sun, D. (2019), Nanoemulsion formation by the phase inversion temperature method using polyoxypropylene surfactants, *Journal of Colloid and Interface Science*, Vol. 540, 177–184.

[45] Ganjali, M.; Ganjali, M.; Aljabali, A.; Barhoum, A. (2022), Drug delivery systems based on nano-herbal medicine, In: Barhoum, A.; Jeevanandam, J.; Danquah, M. K. (Eds.), *Bionanotechnology: Emerging Applications of Bionanomaterials*, Elsevier, 491–530.

[46] Reolon, J.; B.; Sari, M.; Marchiori, C.; Dallabrida, K.; G.; Santos, J.; Almeida, I.; *et al.*(2023), Herbal drugs-loaded soft nanoparticles for treating skin disorders: where do we stand, *Ind Crop Prod* , Vol. 206,117602.

[47] Attama, A.; A.; Agbo, C.; P.; Onokala, O.; Kenechukwu, F.; Ugwueze, M.; Mbah, C.; *et al.* Chapter 6 - applications of nanoemulsions as drug delivery vehicle for phytoconstituents. In: Thomas S, Oyedeji AO, Oluwafemi OS, Jaquilin Pj R, editors. Nanotechnology in herbal medicine. Woodhead Publishing; 2023, 119-94.

[48] Qian, C.; Decker, E.; A.; Xiao, H.; McClements, D.; J. (2012), Nanoemulsion delivery systems: Influence of carrier oil on β-carotene bioaccessibility. *Food Chemistry*, Vol. 135(3),1440-1447.

[49] Kerwin, B.; A. (2008), Polysorbates 20 and 80 Used in the Formulation of Protein Biotherapeutics: Structure and Degradation Pathways, *Journal of Pharmaceutical Sciences,* Vol. 97(8), 2924-35.

[50] Bilia, A.; R.; Guccione, C.; Isacchi, B.; Righeschi, C.; Firenzuoli, F.; Bergonzi, M.; C. (2014), Essential oils loaded in nanosystems: A developing strategy for a successful therapeutic approach, *Evid.-Based Complement. Altern. Med.* [CrossRef] DOI: 10.1155/2014/651593.

[51] By, W.; (2013), Polymeric Nanoparticle-Based Insecticides: A Controlled Release Purpose for Agrochemicals. *Insecticides - Development of Safer and More Effective Technologies*, Intech Open: Rijeka, Croatia.

[52] Gupta, A.; Eral, H.; B.; Hatton, T.; A.; Doyle, P.; S.; (2015), Nanoemulsions: formation, properties and applications, *Soft Matter*, Vol. 11.

[53] Ratnakar, G.; R.; Aappasaheb, P.; S.; Bhausaheb, D.; S.; Sitaram, M.; D.; (2020), Overview of Nanoemulsions: Concept, Formulation and Applications, , *Indo American Journal of Pharmaceutical Research*, Vol. 10 (10), 1401-1411.

[54] Nabi, S.; U.; Shakeel, F.; Talegaonkar, S.; Ali J.; Baboota, S.; Ahuja, A.; Khar R.K., Ali M. (2007) Formulation Development and Optimization using nano emulsion technique: A Technical Note, *AAPS Pharma SciTech*, Vol. 8 (2), article 28.

[55] Nikolaev, B.; Yakovleva, L.; Fedorov, V.; Li, H.; Gao, H.' Shevtsov, M. (2023), Nano- and Microemulsions in Biomedicine: From Theory to Practice, ***Pharmaceutics***, Vol. 15(7), 1989.

[56] Jain N.; K.; Yadav, A.; K. (2006) Advances in Pharmaceutical Product Development', CBS Publishers. pp. 58.

[57] Flanagan, J.; Singh, H. (2006), Microemulsions: a potential delivery system for bio actives in food. *Crit Rev Food Sci Nutr*, Vol. 46(3), 221-37.

[58] Tenjarla, S.; (1999), Microemulsions: an overview and pharmaceutical applications. *Crit Rev Ther Drug Carrier Syst*, Vol. 16(5), 461- 521.

[59] Thorat, P.; S.; Shelke, R.; Shelke, S.; Vanarase, M. (2023), "Comparative Study of Nano Emulsion & Microemulsion", *International Journal for Research Trends and Innovation*, Vol. 8(10), 2456-3315.

[60] Rabbani, A.; Srikumar, Sh.; Niroula, A.; Khan, K. (2025), Stability and Shelf-Life Modeling of Lemongrass Essential Oil-in-Water Nanoemulsions, *European Journal of Lipid Science and Technology*, Vol.127(2), 1-7. DOI:10.1002/ejlt.202400096.

[61] Elsewedy, H.; S. (2025), Insights of Nanoemulsion as a Drug Delivery System: An Overview of Current Trends and Applications, *Ind. J. Pharm. Edu. Res*, Vol. 59(2), 1-21.

[62] Delmas ,T.; Piraux ,H.; Couffin, A.; Texier, I.; Vinet, F.; Poulin, P.;. Cates, M.; Bibette, J. (2011), How To Prepare and Stabilize Very Small Nanoemulsions, *Langmuir*, Vol. **27** (5), 1683-1692.

[63] Gupta, A.; Eral, H.; B., Hatton, T.; A., Doyle, P.; S. (2016), Nanoemulsions: formation, properties and applications, *Soft Matter Lectureship Winners*, Vol. 11.

[64] Anton, N.; Vandamme, T.; F. (2009), the universality of low-energy nano-emulsification, *International Journal of Pharmaceutics*, Vol. 377, (1–2), 142-147.

[65] Bouchaala, R.; Richert, L.; Anton, N.; *et al*.(2018), Quantifying Release from Lipid Nanocarriers by Fluorescence Correlation Spectroscopy. *ACS Omega*, Vol.3, 14333–14340. Available from: https://doi.org/10.1021/acsomega.8b01488.

[66] Li, X.; Anton, N.; Zuber, G.*; et al*. (2013), Iodinated α-tocopherol nano-emulsions as non-toxic contrast agents for preclinical X-ray imaging, *Biomaterials*, Vol. 34, 481–491.

[67] Hunter, R.; J. (1988,) Zeta Potential In Colloid Science: Principles And Applications, Academic Press, UK.

[68] Tamboli, A.; M.; M.; Tade, J.; M. (2025), "Zeta Potential: A Comprehensive Review," *International Research Journal of Pharmacy and Medical Sciences (IRJPMS)*, Vol. 8(2), 115-124.

[69] Sharif, F.; *et al*. (2021), Zeta potential changing nanoemulsions based on a simple zwitterion, *Journal of Colloid and Interface Science*, Vol. 585,126–137.

[70] Suchaoin, W.; I.; P. De Sousa, K. Netsomboon, H.; T. Lam, F.; Laffleur, A.(2016), Bernkop Schnürch, Development and in vitro evaluation of zeta potential changing selfemulsifying drug delivery systems for enhanced mucus permeation, *Int. J. Pharm*. Vol. 510 (1), 255–262.

[71] Salopek, B.; Krasic, D.; Filipovic, S. (1992), "Measurement and application of zeta-potential," *Rudarsko-geolosko-naftni zbornik*, Vol. 4(1), 147.

[72] Předota, M.; Machesky, L.; M.; Wesolowski, D.; J.; (2016), "Molecular origins of the zeta potential," *Langmuir*, Vol.. 32(40), 10189–10198.

[73] Bhatt, P.; Bhatt, T.; Jain, V.; Jain, R.; Bigoniya, P. (2024), Nanoemulsion through cold emulsification: An advanced cold manufacturing process for a stable and advanced drug delivery system*, Journal of Applied Pharmaceutical Science*, Vol. 14(05), 12-21.

[74] Bashir, A.; M.; Maqboo, S.; M. (2019), Preparation, Characterization and Applications of Nanoemulsions: An Insight, *Journal of Drug Delivery & Therapeutics*, 9(2), 520-527.

[75] Nebolisa, N.; M, Afuape, A.; R, Aigbagenode, A.; A, Onana, E.; T.; Oluwafemi, O.; F. (2024), Ntimicrobial Activity of Nanoemulsion Containing Moringa Oleifera seed protein, *European Journal of Sustainable Development Research*, 8(3), 2-11.

[76] Mitchell, M.; J.; Billingsley, M.; M.; Haley, R.; M.; Wechsler, M,; E,; Peppas, N.; A. (2020), Langer R. Engineering precision nanoparticles for drug delivery. *Nature Reviews Drug Discovery* , Vol. 4 (2),101-124.

[77] Muso-Cachumba, J.; Lara, G.; Monteiro, G.; Rangel-Yagui, C.; (2023), hallenges in estimating the encapsulation efficiency of proteins in polymersomes – Which is the best method?, *Brazilian Journal of Pharmaceutical Sciences*, Vol. 29, 1-9.

[78] Christensen, S. M.; Stamou, D. Soft Matter 2007, 3 (7), 828–836. (b) Bolinger, P.-Y.; Stamou, D.; Vogel, H. J. Am. Chem. Soc. 2004, 126, 8594– 8595. (c) Rhoades, E.; Gussakovsky, E.; Haran, G. Proc. Natl. Acad. Sci. U.S.A. 2003, 100, 3197–3202.

[79] Sun, B.; Chiu, D. T. Anal. Chem. 2005, 77, 2770–2776. (b) Edwards, K. A.; Baeumner, A. J. Talanta 2006, Vol. 68, 1432–1441.

[80] Kuyper, C.; L.; Kuo, J. S.; Mutch, S.; A.; Chiu, D.; T. Am. Chem. Soc. 2006, 128, 3233–3240. (b) Kunding, A. H.; Mortensen, M. W.; Christensen, S. M.; Stamou, D. Biophys. J. 2008, 95, 1176–1188.

[81] Tan, A.; L, *et al*. (2005) Essential tension and constructive destruction: the spindle checkpoint and its regulatory links with mitotic exit. *Biochem J*, Vol. 386(1), 1-13.

[82] Turki, S.; Mohammed, N.; Muhialdin, B.; Hussin, A. (2024), Nnoemulsion of Amber rice bran oil (Oryza sativa L.), characterization and properties, *Tikrit Journal for Agricultural Sciences*, Vol. 24 (2),260-279.

[83] Xu, Y.; Hanna, M.; A. (2026), Electrospray encapsulation of water-soluble protein with polylactide Effects of formulations on morphology, encapsulation efficiency and release profile of particles, *International Journal of Pharmaceutics*, Vol. 320 (2006) 30–36.

[84] Venkata, N.; N.; Prasanna, P.; M.; Sakarkar, S.; N.; Prabha, K.; S.; Ramaiah, P.; S.; Srawan, G.; Y. (2010), Microencapsulation techniques, factors influencing encapsulation efficiency, *Journal of Microencapsulation*, Vol. 27(3),187–197.

[85] Yeo, Y.; Park, K. (2004), Control of encapsulation efficiency and initial burst in polymeric microparticle systems. *Arch Pharm Res*, Vol. 27(1):1–12.

[86] Teixeira, M.; C. Severino, P.; Andreani, T.; Boonme, P.; Santini, A.; Silva, A.; M. Souto, E.; B. (2017), d-α-Tocopherol nanoemulsions: Size properties, Rheological Behavior, Surface Tension, Osmolarity and Cytotoxicity, *Saudi Pharmaceutical Journal*, Vol. 25(2), 231-235.

[87] Gupta, A.; Eral, H.; B, Hatton, T.; A.; *et al*. (2016), Nanoemulsions: formation, properties and applications. *Soft Matter*. Vol. 12, 2826–2841.

[88] Chen, P.; Prokop, R.; M, Susnar, S.; S.; *et al*. (1998), Proteins at Liquid Interfaces. Möbius D, Miller R, Editors. *Amsterdam*: Elsevier Ltd.

[89] Thakur, A.; Walia, M.; K.; Hari Kumar, S.; L. (2013), Nanoemulsions in Enhancement of Bioavailability of Poorly Soluble drugs: A Review, *Pharmacophore* , Vol. 4 (1), 15-25.

[90] Zhou, Y., (2022), Research Progress in Preparation, Stability and Application of Nanoemulsion, *Journal of Physics: Conference Series*, Vol. 2152 (2022), 1-8.

[91] Hasenhuettl, G.; L. and Hartel, R.; W. Food Emulsifiers and Their Applications, Second Edition, 2008, Springer, New York, USA.

[92] Ogbonna, C.; *et al*. (2025), mulsion Concept, Types and Techniques: A Review, *World News of Natural Science*, Vol. 63(2), 465-476.

[93] Hang, J.; Novel Emulsion-Based Delivery Systems, Faculty of The Graduate School of the University of Minnesota, Master Thesis, 2011.

[94] Singh, S.; K.; Verma, P.; R.; P.; Balkishen Razdan, B. (2010), Development and characterization of a lovastatin loaded selfmicroemulsifying drug delivery system, *Pharmaceutical Development and Technology*, Vol.15(5), 469-483.

[95] Rajalakshmi, R.; Mahesh, K.; Ashok Kumar, C.; K.; A. (2011), Critical Review on Nano Emulsions, *International Journal of Innovative Drug Discovery*, Vol. 1(1), 1-8.

[96] Saini, R.; Gay, J.; Adhikary, S. (2024), Nano Emulsion Type, Theories, And Factors Influencing: A Review of Nano Emulsion Formulation, *International Journal of Creative Research Thoughts (IJCRT)*, Vol. 12(3), 466-472.

[97] Pavoni, L.; Perinelli , D.; R, Bonacucina, G.; Cespi, M.; Palmieri, G.; F. (2020), An Overview of Micro- and Nanoemulsions as Vehicles for Essential Oils: Formulation, Preparation and Stability, *Nanomaterials*, Vol.10 (135), 1-24.

[98] Brouwer, W.; M.; El-Aasser, M.; S. Vanderhoff, J.; W. (1986), The role of water solubility of the oil phase in the formation of miniemulsions, *Colloids and Surfaces*, Vol. 21, 69-86.

[99] Khalil, R.; M.; Basha, M.; Kamel, R. (2015), Nanoemulsions as parenteral drug delivery systems for a new anticancer benzimidazole derivative: formulation and *in-vitro* evaluation, *Egyptian Pharmaceutical Journal*, Vol. 14,166–173.

[100] Zainab, S.; A. (2020), Review on Nanoemulsion: Preparation and Evaluation, *International Journal of Drug Delivery Technology*, Vol. 10(1), 188-189.

[101] Anton, N.; Vandamme, T.; F. (2016),Nano-Emulsions. In: Aliofkhazraei M, editor. Handb Nanoparticles . Cham: *Springer International Publishing*, 93–116. Available from: https://doi.org/10.1007/978-3-319-15338-4_2.

[102] Wulff-Pérez, M.; Barrajón-Catalán, E.; Micol, V.; *et al*.(2014), In vitro duodenal lipolysis of lipidbased drug delivery systems studied by HPLC–UV and HPLC–MS. *Int J Pharm,* Vol. 465, 396–404. Available from: https://www.sciencedirect.com/science/article/pii/S0378517314001203.

[103] Chung, C.; McClements, D.; J. Chapter 17 - Characterization of Physicochemical Properties of Nanoemulsions: Appearance, Stability, and Rheology. In: Jafari SM, McClements DJ, editors. Nanoemulsions Academic Press; 2018. p. 547–576. Available from:https://www.sciencedirect.com/science/article/pii/B9780128118382000175.

[104] Pavoni, L.; Benelli, G.; Maggi, F.; Bonacucina, G. (2019),Green nanoemulsion interventions for biopesticide formulations. *In Nano-Biopesticides Today and Future Perspectives*; Academic Press: Cambridge, MA, USA, pp. 133–160. ISBN 978-0-12-815829-6.

[105] Donsì, F.; Annunziata, M.; Vincensi, M.; Ferrari, G.(2012), Design of nanoemulsion-based delivery systems of natural antimicrobials: Effect of the emulsifier, *Journal. Biotechnol.* Vol. *159*, 342–350. [CrossRef].

[106] Terjung, N.; Löffler, M.; Gibis, M.; Hinrichs, J.; Weiss, J.(2012), Influence of droplet size on the efficacy of oil-in-water emulsions loaded with phenolic antimicrobials. *Food Funct.* Vol. *3*, 290–301. [CrossRef].

[107] Li, Y.; Le Maux, S.; Xiao, H.; McClements, D.J.; (2009), Emulsion-based delivery systems for tributyrin, a potential colon cancer preventative agent, *J. Agric. Food Chem.* Vol. 57, 9243–9249. [CrossRef].

[108] Wooster, T.; J.; Golding, M.; Sanguansri, P. (2008), Impact of Oil Type on Nanoemulsion Formation and Ostwald Ripening Stability. *Langmuir,* Vol. 24, 12758–12765. [CrossRef] [PubMed].

[109] Donsì, F.; Cuomo, A.; Marchese, E.; Ferrari, G. (2014), Infusion of essential oils for food stabilization: Unraveling the role of nanoemulsion-based delivery systems on mass transfer and antimicrobial activity. *Innov. food Sci. Emerg. Technol.* Vol. *22*, 212–220. [CrossRef].

[110] Tai, H.; T.; Nardello-Rataj, V.; (2001),The main surfactants used in detergents and personal care products, *Oléagineux Corps gras Lipides*, Vol. 8(2), 141-144.

[111] Silva, H.; D.; Cerqueira, M.; A.; Vicente, A.; A. (2015), Influence of surfactant and processing conditions in the stability of oil-in-water nanoemulsions, *Journal of Food Engineering*, Vol. 167, Part B, 89-98.

[112] Mushtaq, A.; *et al*. (2023). Recent insights into Nanoemulsions: Their preparation, properties and applications, *Food Chem X*, Vol. 18, 100684.

[113] Pardeshi, S.; Gholap, A.; Sen, N.; Khandagale, P. (2025), Prospects and applications of nanoemulsions in

cosmeceuticals including those for text and data mining, AI training, and similar technologies, In book: Nanotechnology in Cosmeceuticals Advances, Challenges and Future PerspectivesPublisher, 2025, *Elsevier*.

[114] Sanatkaran, N., Masalova, I., Malkin, A., (2014), Effect of surfactant on interfacial film and stability of highly concentrated emulsions stabilized by various binary surfactant mixtures, *Colloids and Surfaces A: Physicochemical and Engineering Aspects*, Vol. 461(5), 85-91.

[115] Vedhachalam, D., Ravichandran, V. (2011), Nanoemulsions: As Modified Drug Delivery Tool, *International Journal of Comprehensive Pharmacy*, Vol. 2 (04), 1-6.

[116] Becher, P. (1977), "Emulsions: Theory and Practice", Reprint, Krieger Publication.

[117] Proceedings, (1978), World Conference on Soaps and Detergents, *Journal of the American Oil Chemists Society*, Vol. 55(1).

[118] Raza, M.; Q.; N. Kumar, R. (2016), Surfactants for Bubble Removal against Buoyancy. ScientificReports, 6: 19113.Sharma, S.N., N.K. Jain, 1985. A text book of professional pharmacy. Vallabh Prakashan,1st edn, 201.

[119] Shaikh, N.; M.; Vijayendra, S.;M.; Nagoba, Sh, N.; Shaikh, A.; L. (2019), A Review on Current Trends of Nanoemulsion, *Indo American Journal of Pharmaceutical Sciences*, Vol. 6 (1), 721-732.

[120] Widyaningrum, I .; Triyoga, E.; F.; Wibisono , N.; Kusumawati , Sh.; Widiyana, A.; P. (2023), Type of Cosurfactant Effects on Particle Size in Nanoemulsion Drug Delivery Systems, *East Asian Journal of Multidisciplinary Research (EAJMR)*, Vol. 2 (9) , 3811-3820.

[121] Smail, Sh.; S. Ghareeb, M.; M. Omer, H.; K. Al-Kinani, A.; A. Alany, R.; G. (2021), Studies on Surfactants, Cosurfactants, and Oils for Prospective Use in Formulation of Ketorolac Tromethamine Ophthalmic Nanoemulsions, *Pharmaceutics***,** Vol. *13*(4), 467.

[122] Choudhury, H.; Gorain, B.; Karmakar, S.; Biswas, E.; Dey, G.; Barik, R.; Mandal, M.; Pal.; K. (2014), Improvement of cellular uptake, in vitro antitumor activity and sustained release profile with increased bioavailability from a nanoemulsion platform. *Int. J. Pharm,* Vol. 460, 131–143. [Google Scholar] [CrossRef].

[123] Mansouri, S.; Pajohi-Alamoti, M.; Aghajani, N.; Bazargani-Gilani, B.(2021), Stability and antibacterial activity of Thymus daenensis L. essential oil nanoemulsion in mayonnaise, *J. Sci. Food Agric*, Vol. 101 , 3880–3888, https://doi.org/10.1002/jsfa.11026.

[124] Arora, R.; Aggarwal, G.; Harikumar, S.; L.; Kaur, K.; Keck, C.; M. (2014), Nanoemulsion based hydrogel for enhanced transdermal delivery of ketoprofen, *Adv. Pharmaceut. Sci*, Vol. 468456, https://doi.org/10.1155/2014/468456.

[125] Shi, Y.; Zhang, M.; Chen, K.; Wang, M. (2022), Nano-emulsion prepared by high pressure homogenization method as a good carrier for Sichuan pepper essential oil: *Preparation, stability, and bioactivity*. LWT, Vol.154, 112779. [Google Scholar] [CrossRef].

[126] Ushikubo, Y.; Cunha , R.; (2014), Stability mechanisms of liquid water-in-oil emulsions, *Food Hydrocolloids*, Vol. 34, 145-153.

[127] Zhou, Y.; *et al.* (2020), Liquid Thermo-Responsive Smart Window Derived from Hydrogel, *Joule*, Vol. 4(11), 2458-2474.

[128] Zhu, P., Wang, L., (2025), Thermo-induced reversible nanoemulsification, *Matter*, Vol. 8 (7), 102103.

[129] Ren, G., Li, B., Ren, L., Lu, D., (2021), pH-Responsive Nanoemulsions Based on a Dynamic Covalent Surfactant, *MDPI -Nanomaterials,* Vol.11, (1390), 1-14. *https://doi.org/10.3390/nano11061390* *https://www.mdpi.com/journal/nanomaterials*.

[130] Shoviantari, F.; Z. Liziarmezilia, A. Bahing, and L. Agustina, U. (2020), Aktivitas Tonik Rambut Nanoemulsi Minyak Kemiri (Aleurites moluccana L.), *Jurnal Farmasi Dan Ilmu Kefarmasian Indonesia*, Vol. 6, (2) .

[131] Rahman, S.; Mojiono, M.; Fansuri, H.; Alhamal, B.,m S. (2024), Nanoemulsion stability of Javanese long pepper extract (Piper retrofractum Vahl): Effects of emulsion system and storage temperature, *BIO Web of Conferences* , Vol. 146(01055), 1-10.

[132] Dungan , S.; Tai , B.; Gerhardt , N. (2003),Transport mechanisms in the micellar solubilization of alkanes in oil-in-water emulsions, *Colloids and Surfaces A Physicochemical and Engineering Aspects*, Vol. 216(1-3),149-166.

[133] Liu, Ch.; Wu, Ch.; (2010), Optimization of nanostructured lipid carriers for lutein delivery, *Colloids and Surfaces A Physicochemical and Engineering Aspects* , Vol. 353(2-3),149-156.

[134] Haahr, A.; M.; LP Bredie, W.; Stahnke, A.; Jensen, B.;(2000), lavour release of aldehydes and diacetyl in oil/water systems, Food Chemistry, Vol. 71(3), 355-362.

[135] Li, H.; Po; Lu, W.; Ch. (2016), Effects of storage conditions on the physical stability of d-limonene nanoemulsion, *Food Hydrocolloids*, Vol. 53, 218-224.

[136] McClements, D.; J.; (2021), Advances in Edible Nanoemulsions: Digestion, bioavailability, and potential toxicity. *Prog. Lipid Res*. Vol. 81, 101081. [Google Scholar] [CrossRef] [PubMed].

[137] Çinar, K., (2017), A Review on Nanoemulsions: Preparation Methods and Stability, *Trakya University Journal of Engineering Sciences*, Vol. 18(1): 73-83.

[138] Setya, S.; Talegaonkar, S.; Razdan, B.; K. (2014), Nanoemulsions: Formulation Methods and Stability Aspects, *World Journal of Pharmacy and Pharmaceutical Sciences*, Vol. 3, 2214-2228.

[139] Anton, N.,; Benoit, J.; P.; Saulnier, P.(2008), Design and production of nanoparticles formulated from nano-emulsion templates-A review, *Journal of Controlled Release,* Vol. 128, 185-199.

[140] Sokolov, Yu.; V. (2014), Nanoemulsion formation by low-energy methods: a review, News of Pharmacy, Vol. 3(79), 16-19.

[141] Anton, N.; Vandamme, T.; F. (2009). The Universality of Low-Energy Nanoemulsification, Journal of Pharmaceutics, Vol. 377 (1-2), 142-147.

[142] Komaiko, J.; McClements, D.; J. (2015), Low-energy formation of edible nanoemulsions by spontaneous emulsification: Factors influencing particle size. *J. Food Eng*. Vol. 146,122–128. doi: 10.1016/j.jfoodeng.2014.09.003. [DOI] [Google Scholar].

[143] Bouchemal, K.; Briançon, S.; Perrier E.(2004), Nano-emulsion formulation using spontaneous emulsification: solvent, oil and surfactant optimization, *International Journal of Pharmaceutics*, Vol. 280(1–2), 241-251.

[144] Sole, I.; Solans, C.; Maestro, A.; Gonzalez, C.; Gutierrez, J.; M.(2012), Study of nano-emulsion formation by dilution of microemulsions, *Journal of Colloid and Interface Science*, Vol. 376, 133–139.

[145] McClements, D.; J.; Rao, J. (2011), Food-Grade Nanoemulsions: Formulation, Fabrication, Properties, Performance, Biological Fate, and Potential Toxicity, *Critical Reviews in Food Science and Nutrition*, Vol. 51, 285–330.

[146] Ozawa, K.; Solans, C.; Kunieda, H.; (1997) Spontaneous formation of highly concentrated oil-inWater Emulsions. *J Colloid Interface Sci*, Vol.188 (2), 275-281.

[147] Zhang, L.; Hayes, D.; G.; Chen, G.; Zhong, Q.(2013), Transparent dispersions of milk-fat-based nanostructured lipid carriers for delivery of β-carotene. *J Agric Food Chem*, Vol. 61(39), 9435-43.

[148] Jintapattanakit, A. (2018), Preparation of nanoemulsions by phase inversion temperature (PIT) method, *Pharm Sci Asia*, Vol. 45 (1), 1-12. DOI : 10.29090/psa.2018.01.001.

[149] McClements, D.; J. (2011), Edible nanoemulsions: fabrication, properties, and functional performance. *Soft Matter*, Vol. 7(6), 2297- 316.

[150] Solans, C.; Solé, I. (2012), **Nano-Emulsions Formation by Low-Energy Methods**, *Current Opinion in Colloid & Interface Science*, Vol. 17, 246-254.

[151] Yang, Y.; Leser, M., E. Sher, A.; A.; McClements, D.; J. (2013), Formation and stability of emulsions using a natural small molecule surfactant: Quillaja saponin (Q-Naturale®), *Food Hydrocolloids*, Vol. 30(2), 589-596.

[152] Fernandez, P.; André, V.; Rieger, J.; Kühnle, A. (2004), Nano-emulsion formation by emulsion phase inversion, *Colloids and Surfaces A: Physicochemical and Engineering Aspects*,Vol. 251(1–3), 53-58.

[153] Yang, Y.; McClements, D.; (2013), Vitamin E and Vitamin E acetate solubilization in mixed micelles: Physicochemical basis of bioaccessibility, *Journal of Colloid and Interface Science*, Vol. 405, 312-321.

[154] Ostertag, F.; Weiss, J.; McClements, D.; J. (2012), Low-energy formation of edible nanoemulsions: factors influencing droplet size produced by emulsion phase inversion, *J Colloid Interface Sci*, Vol. 388(1), 95-102.

[155] Jahanzad, F.; Crombie, G.; Inne, R.; Sajjadi, Sh. (2009),Catastrophic phase inversion via formation of multiple emulsions: A prerequisite for formation of fine emulsions, *Chemical Engineering Research and Design*, Vol. 87(4), 492-498.

[156] Preziosi, V.; Perazzo, A.; Caserta , S.; a Tomaiuolo,G.; Guido, S. (2013), Phase Inversion Emulsification, *Chemical Engineering Transactions*, Vol. 32, 1585-1590.

[157] Akay, G. (1998), Flow-induced phase inversion in the intensive processing of concentrated emulsions, *Chemical Engineering Science*, Vol. 53(2), 203-223.

[158] Fernandez, P.; Andre, V.; Rieger, J.; Kuhnle, A. (2004), "Nano-emulsion formation by emulsion phase inversion, *Colloids and Surfaces A*, Vol. 251, 53-58.

[159] Thakur, R.; K.; Villette, C.; Aubry, J.; M.; Delaplace, G. (2008), Dynamic emulsification and catastrophic phase inversion of lecithin-based emulsions, *Colloids and Surfaces A: Physicochemical and Engineering Aspects*, Vol. 315(1-3), 285-293.

[160] Rao, J.; McClements, D.; J. (2010), Stabilization of phase inversion temperature nanoemulsions by surfactant displacement, *J. Agric. Food. Chem,* Vol. 58(11), 7059-7066.

[161] Safaya , M.; Rotliwala , Y.; (2020), Nanoemulsions: A review on low energy formulation methods, characterization, applications and optimization technique, *Materials Today Proceedings*, Vol. 27,454-459.

[162] Gaulin, A. (1904), System for intimately mixing milk. US756953A. . George, A., Sanjay, M.R., Srisuk, R., Parameswaranpillai, J., Siengchin, S., 2020. A US753792A 1904-03-01 Process of treating milk or similar liquids. KR20200025824A 2020-03-10 A Servo.

[163] Ghazali, N.; S., M.; Zakaria, R. (2025), Preparation of essential oil nanoemulsions and its incorporation in chitosanbased edible coating on guava, *Food Research*, Vol. 9 (1), 133 – 145.

[164] Shrivastava, A.; A REVIEW ON PEPPERMINT OIL(2009), *Asian Journal of Pharmaceutical and Clinical Research* , Vol. 2(2):27-33.

[165] Barzegar, H., Mehrnia, M.; A., Nasehi, B.; Alipour, M.(2018), Fabrication of peppermint essential oil nanoemulsions by spontaneous method: Effect of preparing conditions on droplet size. *Flavour and Fragrance Journal*, Vol. 33(5), 351–356. doi: 10.1002/ffj.3455. [DOI] [Google Scholar].

[166] Wang, L.; Zhang, Y. (2017), Eugenol Nanoemulsion Stabilized with Zein and Sodium Caseinate by Self-Assembly, *J. Agric. Food. Chem*, Vol. 65, 2990–2998. doi: 10.1021/acs.jafc.7b00194. [DOI] [PubMed] [Google Scholar].

[167] Syapitri, H.; Panduragan, S.; L.; Babu, S.; Purwandari, V.; Thaib, C.; M. (2022), Preparation of Black Cumin Extract Nanoemulsion Using the Oil Phase of Virgin Coconut Oil (VCO) Tween 80 and PEG 400 Surfactants, *Mal J Med Health Sci* ,Vol. 18(SUPP2), 2-5.

[168] Purkait, A.; Worede, R.; E.; Baral, D. (2020), Development of nanoemulsion formulation of mustard oil, its chemical characterization and evaluation against post-harvest anthracnose pathogens, *Indian Phytopathology*, Vol. 73(20).

[169] Ghosh, V.; Mukherjee, A.(2014), Chandrasekaran, N. Eugenol-Loaded Antimicrobial Nanoemulsion Preserves Fruit Juice against, Microbial Spoilage. Colloids Surf., B 2014, Vol. 114, 392– 397, DOI: 10.1016/j.colsurfb.2013.10.034.

[170] Jintapattanakit, A.; Hasan, H.M.; Junyaprasert, V.; B. (2018), Vegetable oil-based nanoemulsions containing curcuminoids: Formation optimization by phase inversion temperature method, *J. Drug Deliv. Sci. Technol*. Vol. 44, 289–297. doi: 10.1016/j.jddst.2017.12.018. [DOI] [Google Scholar].

[171] Su, D.; Zhong, Q.(2016), Lemon oil nanoemulsions fabricated with sodium caseinate and Tween 20 using phase inversion temperature method, *J. Food Eng*. Vol. 171, 214–221. doi: 10.1016/j.jfoodeng.2015.10.040. [DOI] [Google Scholar].

[172] Hasan, H.; M.; Leanpolchareanchai, J.; Jintapattanakit, A. (2014), Preparation of Virgin Coconut Oil Nanoemulsions by Phase Inversion Temperature Method, Advanced *Materials Research* ,Vol. 1060, 100-102.

[173] Silva, K., J., (2024), Low Energy Nanoemulsification of Origanum Vulgare Essential Oil: Factors of Influence, *PlumX Metrics*, 26. Available at SSRN: https://ssrn.com/abstract=5019924 or http://dx.doi.org/10.2139/ssrn.5019924.

[174] Hassan, Kh.; M., A.; Mujtaba, Md.; A.; (2017), ORAL NANO-EMULSION OF FENUGREEK OIL FOR TREATMENT OF DIABETES, *International Journal of Pharmaceutical Sciences and Research* (IJPSR), Vol. 8(7): 3151-3154.

[175] Mehmood, T., (2015), Optimization of the canola oil based vitamin E Nanoemulsions stabilized by food grade mixed surfactants using response surface methodology, *Food Chemistry*, Vol. 183 , 1–7.

[176] Yotsawimonwat, S.; Okonoki, S.; Krauel, J.; Sirithunyalug, B.; Rades, T (2006), Characterisation of microemulsions containing orange oil with water and propylene glycol as hydrophilic components, *Pharmazie*, Vol. 61, 920-926.

[177] Wang, X , *et al*. (2024), Construction and characterization of sesame meal-stabilized Pickering high internal phase emulsions and their application in cake production, *International Journal of Biological Macromolecules*, Vol. 281, Part 2, 136364.

[178] Koroleva, M.; Yurtov, E. (2012), Nanoemulsions: The properties, methods of preparation and promising applications, *Russian Chemical Reviews*, Vol. 81(1),21.DOI:10.1070/RC2012v081n01ABEH004219.

[179] Al-Edresi, S.; Saringat, H. (2009), Formulation and stability of whitening VCO-in-water nano-cream, *International Journal of Pharmaceutics* , Vol. 373(1-2),174-8.

[180] Li, C.; Mei, Z.; Liu, Q.; Wang, J.; Xu, J.; Sun, D. (2010), Formation and properties of paraffin wax submicron emulsions prepared by the emulsion inversion point method, *Colloids and Surfaces A: Physicochemical and Engineering Aspects*, Vol. 356(1–3) , 71-77.

[181] Semenoglou, I.; Katsouli, M.; Giannakourou, M.; Taoukis, P. (2025), Effect of High-Pressure Homogenization and Wall Material Composition on the Encapsulation of Polyunsaturated Fatty Acids from Fish Processing, *Molecules,* Vol. 30(7), 1434.

[182] Yukuyama, M.; N.; Kato, E.; T., Araujo, G.; Löbenberg, R. (2019),Olive oil nanoemulsion preparation using high-pressure homogenization and D-phase emulsification – A design space approach, *Journal of Drug Delivery Science and Technology*, Vol. 49, 622-631.

[183] Aouf, A.; Ali, H.; Al-Khalifa, A.; R.; Mahmoud, Kh., F.; Farouk, A. (2020), Influence of Nanoencapsulation Using High-Pressure Homogenization on the Volatile Constituents and Anticancer and Antioxidant Activities of Algerian Saccocalyx satureioides Coss. et Durieu, *Molecules*, Vol. 25(20),4756. doi: 10.3390/molecules25204756.

[184] Liu, X.; Chen, L.; Kang, Y.; He, D.; Yang, B.; Wu, K. (2021), Cinnamon Essential Oil Nanoemulsions by High-Pressure Homogenization: Formulation, Stability, and Antimicrobial Activity, LWT, Vol. 147, 111660.

[185] Agustin, R.; Silsadilla, A.; A.; Ilsadilla, A., Ismed F. (2025),), Nanoemulsiion Formulation of Cardamom Essential Oil (AMOMUM COMPACTUM S.) and it's in Vitro Anti-Aging Activity, *International Journal of Applied Pharmaceutics*, Vol. 17, (1), 132 – 137.

[186] Wong, S.; Kamari, A.; Abdullah, N.; Yusof , N.; Sutapa, W. (2025), Preparation and Characterization of Bergamot Essential Oil Nanoemulsion, *Earth and Environmental Science*, Vol. 1425, 1-12.

[187] Mathias, G.; *et al,* (2025), Encapsulation of curcumin in groundnut oil-in-water (O/W) nanoemulsions: Experimental analysis and molecular dynamics simulations**,** *Ultrasonics Sonochemistry*, Vol. 123, 107686.

[188] Battisti, A.; P.; *et al*. (2025), Antifungal nanoemulsions based on basil essential oil stabilized with saponins extracted from Quillaja lancifolia, *Journal of Molecular Liquids,* Vol. 443(1), 129151.

[189] Giang, H.; Phuong Nhi, T.; Tuan, H. (2024), Preparation of Essential Oil Nanoemulsion With Cellulose Derivatives, *Tạp chí Khoa học Đại học Công Thương*, Vol. 24(5), 114-125.

[190] Noshad, M., Mohebbi, M., Koocheki, A., & Shahidi, F. (2016). Influence of Interfacial Engineering on Stability of Emulsions Stabilized with Soy Protein Isolate. *Journal of Dispersion Science and Technology, 37*(1), 56-65.

[191] Vasconcelos, N.; F.; Agrelli, A.; Silva, C.; S.; Marques, C., L. (2025), Multifunctional anionic nanoemulsion with linseed oil and lecithin: a preliminary approach for dry eye disease, *Beilstein Journal of Nanotechnology*, Vol. 16, 1711-1733.

[192] Morales, D., Solans, C.; Gutiérrez, J., M.; Garcia-Celma, M.; J.; Olsson U.; (2006), Oil/water droplet formation by temperature change in the water/C16E6/mineral oil system, *Langmuir*, Vol. 22, 3014–3020. doi: 10.1021/la052324c. [DOI] [PubMed] [Google Scholar][Ref list].

[193] Censi, N.; Julio, L.; M., Tomás, N.; C. (2022), Chia Oil-in-Water Nanoemulsions Produced by Microfluidization , *Biology and Life Sciences Forum*, Vol. 17(1),14.

[194] Ganesan, P.; *et al.* (2018), Microfluidization trends in the development of nanodelivery systems and applications in chronic disease treatments, *International Journal of Nanomedicine* , Vol. 13, 6109–6121.

[195] Eid, A.; M.; Elmarzugi, N.; A.; El Enshasy, H.; (2013), Preparation and Evaluation of Olive Oil Nanoemulsion Using Sucrose Monoester, *International Journal of Pharmacy and Pharmaceutical Sciences* , Vol. 5, 434-440.

[196] El-Naby, A.; Mahmoud, F.; El-Habal, N.; (2020), Efficacy of prepared Castor Oil Nanoemulsion Formulation against Rice Weevil Sitophilus Oryzae on Stored Wheat Grain and Its Acute Toxic effect on Albino Rats, *gyptian Scientific Journal of Pesticides (Egy Sci J Pestic)*, Vol. 6 (4), 33 – 44 .

[197] Ghotbi, R.; S.; Khatibzadeh, M.; Kordbacheh, Sh. (2014), Preparation of Neem Seed Oil Nanoemulsion, Proceedings of the 5 th International Conference on Nanotechnology: Fundamentals and Applications Prague, Czech Republic, 11-13.

[198] Liew, S.; N.; Uthumporn, U.; Alias, A.; K.; Tan, T.; B. (2020), Physical, morphological and antibacterial properties of lime essential oil nanoemulsions prepared via spontaneous emulsification method, *LWT*, Vol. 128(2),109388.Https://doi.org/10.1016/j.lwt.2020.109388.

[199] Federica, R.; *et al*. (2022), Neem Oil or Almond Oil Nanoemulsions for Vitamin E Delivery: From Structural Evaluation to in vivo Assessment of Antioxidant and Anti-Inflammatory Activity, *International Journal of Nanomedicine*, Vol.17, 6447-6465.

[200] Bajac, J.; D.; Nikolovski, B.; G.; Mestrovic, A.; G.; Lončarević, I.; S.; Petrović, J.; S. (2019), Determination of Optimal Ultrasound Conditions for Preparation of O/W Emulsions With Encapsulated Juniper Berry Essential Oil (Juniperus communis L.), *Acta periodica technologica*, Vol. (50), 23-32.

[201] Ochoa, A.; A.,Hernandez-Becerra, J.; A. Cavazos-Garduno, A.; Vernon-Carter , E.; J.; Garcia, H.; S. (2016), Preparation and Characterization of Curcumin **nanoemulsions** Obtained by Thin-Film Hydration Emulsification and Ultra sonication Methods, *Revista Mexicana de Ingeniería Química*, Vol. 15(1), 79-90.

[202] Abdelmawla , N.; A.; Mohafrash , S.; M.; El Sharkawy , A.; Z.; Farghaly, D.; S.; Mossa, A.; T. (2025), Preparation of Citronella and Thyme Essential Oil Nanoemulsions and Their Insecticidal Efficiency against Mosquitoes (Culex pipiens), *Egyptian Journal of Chemistry*, Vol. 69(2), 245 – 253.

[203] Faradisa, H.; Cahyani, M., Rosyidi, V.; Hidaya, M. (2020), The formulation of ginger oil nanoemulsions of three varieties of ginger (Zingiber officinale Rosc.) as natural antioxidant, *Journal of Research in Pharmacy* , Vol. 24(6),914-924.

[204] Farshbaf-Sadigh, A.; Jafarizadeh-Malmiri, H.; Anarjan, N.; Najian, Y. (2021), Preparation ofginger oil in water nanoemulsion using phase inversion composition technique:Effects of stirring and water addition rates on their physico-chemical properties and stability, *Z. Fur Phys. Chem*, Vol. 235 (2021) 295–314, https://doi.org/10.1515/zpch-2019-1427.

[205] Gerb er, M.; Oosthuysen, E.; Jaarsveld, J.; Jaarsveld, J.; Shahzad, Y. (2023), Grapeseed oil nanoemulsions and nanoemulgels for transdermal delivery of a series of statins, *Journal of Drug Delivery Science and Technology*, Vol. 88,104900.

[206] Abdelraouf , ·W.; Abd-alla , A .; El-Desouky· Elrefaey, A. (2023), Preparation and characterization Nanoemulsion Moringa Oil by Whey Protein and Application in Ice Cream as a Food Model , *Egyptian Journal of Dairy Science*, Vol. 36(196).

[207] Liu, M., et al. (2022), Garlic essential oil in water nanoemulsion prepared by high-power ultrasound: Properties, stability and its antibacterial mechanism against MRSA isolated from pork, *Ultrasonics Sonochemistry* , Vol. 90, 106201.

[208] Muñoz, A.; Echeverry, S.; Novoa, D. (2022), Ultrasonic nanoemulsification of Aloe vera: formulation, optimization, and characterization , *J. Excipients and Food Chem*,13 (2), 48-63.

[209] Javanmardi, M.; Fallah, A.; Abbasvali, M. (2021), Effect of safflower oil nanoemulsion and cumin essential oil combined with oxygen absorber packaging on the quality and shelf-life of refrigerated lamb loins, *LWT*, Vol. 147,111557.

[210] Nirmala, J.; Durai, L.; Gopakumar, V.; Nagarajan, R. (2020), Preparation of Celery Essential Oil-Based Nanoemulsion by Ultrasonication and Evaluation of Its Potential Anticancer and Antibacterial Activity, *International Journal of Nanomedicine,* Vol. 15, 7651-7666.

[211] Omidi, M.; *et al*.(2025), Lavender essential oil nanoemulsion gel as skin lightener: green formulation, full characterization, anti-melanogenesis effect, and in-vitro/in-vivo safety profile assessment, *Nanomedicine Journal*, Vol. 12 (3), 404-420.

[212] Firoozi, M.; Rezapour-Jahani, S.; Shahvegharasl, Z.; Anarjan, N.; (2020), Ginger essential oil nanoemulsions: Preparation and physicochemical characterization and antibacterial activities evaluation, *Journal of Food Process Engineering*, Vol. 43, (8).

[213] Moraes-Lovison, M.; *et al*.(2017), Nanoemulsions encapsulating oregano essential oil: Production, stability, antibacterial activity and incorporation in chicken pate, *Food Science and Technology*, Vol. 77 (2017) 233-240.

[214] Pereira, F.; S. Barroso, A.; Rosa, H.; V, Fernandes, C.; P. (2021), ALow Energy Approach for the Preparation of Nano-Emulsions with a High Citral-Content Essential Oil, *Molecules*, Vol. 26(12), 3666.

[215] Akshay, Parihar, A.; Prajapati, P., G. Macwan, M., Pal, S. (2023), A comprehensive review on applications, preparation & characterization of nanoemulsion, *IP International Journal of Comprehensive and Advanced Pharmacology*, Vol. 8(2),104-111. https://doi.org/10.18231/j.ijcaap.2023.018.

[216] Çinar, K. (2017), A Review on Nanoemulsions: Preparation Methods and Stability, *Trakya University Journal of Engineering Sciences*, Vol. 18(1), 73-83.

[217] Gupta, P.; K.; Pandit, J.; K.; Kumar, A.; Swaroop, P.; Gupta, S. (2010), Pharmaceutical Nanotechnology Novel Nanoemulsion–High Energy Emulsification Preparation, Evaluation and Application, *The Pharma Research*, Vol. 3, 117-138.

[218] Sharma, N.; Mishra, Sh.; Sharma, S.; Deshpande, R.; (2013), Preparation and Optimization of Nanoemulsions for

targeting Drug Delivery, *International Journal of Drug Development and Research*, Vol. 5(4),37-48.

[219] Schultz, P.; H.; Zárate, M.; Hames, B.; Koeberl, Ch.; Bunch, Th.; Storz, D.; Renne, P.; Wittke, J. (2004), The Quaternary impact record from the Pampas, Argentina, Earth and Planetary Science Letters, Vol. 219(3–4),1, 221-238.

[220] Peng, Y.; Bie, Sh.; Cai, Sh.; Zhou, L.; Guo, Ch. (2025), Effects of high-pressure homogenization on phenolics profile, antioxidant activity, α-glucosidase inhibitory activity, and insulin resistance of peach juice during simulated gastrointestinal digestion, *Food Chemistry*: X, Vol. 26,102263.

[221] Taha, A.; Ahmed, E.; Ismaiel, A. (2020), Ultrasonic emulsification: An overview on the preparation of different emulsifiers-stabilized emulsions, *Trends in Food Science & Technology*, Vol. 105, 363–377.

[222] Leong, S. H., Zhou, M., Kukan, N., Ashokkumar, m., Gregor, J., O,(2017), Preparation of water-in-oil-in-water emulsions by low frequency ultrasound using skim milk and sunflower oil, *Food Hydrocolloids*, Vol. 63, 685-695

[223] Ashokkumar, M. (2011), The characterization of acoustic cavitation bubbles – An overview, *Ultrasonics Sonochemistry*, Vol. 18(4), 864-872.

[224] Awad, T.; S.; Moharram, H.; A.; Shaltout , O.; E.; Asker, D.; Youssef, M.; M. (2012), Applications of ultrasound in analysis, processing and quality control of food: A review, *Food Research International*, Vol. 48(2), 410-427.

[225] Pouton, C.; W. (1985), "Self-emulsifying drug delivery system, assessment of the efficiency of emulsification", *Int J Pharm*, Vol. 27, 335-48.

[226] Tadros, T.; F. Becher, P. (1983), "Encyclopedia of Emulsion Technology", Marcel Dekker, New York, 129-285.

[227] Donsi, F. (2018), Applications of nanoemulsions in foods,‖ in Nanoemulsions: Formulation, Applications, and Characterization, eds S. M. Jafari and D. J. McClements (Cambridge, MA: Academic Press), 349–377

[228] Alkilani , A.; McCrudden , M.; Donnelly , R. (2015),Transdermal Drug Delivery: Innovative Pharmaceutical Developments Based on Disruption of the Barrier Properties of the Stratum Corneum, *Pharmaceutics*, **Vol.** *7*(4), 438-470.

[229] Yadav, V.; Warghade, S.; Vare, S.; Ugale, P. (2024), One of the Most Promising Methods for Increasing Drug Penetration through the Transdermal Route is the nanoemulsion Technique , *International Journal of Research Publication and Reviews*, Vol. 5(11), 2075-2088.

[230] Bisen, V.; R.; Mokaswad, D.; D.; Sikdar, P.; A.; Taksande, J.; B.; Umekar, M.; J.; A. (2023), Comprehensive Review on Nanoemulsion: Formulations, Characterization, and Applications [Internet].Vol. 10.

[231] Deveci, E.; (2025), Nanoemulsions in cosmetics: Enhancing efficacy and stability, *Journal of Dermatologic Science and Cosmetic Technology*, Vol. 2(3), 100107.

[232] Date, A.; A, Nagarsenker, S. (2008), "Parenteral microemulsion: An overview", *Int J Pharm*, Vol. 355, 19-30.

[233] Mohammad, S.; Sahid, A.; (2014), Chowdeswari; A review on Nanoemulsion, *Scandinavian journal of pharmaceutical science and research*, vol. 1(1), 6-9.

[234] Suryavanshi,, S.; Gade, S.; Bhonagle, A.; Devale, R.; Thorat, A. (2025), Overview of Nanoemulsion, *International Journal of Pharmaceutical Science Invention,* Vol. 14 (3), 95-106.

[235] Savardekar, P.; Bajaj, A. (2016), A Nanosuspension – Areview, International *Journal of Research in Pharmacy and Chemistry,* Vol. 6(2), 312-322.

[236] Birade, A.; Pooja, K.; A.; (2018), Vaishali Formulation and Evaluation of Glimepiride Nanosuspension Using Simple High Shear Homogenizer at Lab Scale *www.ijppr.humanjournals.com*, Vol. 14(1).

[237] Akram, T.; Kharroubi, H.; M.; Darwish, D.; (2015), The epidemic of the century, World J Diabetes, Vol. 6(6): 850-867, ISSN 1948-9358.

[238] Dumont, C.; Bourgeois, S.; Fessi, H.; Jannin, V.; (2018), Lipid-based Nanosuspensions for Oral Delivery of Peptides, A Critical Review, *Int. J. Pharm*, Vol. 541 (1–2) , 117– 135.

[239] Aboul Fotouh, K.; Allam, A.; El-Badry, M.; El-Sayed, A.; M. (2018), Role of self-emulsifying drug delivery systems in optimizing the oral delivery of hydrophilic macromolecules and reducing interindividual variability, *Colloids Surf. B Biointerfaces* , Vol.167 82–92.

[240] Malode, G.; P.; Ande, S.; Chavhan, S.; Bartare, S.; A. (2021), A Critical Reveiw on Nanoemulsion: Advantages, techniques and characterization, *World Journal of Advanced Research and Reviews,* Vol.11(3), 462-473.

[241] Sainsbury, F.; Zeng, B.; Middelberg, A. (2014), Towards designer nanoemulsions for precision delivery of therapeutics, *Current Opinion in Chemical Engineering*, Vol. 4, 11-17.

[242] 242. Pabale, M.; Yenare, V.; Handal, M.; Utage, M.; Nagrale, S.; Pondkule, A.; Babar, V. (2022), Nanoemulsions Formulation Design and Development : A Review, (2022), *International Journal of Novel Research and Development*, Vol. 7 (12), 55-69.

[243] Ranke, W.; Low Energy Electron Diffraction – LEED, Modern Methods in Heterogeneous Catalysis Research: Theory and Experiment, M. Horn-von Hoegen, Zeitschrift für Kristallographie 214 (1999) 1-75.

[244] Majeed, A.; Roy, P.; S.; Sharma, N.; Chalotra, R.. (2021), Nanoemulsions: Applications, Challenges and Future Perspectives, *Indian Journal of Agricultural Biochemistry*,Vol. 34(2):107-115.