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Nanoemulsions: Potential Applications in Food, Health and Cosmetics Industry

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Abstract

Nanoemulsions are kinetically stable colloidal systems with smaller droplet sizes. Because of its outstanding features such as durable stability and adaptable rheology, nano emulsions are used in a wide range of industrial applications. Nanoemulsions can be utilised in the food industry to deliver antimicrobials, colouring and flavouring components, and nutraceuticals. Biodegradable coatings and packaging films may be created through active component nanoemulsion compositions to improve the quality, functionality, nutritional content, and shelf life of foods. Nanosized emulsions also used to promote delivery of active pharmaceutical ingredient. Nanoemulsions have wide range of applications in the cosmetic industry. These compositions are relatively stable, contain small droplet sizes, and spread easily over the skin without creaming or leaving a glossy covering. This review focuses on providing a fundamental understanding of the composition, preparation, and applications of nano emulsion in the food, health and cosmetics industries.

Keywords: Food, health and cosmetics industries, Nanoemulsions,

Introduction

An emulsion is a liquid preparation that consists of two immiscible liquids, one of which is dispersed as globules (dispersed phase) in the other liquid (continuous phase) and is stabilised by an emulsifying agent. Emulsifying agents are substances added to an emulsion to prevent the globules of the dispersed phase from coalescing, also known as emulsifiers. Emulsifiers reduce the interfacial tension, thereby reducing the amount of energy needed to produce an emulsion. In addition to emulsifiers, surfactants are also used to reduce emulsion destabilisation. Adsorption of surfactants at the oil/water interface results in the formation of a monomolecular film, which reduces the interfacial tension. This group contains surface active agents that act by becoming adsorbed at the oil-water interface in such a way that the hydrophilic polar groups are oriented towards water and the lipophilic non-polar groups are oriented towards oil, resulting in the formation of a stable film. This film acts as a mechanical barrier, preventing the globules of the dispersed phase from coalescing. Emulsions are classified into simple emulsions and multiple-emulsions. Simple emulsion has one internal phase; Oil-in-water (o/w) or water-in-oil (w/o) and multiple-emulsion contains two internal phases; Oil in water in oil (o/w/o) or water in oil in water (w/o/w). Nanoemulsions contain a large number of small sized particles with increased surface area, high kinetic stability and less sensitivity to physical and chemical changes, making them ideal formulas in the food and cosmetic industry (Souto et al., 2022). The use of nano technology/nano particles in emulsion manufacturing is critical since emulsions have been made for many years from a variety of materials and additives, establishing markets and profitability. Numerous industries, particularly those in the cosmetics, pharmaceutical, food, and

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agricultural sectors, are rapidly adopting nano technology (Chowdhury et al., 2017). Nano emulsions, which are extremely small in size, have a wide range of functional applications, including the fortification of numerous aqueous-based food and beverage items as well as improved stability, surface area, optical transparency, rheology, and other functionalities associated with innovative technology. (Dasgupta et al., 2019). Nanoemulsions are employed in a variety of products besides food, including cosmetics, polymers, and healthcare delivery. Nanoemulsion's physical-chemical characteristics, such as stability, emulsification, solubility, ionic strength, pH, and temperature, are indicative of their functional properties and use in a variety of industries outside the food sector.

Classification of emulsions

Based on the stability and size of the droplets, emulsions are classified as coarse, micro, and nano emulsions. Coarse emulsions are optically turbid and are also known as conventional emulsions or macroemulsions. They have particles with diameters greater than 200 nm and are thermodynamically metastable. They degrade over time due to a variety of destabilising factors. Microemulsions are optically clear and droplets are <100 nm in size and thermodynamically stable (Guptha et al., 2016). However, even modest changes in environmental factors like temperature and composition can have an impact on their stability. Microemulsions form spontaneously because their free energy is lower than that of their phase-separated components. The droplet dimensions of nanoemulsions are similar to those of microemulsions, ranging from <200 and < 100 nm in some cases. So, it is difficult to distinguish microemulsions and nanoemulsions based on particle size. Conventional emulsions are thermodynamically metastable as phase separation occurs over time. However, nanoemulsions have kinetic stability, because there is no gravitational separation and droplet aggregation due to the reduced attractive force between the small-sized droplets. Unlike thermodynamically stable microemulsions, nanoemulsions are unaffected by physical and chemical variations such as temperature and pH. They require fewer surfactants in their preparation. The droplet size and stability of nanoemulsion influence its rheological and release behaviour. As a result, nanoemulsions are better suited for various applications than microemulsions. The current review focuses on the increasing use of nanoemulsions in the food industry for more environmentally friendly food processing and packaging. Functional compounds and active ingredients such as antioxidants and nutraceuticals can be encapsulated in nanoemulsions. They can also be used to regulate the release of flavour compounds in foods. Nanoemulsions have the ability to dissolve nonpolar active chemicals, which is essential for their usage as drugs and bioactive compound delivery systems (Mansour et al., 2009). Since nanoemulsions' droplet sizes are below the microscopic range and they easily pass the criteria for intravenous drug administration, they are more advantageous than conventional emulsions and other systems (Quintão et al., 2013). Delivery of vaccines by nanoemulsionsis very effective and spontaneous (Goddard et al., 2009). Nanoemulsions could also be employed in anti-inflammatory functions (Yen et al., 2018). Based on their liquid-liquid affinity to macromolecular moieties, small size, and vast surface area, nanoemulsions could be linked to additional applications such as complex matter developments and cosmetics (Barradas et al., 2020).

Composition of nanoemulsions

Two incompatible liquids must be combined with an emulsifier to create a nanoemulsion. The dispersed and aqueous phases are formed by one of the immiscible liquids being oleaginous and the other being aqueous in nature. The o/w and w/o nanoemulsion consist of a core–shell structure. Triacylglycerols, diacylglycerols, monoacyl-glycerols, and free fatty acids make up the oil phase of a nanoemulsion. Additionally employed as oil phasing agents are non-polar essential oils, mineral oils, lipid replacements, waxes, weighing agents, oil-soluble vitamins, and numerous lipophilic substances. In a nanoemulsion, apolar solvent and a cosolvent make up the aqueous phase(Jaiswal et al., 2015). It controls the ionic strength, polarity, rheology, phase behaviour, and interfacial tension of the nanoemulsion. Water is typically employed as the polar solvent, whereas cosolvents include carbohydrates, protein, alcohol, and polyols.

Properties of nanoemulsion and destabilizing mechanism

Nanoemulsions are emulsions that have very fine particle sizes. They have some distinguishing features, such as small size, increased surface area, and lower sensitivity to physical and chemical changes, which make them ideal formulas in the food industry. Their optical qualities are crucial for nanoemulsions to be used in the food industry. Nanoemulsions are optically clear or faintly turbid depending on the size of their droplets.

Nanoemulsions are characterized as kinetically stable systems. They degrade with time as a result of chemical instability and destabilising physical phenomena such as gravitational separation, flocculation and coalescence. Gravitational separation occurs when the relative densities of the dispersed and continuous phases differ, resulting in creaming or sedimentation. Coalescence occurs when two or more droplets combine to form a single larger droplet. As aresult of their relatively small particle size, nanoemulsions exhibit less droplet aggregation, such as flocculation or coalescence. Chemical degradation occurs as a result of oxidation and hydrolysis. Phase inversion occurs when an o/w emulsion changes to a w/o emulsion or vice versa. Brownian motion affects the mobility of smaller particles in nanoemulsions with particle diameters of 70 nm and avoids creaming (Walstra, 2003; McClements and Rao, 2011). Because of its small particle size, nanoemulsions have less droplet aggregation, such as flocculation or coalescence (Tadros et al., 2004). Colloidal interactions in nanoemulsions are linked to droplet size and arise as a result of attractive (van der Waals and hydrophobic) and repulsive (electrostatic and stearic) interactions between two neighbouring droplets (McClements, 2005; McClements and Rao, 2011). Ostwald ripening happens when the size of the droplet rises over time as a result of diffusion or transfer of solubilized oil molecules from small droplets to big droplets through the dispersed phase (Kabalnov et al., 2011).

Methods of preparation

High-Energy Emulsification Methods

Nanoemulsions cannot arise spontaneously since they are non-equilibrium systems. They must therefore be created via mechanical or chemical energy. In order to create nanoemulsions, high-energy techniques are typically used, including high-pressure homogenizers, high-shear stirring, and ultrasound generators (Sole et al., 2012). To create nanoemulsions, these mechanical devices apply powerful forces that separate the phases of water and oil. The input energy density for high energy technologies ranges between 10^8 and 10^{10} W^{-1} (Gupta et al., 2016). To produce uniform smallsized particles, the system is given the necessary energy in the least amount of time. Because they can do this, high-pressure homogenizers are the tools most frequently employed to create nanoemulsions. (Solans et al., 2005).

High-Pressure Homogenization

It is the most widely used technique for creating nanoemulsions. The high-pressure homogenizer or the piston homogenizer is advantageous for this procedure to manufacture nanoemulsionswhose particle sizes are up to 1 nm. The macroemulsion is forced to pass through a tiny opening during the process at an operating pressure of 500 to 5000 psi (Chime et al., 2014). Due to the interaction of various factors, including cavitation, hydraulic shear, and severe turbulence during the process, extremely small dropletsized nanoemulsions are produced.

Sonication

High-intensity ultrasonic waves with a frequency greater than 20 kHz are employed in the sonication process to create nanoemulsions with incredibly small droplets (Leong et al*.,* 2009). According to the literature, researchers frequently utilise bench-top sonicators to create nanoemulsions with incredibly small droplets.

The ultrasonic probe used in these devices has a piezoelectric crystal that transforms electrical waves into powerful pressure waves. The probe is dipped into the material to be homogenised during the creation of the nanoemulsions, and intense disruptive forces are created at its tip through a combination of cavitation, turbulence, and interfacial waves. This is the primary outcome of the sonication process used to create nanoemulsions. (Kentish et al., 2008; Abismail et al., 1999).

Low-Energy Emulsification Methods

Low-energy techniques can also produce nanobubbles, which are smaller and more uniform in size (Solans et al*.,* 2005; Sole et al*.,* 2012). By utilising the physicochemical characteristics of the system, these techniques, such as phase inversion temperature and phase inversion component, produce smaller and more uniform droplets (Caldero *et al.,* 2011). There are some restrictions on the use of specific types of oils and emulsifiers such as proteins and polysaccharides for low-energy operations, despite the fact that they are typically more effective at producing small droplet sizes than high-energy techniques.

Spontaneous nanoemulsification

When an organic phase and an aqueous phase are combined at a specific temperature, the production of a nanoemulsion occurs spontaneously (Anton and Vandamme, 2009). The size of the droplet produced by this approach relies on several factors, including the organic and aqueous phase compositions, temperature, pH, ionic strength, and the mixing circumstances, including the rate, order, and speed of addition. Nanoemulsion is created when nonpolar oil, a hydrophilic surfactant, and an organic solvent that is water-miscible are added to water, or when water is added to an organic phase that already contains nonpolar oil, a water-miscible organic solvent, and a surfactant (Anton and Vandamme., 2009; Sonneville-Aubrun et al*.,* 2004).

Phase Inversion Methods

These techniques make use of the chemical energy released by phase transitions during the emulsification process (Anandharamakrishnan., 2014). Changes in composition at constant temperature produce the necessary number of phase transitions (Thakur et al., 2013). The phase inversion method offers numerous benefits, including low cost and the need for simple equipment. Due to the smaller driving pressures of the phase inversion method, this procedure required a lengthier preparation time than the spontaneus emulsifiction technique.

Membrane Emulsification Method

These techniques make use of the chemical energy released by phase transitions during the emulsification process (Anandharamakrishnan., 2014) Emulsification process relies on temperature-dependent changes in hydrophilicity and lipophilicity of emulsifier molecules. Membrane emulsification was introduced in the 1980s in Japan (Nakashima and Shimizu, 1986; Nakashima et al., 1991). The fundamental idea behind this technique is the application of force to cause the scattered phase to pass through the pores of a microporous membrane and into a continuous phase (Nakashima et al., 1992).

Solvent Displacement Method

The solvent displacement approach results in the spontaneous formation of nanoemulsions. When the oil phase is combined with some organic solvents such as low molecular weight alcohols and ketones, which are miscible with the aqueous phase, the oil phase diffuses into the continuous phase. The organic solvent is eliminated following the creation of the nanoemulsion using a straightforward vacuum evaporation procedure. Rapid diffusion of organic solvents in an oil phase added to an aqueous phase devoid of any surfactant can cause a nanoemulsion to form spontaneously(Jasmina et al., 2017)

Nanoemulsions are created in solvent displacement procedures at room temperature with minimal stirring. However, one drawback of this process is that in order to remove the organic solvents that are utilised to create nanoemulsions, external input is needed.

Additionally, to generate a nanoemulsion with ideal droplets, a high solvent-to-oil ratio value is necessary, and in such circumstances, the solvent removal procedure may provide various challenges.

Potential applications in food industry

Nanoemulsions are effective agents for cellular uptakes and dispersal phenomena because they are liquid and readily deformable from large-size particles to tiny ones. Drug molecules that are water- and oil-soluble must be trapped in nanodroplets of direct and inverse nanoemulsions for usage in pharmaceutical applications.

Nanoemulsions are becoming an increasingly popular choice in the food sector. These compounds include nutraceuticals, flavour, vitamins, antioxidants, and colours. Encapsulation based on nanoemulsions offers a number of benefits, including greater bioavailability, increased solubility, control over the release of the substance, protection from chemical degradation, and the capacity to incorporate a variety of components into food products. Food businesses are interested in the manufacture of clean-label products, which can be accomplished by manufacturing nanoemulsions based on natural polymers. In order to manufacture nanoemulsionbased delivery systems for nutraceuticals and micronutrients, a wide variety of polymers have been employed. Some examples of these polymers include soya lecithin and modified starches. Because of this, food products that have nanoemulsions added to them have garnered a lot of attention as a result of the need among consumers for safer and healthier food products (Aswathanarayan et al., 2019). In addition, nanoemulsions have a wide range of potential applications, including the alteration of the consistency of food products, encapsulation, and the delivery of antimicrobial agents.

Nanoemulsions have a lot of applications in food processing compared to microemulsions due to their very small size, thermodynamic stability, transparency, continuous self-assembly with hydrophilic and hydrophobic portions and weak light wave scattering capacity, which eventually lead to their incorporation into optically transparent products such as fortified soft drinks. The active ingredients and functional compounds, such as antioxidants and nutraceuticals, can be encapsulated by the nanoemulsions. They are important for releasing flavour components in food in a controlled manner (Velikov et al.,2008). To extend the shelf life of foods like meats, dairy products like cheese, fresh produce, fresh cuts of fruit and vegetables, and confections, edible nanocoatings based on nanoemulsions that contain flavouring and colouring components, antioxidants, enzymes, antimicrobials, and antibrowning agents can be used (Azerdo et al., 2009).

Carotenoids

Carotene is a pigment that gives plants like carrots and other colourful vegetables their reddish-orange hue. The terpenoid carotenes, which include beta carotene, are produced by the body from geranyl phosphate. The most well-known carotenoid (provitamin A) is β-carotene. A nanoemulsion is used for increased digestability and taste of carotene rich foods. (Yi et al., 2014).

Nanoemulsions and encapsulation of lipophilic components

The encapsulation of lipophilic ingredients including vitamins, flavours, and nutraceuticals is one of the most significant uses of nanoemulsions in the food industry. To improve the distribution of bioactive molecules inside living cells, encapsulation is a helpful technique to entrap a bioactive ingredient in a core or a fill within a carrier (coating, matrix, membrane, capsule, or shell) (Lane *et al*., 2016). Omega-3 fatty acids and polyunsaturated fatty acids are two examples of physiologically active lipids that are increasingly being encapsulated by nanoemulsions made from food-grade components.

Essential oils and flavour compounds

Essential oils, in the form of aromatic volatile liquids, as well as semi-liquids, are frequently obtained from the seeds, flowers, leaves, buds, fruits, bark, resins, and roots of plants. The antibacterial activity given by essential oils is beneficial against numerous types of fungi and bacteria. The inherent properties of essential oils, such as being hydrophobic, volatile, and reactive, present challenges in directly incorporating them into food structures. By encapsulating essential oils in nanoemulsions, application issues associated with the inclusion of essential oils into food could be eliminated.

Pre-dissolving essential oils with regularly used oils before emulsifying them in an aqueous medium phase is the method of preparation. According to Yang *et al.,* 2018nanoemulsions of typical triglycerol oils such as maize oil containing citrus oils like bergamot oil and sweet orange oil in varied mixing ratios are effective antibacterial agents. Nanoemulsions combining cinnamaldehyde and medium chain triglycerides may offer increased long-term inhibition on the bacterial growth of *Escherichia coli*, compared to pure cinnamaldehyde. (Moghimi *et al*., 2018).

Vitamins

Lipophilic vitamins are physiologically sensitive substances with limited chemical stability and solubility in water. Vitamins A and E are particularly susceptible to oxidation when exposed to light, heat, oxygen, and metal ions. Furthermore, visible and fluorescent light has the ability to drastically modify the structure of vitamin K.Typically, nanoemulsions are created to enhance their chemical stability, solubility, and oral bioavailability.The nanoemulsions - based delivery system increased the in vitro bio accessibility of vitamin D by 3.94 folds, as evidenced by the significantly higher concentration of vitamin D_3 in micelles (Katouzian *et al*., 2017).

Potential application of nanoemulsionsin cosmetic industry

Nanoemulsions may offer rheological qualities for transparent or soft solids in the food and cosmetic industries. Because it can block UV radiation, nanoemulsion is mostly utilised in sunscreen in cosmetics (Mason *et al*., 2006). Nanoemulsions with small nanodroplets improve the efficiency with which specific medications or other bioactive compounds are transported across biological membranes.

Nanoemulsions to improve drug bioavailability and pharmacological effects

Some naturally occurring active chemicals have low bioavailability that prevents them from performing their pharmacological functions effectively. It has been proven that nanoemulsions are an effective form for increasing the bioavailability of natural extracts. The yellow-coloured polyphenolic chemical curcumin, also known as 1,7-bis-(4-hydroxy-3-methoxyphenyl)-1,6-heptadiene-3,5-dione extracted from the rhizomes of turmeric (Curcuma longa, family Zingiberaceae) has been utilised as a natural colouring agent because of its anti-inflammatory and anticarcino genic properties. Curcumin-loaded NEs were prepared through high-pressure homogenization. The lipid phase, constituted by Corn oil (long chain triglycerides) and 0.1% of curcumin, was homogenized at room temperature and a volume ratio of 1:9 (Raquel *et al*., 2021).

Nanoemulsions to improve drug solubilization

The solubilization of phytosterols has been improved using nanoemulsion formulation. It has been demonstrated that phytosterols lower blood cholesterol, which in turn lowers the risk of coronary heart disease. Sitosterol, a phytosterol, has been isolated from numerous fruits and vegetables. Additionally, the solubilization of lycopene was boosted by nanoemulsion formulations. Tomatoes and other red fruits and vegetables contain lycopene, a carotenoid pigment and phytochemical. Cardiovascular disorders and prostate cancer may be affected by lycopene (Saline et al., 2019). Nanoemulsion drug delivery systems are lipid-based formulation technologies that have the potential to deliver and improve the bioavailability of hydrophobic medicines and bioactive food components in the bloodstream. (Subramanian., 2021).

The bioavailability of bioactive substances is known to be increased and protected by nano emulsification. Applications for functional food components in the food sectors are quite promising. The functions of food can be improved, as well as their quality and shelf life, with the help of edible coatings made of nanoemulsions and emulsion-based delivery systems (Oliveira et al., 2021). Based on their physicochemical and functional properties, nanoemulsions have very promising multisectoral uses in the healthcare, food, polymer manufacturing and cosmetics industries (Nirmal et al., 2018). Agrochemical, cosmetics, pharmaceutics, texturizing agents and creams, non-steroidal anti-inflammatory drugs, drug and vaccine delivery, cosmeceutical applications, and alcohol-free perfume formulations are just a few of the non-food uses for nanoemulsions that have recently been demonstrated (Aithal et al., 2018).

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