REVIEW ARTICLE

A comprehensive review on oleogels, formulation consideration and potential applications in bioactive delivery

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Abstract

The scientific community faces a new challenge as a result of rising concerns about the consumption of unhealthy transfats and saturated fats in the diet: Developing effective replacements for bad fats without compromising the sensory characteristics of the food product. Oleogels are said to be a cutting-edge structured fat system employed for industrial application due to their nutritional and ecological advantages among various strategies aimed to reduce/replace transfats and saturated fats in foods. The oleogel's mechanical strength, constitution, and gelator type are all elements that could influence how much and how quickly the material is being liquefied. These in turn have an impact on how lipid-soluble molecules are delivered by the oleogel. The formulation considerations of oleogels will be the main focus of this review, along with their recent food applications, particularly in the delivery of bioactives and as nutraceuticals. There will be a discussion about an understanding of oleogelators.

Key words: Nutraceuticals, oleogel, oleogelators, oral delivery, transdermal drug delivery

INTRODUCTION

Vegetable fats and oils play an essential function in our diet and the standard methods of food preparation. Different fat phases offer distinctive characteristics that fulfill the criteria of several uses. One could tell whether aqueous or structured lipid phases had been used as a first cut. It makes sense to see the first as an elementary use of seed oils.[1] Food trends are currently moving more toward plant-based diets and healthful eating. To meet demand from consumers, food producers must overcome new obstacles as a result of consumers' growing awareness of the negative environmental impacts of the production of animal-source food and the hazards associated with the ingestion of overly processed animal-derived products.[2] People's attention is being drawn to the use of meals with a high number of calories (i.e., unsaturated and trans fats) that provide instant satisfaction but promote long-term numerous issues owing to fat build-up in the human body. In reality, diets high in saturated and trans fatty acids promote arterial damage by accumulating as platelets on the artery walls, producing thrombi in the blood vessels and initiating a variety of metabolic conditions. The World Health Organization (WHO) advises a daily intake of 15–30%, with a maximum of 10% saturated fatty acids. Saturated fats, in addition to their nutritional worth, ensure the gustatory and textural quality of food items in the sweet item, meat, bakery, and other industries. Saturated fats are, in fact, essential since they (i) give mechanical properties, (ii) improve taste impressions on the palate, (iii), (iv) help starch gelatinize, and (v) make it easier for complexes to form between the sugar amylose and fatty acids. As a result, they are crucial to the sensory and longevity quality of food things.[3] The desire to alter buyer behavior and create new bio-based and environmentally friendly ingredients that might be employed in new product formulations has been consistently driven by growing awareness of human health and sustainability. Organogels and oleogels are two remarkable new materials that have appeared in the last 15 years. They are partially solid materials with a significant portion of liquid oil or organic solvents trapped inside a web of supporting molecules. These compositions have a gel-like consistency

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and solid-like structures.[4] Oleogelation, which structures liquid oils with low concentrations of gelators that allow the creation of a semisolid matter, could be able to overcome this problem. To (i) prevent the loss of oils in already packaged products, (ii) protect and regulate the release of water-resistant bioactive substances, (iii) trap organic solvents, (iv) grant longer shelf-life, and (v) provide strong rheological characteristics despite having a predominantly liquid composition, oleogels are used.[3] Oleogels have just discovered an incredible usage in the pharmaceutical, food, and cosmetics industries. The ability of oleogel structures to serve as drug delivery matrices and as substitutes for trans and saturated fats in processed foods has been shown to be a critical advance. Oleogel research and future food component introduction are anticipated as complementing approaches for various consumer demands. As a technique to customise the fatty acid profile associated with food items, they can be used to structure edible oils, replace saturated fats, and both at the same time. As previously indicated, polyunsaturated fatty acids have drawn significant attention for their capacity to protect from inflammation in several kinds of chronic degenerative diseases with extensive birth. As this method appears to be a beneficial strategy for their integration in meals, structuring PUFA-rich oils is a technical advancement that has stayed underneath the scientific radar. Another significant factor is that, in addition to the oil medium itself, which may be an indicator of functionality and health, the molecules that cause the oil to gel may also play a significant role owing to their potential inherent bioactivity. It will also be investigated how edible oils' conformation modifications (which mimic the texture and rheology of regularly used fats) may be used to give nutrition. It also discussed how oleogels might affect a person's overall metabolic health.[5] Topical drug delivery refers to the application of a medication-containing formulation to the skin to address skin-related issues immediately. When other methods of medicine administration (such as oral, sublingual, rectal, or parental) are ineffective, or when a local skin disease, such as a fungal infection, develops, the topical drug delivery strategy is usually used. The main benefit of applying lotion is that it avoids first-pass metabolism. Another benefit of oral medicine is that it avoids the risks and problems associated with intravenous treatment, as well as the different absorption conditions, such as pH changes, the presence of enzymes, and the passage of time. The topical medication delivery mechanism is usually utilized when other drug administration methods are inefficient. The study is also conducted to prevent the hazards and inconvenience of intravenous medication as well as the varied absorption circumstances, such as pH fluctuations, the presence of enzymes, and emptying of the stomach time.[6] Gel formulations often offer quicker medication release than traditional ointments and lotions. Gels' main drawback is their difficulty in releasing hydrophobic medications. Emulgel are created as a result to get around this restriction, allowing even hydrophobic drugs to take use of the special qualities of gels. Emulgel is a brand name given to dosage formulations consisting of emulsions with gels. In reality at all, a traditional emulsion produces an emulgel when a gelling ingredient is present in the water phase. The O/W system is utilized to entrap lipophilic pharmaceuticals, whereas the W/O system is used to encapsulate hydrophilic medications. Emulgel is a mix of an emulsion and gel, as its name suggests.Various medicines are delivered to the epidermis via emulsions that are both water-in-oil and oil-in-water in composition. When a gelling ingredient is introduced to the water part of a conventional emulsion, it converts into an emulgel. Theemulgel for dermatological purposes is thixotropic, greaseless, easily spreadable, easily removable, emollient, non-staining, water-based, has a long shelf life, is environmentally friendly, transparent, and has an appealing look.[7] A three-dimensional cross-linked polymeric network composed of manufactured or natural polymers that can hold water in its porous structure is referred to as a "hydrogel." The hydrophilic groups found in the polymer chains of hydrogels, such as amino, carboxyl, and hydroxyl groups, are mainly responsible for their ability to grasp water. Such polymer components do not dissolve in water at typical temperatures and pH levels, but instead, expand considerably in aqueous environments. Hydrogels can be made from virtually any soluble in water material and can have a wide range of chemical makeup and general physical attributes. Furthermore, hydrogels can be created using a variety of physical forms, such as slabs, microparticles, nanoparticles as coatings, and sheets.[8] About three quarters of the world's population relies on plants and plant extracts for health treatment, and traditional medicines play a significant part in healthcare systems all over the world. Many Indian medicinal plants have been proposed to have a variety of pharmacological effects because they contain different groups of photochemical. Opioids, also known as non-steroidal anti-inflammatory in natural medicines, are frequently used to treat different forms of inflammation but can have major side effects including redness, itching, and others. Consequently, it is important to look for other options that would be more advantageous.[9] It is possible to protect the wound from illness and hasten the healing process by using a variety of topical formulations such as creams and lotions gels, or wound dressings. Gels are easy to use on wounds and are clean to remove. Gels are a viable medication delivery method, particularly for topically applied therapies. All across the world, remedies made from herbs have been used for centuries to treat wounds. The WHO estimates that more than 80% of people in affluent nations use natural goods. In poor nations like India and China, where most wild plants are utilized to heal burns and wounds, several research have been undertaken. Due to their less negative effects than contemporaneous pharmaceuticals and synthetic therapies, herbs have been utilized as folk remedies for a long time.[10]

Wax-based oleogel offers several benefits that they can be found easily, inexpensive, and of food-grade quality. They can be used to create water-in-oil structured emulsions that might or might not require emulsifiers, and their thermo-reversible behavior makes them suitable for use with foods that require temperature changes. Candelilla waxy substance, carnauba wax, rice bran waxes, beeswax, and sunflower waxes constitute some of the food-grade waxes utilized for applications in edible oleogels.[11] Oleogels' ability to offer a wide range of oils and fats to meet the needs of the human body is one of its key advantages. Since vegetable oil makes up the matrix of oleogels, researchers have the option of selecting a range of vegetable oils as raw materials based on market demand (such as oils from sunflowers and maize oil). The fact that the oleogels are largely devoid of TFA throughout gelation without hydrogenation is another key characteristic.[12] This is the advantages of oleogels in food industry and marketed preparation It is easy to prepare, More stable than other gel types. enhanced drug permeability. Moisture has no effect on oleogels. Cost savings as a result of fewer ingredients. Stable in the short term. Drug with a short half-life, prolonged shelf life, regulated medicine release, and use for long-term impact were all used. It removes the need for frequent pharmaceutical dosages. They are less greasy and easier to remove from the skin.[13] On the other hand, a few disadvantages are also associated with oleogel formulation as they must have a suitable partition coefficient; otherwise, they might not be skin-permeable. Drugs that chafe or sensitize the skin should not be administered through this method. These both are the disadvantages and storage conditions of oleogels Gelling will not occur if an impurity is present, Demand adequate storage conditions. If there any impurity around the storage condition or in making of oleogel these two conditions will occur. Swelling occurs when the gel absorbs liquid with a larger volume. When a gel is left to stand for a while, it usually contracts spontaneously and releases part of its liquid, a process known as syneresis. It's the factor called syneresis which is unacceptable in business. Its popularity in the food industry has been hampered by a lack of substantial expertise in a variety of disciplines.[14]

FORMULATION CONSIDERATION OF OLEOGELS

Oleogelation

Oleogelation has become an established method for lowering or replacing unhealthy and contentious lipids in food items. Edible oleogels of different types are created using various methods to be utilized in spreads, bakeries, confectioneries, and dairy and poultry products.[15] Commonly, oleogels are made by dissolving gelators such as waxes, fatty acids, fatty alcohols, monoacylglycerols, and phytosterols in small amounts of vegetable oil, boiling the resulting combination above its melting point, and then chilling it to encourage gelation. The use of oleogels instead of solid fat in W/O emulsions is a novel solution to these structuring systems. Various veggie oils can be used to create oleogels, and their physical and molecular qualities are determined by the lipid phase. Because of their composition, abundance, and expense, vegetable oils such as soybean oil, high oleic sunflower oil (SO), olive oil, and palm oil have the capacity to produce oleogels. As the saturation level of the oil increases, the quantity of gelator required for gelation decreases. Gelators that can shape liquid lubricants at low concentrations are safe and have thermoreversible characteristics are ideal. In order to facilitate the creation of numerous oleogels with various technical application characteristics, several parameters such as hardness, rheology, and oil-binding capacity contribute system's overall efficiency. It is crucial to investigate these gelators characteristics in various concentrations and vegetable oils.[16]

Oleogelators

Oleogelators are lipid materials that trap bulk liquid oil at lower concentrations.[17] In recent years, oleogelation has gained popularity in the lipid research field for developing healthy food applications.[18]

Sorbitan monostearate (SMS)

SMS, a hydrophobic non-ionic surfactant, can produce oleogels in a wide range of organic fluids and vegetable oils, including canola, sesame, and olive oil. It is also known as Span 60, a food preparation emulsifier with a hydrophilic-lipophilic balance (HLB) of about 4.7, making it appropriate for water-in-oil emulsions. Sorbitan monopalmitate (SMP), a surfactant family member, is additionally referred to as Span 40 and can create opaque, thermoreversible semi-solid oleogels with organic liquids. These oleogels have a linked network of rod-like tubules as their substructure. Instead of a clustering effect, the inclusion of modest quantities of a polysorbate monoester causes a substantial rise in tubular length. Oleogels formed by SMS and SMP have very good applications in the delivery vehicle for drugs and antigens.[17]

Ethyl cellulose (EC)

The goal of this research was to make a gelled W/O emulsion (Gelled-W/O-E) with 20% water through the addition of a standard W/O emulsion (W/O-E) fixed with glycerol monostearate (GMS) and an EC oleogel. The mechanical, microstructure, and stability of the resulting Gelled-W/O-E were compared to control systems that included conventional W/O emulsions (W/O-E) and EC-GMS oleogels (EC-GMS-O; no added water) formulated with the same GMS (0.5% and 1.0%) and EC (7%) concentrations as the Gelled-W/O-E. Despite using lesser amounts of EC and GMS to produce a gel and a lower solid composition in the Gelled-W/O-E than in the EC-GMS-O due to the presence of water, the Gelled-W/O-E demonstrated greater elasticity and emulsion stability than the control systems.[19] The research aimed to create *in situ* remedies for periodontitis therapy using EC and antimicrobial medicines. Increasing the quantity of EC improved viscosity and syringe action, but reduced drug release. When injected into synthetic gingival crevicular fluid, the device generated a rigid gel. The antimicrobial action of the produced gels comprising 5% w/w antimicrobial agent was demonstrated against all examined microbes. Overall, solvent exchange-induced *in situ*-creating gels containing EC and antimicrobial medicines have a capacity to cure periodontitis.[20]

Candelilla wax (CW)

Although CW is a popular oil-gelling substance in cosmetic sticks, its hardness is not as great as that of hydrocarbon waxes such as paraffin. To solve this problem, CW was hardened with BB, derived from plants wax ester with a high melting point. When combined, CW and BB produced combinations that were harder than paraffin wax, which is usually used to harden cosmetic oils. This indicates that combining BB and CW could be an appealing strategy for enhancing cosmetic product efficacy.[21]

Sun flower wax

The used oil type is known to influence a variety of structural properties of oleogels. SO, one of the most frequently consumed vegetable oils, is high in MUFAs, PUFAs, vitamin A, and carotenoids and is extensively used in the culinary business due to customer approval. They comprise mainly triacylglycerols (TAGs) with a trace of phospholipids. SO-based oleogels have been successfully prepared using SW as a gelator. These oleogels exhibit higher hardness, thermal stability, and oxidative stability compared to the SO itself, and have potential applications in food products as a replacement for solid fats, and as a delivery system for bioactive compounds. Oleogels made with SO and SW can also be used as a coating material for food products to improve their shelf-life and prevent oxidation. Yes, that's correct. The structural characteristics of oleogels can be influenced by the type of oil used. SO is a commonly used vegetable oil that contains a high proportion of monounsaturated and polyunsaturated fatty acids, as well as other beneficial compounds such as vitamin A and carotenoids. It is also low in phospholipids compared to some other vegetable oils. These differences in the composition of SO can affect its ability to form an oleogel and the properties of the resulting gel.[22]

12-hydroxystearic acid (12-HSA)

12-HSA is a small molecule that can form a supramolecular structure when it crystallizes in oil. This structure allows the molecule to act as an organogelator, which can gel oil at low concentrations of 0.5–2.0% w/w. 12-HSA is made up of stearic acid with a hydroxyl group at carbon twelve and is derived from castor seed oil. To prepare 12-HSA gels, the organogelator is added to the oil and heated until it melts at around 90°C. The gel is then allowed to cool, which causes it to set.[23]

Surfactant Used in Making Oleogels

Polysorbates

For the creation of oleogels according to different research on topical microemulsion gel, emulgel, and floating gastric Nano-emulsion *in-situ* gel, Tween 80, which is essentially a surfactant used as a co-gelator to provide superior performance, increase efficiency, entrapment, drug penetration, and solubility. According to reports, Tween 80 promotes the gelation of oleogels based on Span 80. Fruits and vegetables that are still intact have hydrophobic surfaces and low energy. According to Porter,[24] non-ionic surfactants were adsorbed in greater quantities on non-polar or hydrophobic surfaces than polar surfactants. Consequently, non-ionic surfactants like tween 40 and tween 80 were used. There are accounts of organogels that have an aqueous phase added to them to cause gelation as well.[25] Transdermal bioactive agent distribution using the tween 80 mixture-based organogels might be tested.[26] Tween 80 can be utilized in formulation to produce an efficient coating for food surfaces that are hydrophobic. The usage of 1.25% sodium alginate, 2% glycerol, 0.2% SO, and 1% span 80 in the formulation was advised as a balance between achieving maximal surface tension decrease and implementing minimal amounts of coating component. We may infer from the data that tween 80 was added to the formulation to reduce the number and size of droplets in the bulk solution.[27]

SMS (SPAN)

Span 40 and Span 60 are commonly used surfactants in the preparation of oleogels, which are semi-solid or gel-like structures formed by the dispersion of liquid oil in a solid network. These surfactants have a hydrophilic head and a lipophilic tail, which allows them to interact with both oil and water phases and stabilize the oil-in-water emulsion. Span 40 has a shorter hydrophilic chain than Span 60, which results in a lower HLB value and higher hydrophobicity. In contrast, Span 60 has a longer hydrophilic chain, leading to a higher HLB value and lower hydrophobicity. The choice of surfactant depends on the properties desired for the final oleogel product. For example, a higher concentration of Span 40 can result in a more stable and dense gel network, while Span 60 can lead to a softer and more spreadable texture. Several studies have investigated the use of Span 40 and Span 60 in oleogels, including their effects on the rheological properties and stability of the gels.[25]

Lecithin

Phospholipids such as phosphatidylcholine, phosphatidylethanolamine, and phosphatidylinositol are often found in lecithin, reflecting the makeup of the biological membranes of the plant cells from which it has been generated. Hydrophobic fatty acid "tails" are present in phospholipid molecules, which also have a hydrophilic head group that is typically charged and is esterified to a glycerol backbone. There could be a variety of physicochemical qualities anticipated depending on the features of the chemical groupings. In this instance, we changed the kind of fatty acid "tail." (saturated versus unsaturated). There are two reasons to use lecithin. First off, lecithin is a generally utilized natural surfactant that is frequently employed in food, medicine, and cosmetic applications. Second, lecithin molecules are known to self-assemble through non-covalent interactions like hydrogen bonds. Lecithin is thought to work constructively with the polymeric EC gel and hence modify the rheology of the resulting gels because of its molecular characteristics as well as capacity for hydrogen bonds.[28]

OLEOGELS FOR TRANSDERMAL DRUG DELIVERY (TDD)

TDD, or the administration of medications through the skin, is becoming increasingly popular among patients. For medicinal drugs with low-molecular-weight that are vulnerable to first-pass metabolism, it is a practical method of delivery. Lipids, among other organic substances, operate as penetration enhancers and hence offer the organogel formulations made from them a competitive advantage. Successful researches into the use of organogels as topical pharmaceuticals.[29] Topical transdermal medication distribution can prevent the severe stomach discomfort brought on by oral aceclofenac treatment.[30] Edible oils may aid increase drug penetration through hydrogels. To deal with such problems with hydrogels, the bigel vehicle system has been created. For topical and transdermal medication delivery, it is a semi-solid dosage form created by carefully blending two distinct colloidal species, an oleogel and an aqueous gel.[31] TDD has advantages such non-invasiveness, extended blood levels of the medicine, less side effects, increased bioavailability, better patient compliance, and simple drug discontinuation. The skin's outermost layer, the stratum corneum (SC), is a unique transport barrier that efficiently slows the diffusion of exogenous and endogenous moieties into and out of the host. In TDD, continuing SC has conventionally been the aim. Since the 1960s, topical treatments have included chemical penetration acceleration to temporarily disturb the beautiful molecular structure. For maintenance therapy, a transdermal organogel as a long-acting formulation might be suitable. The study's model medicine is haloperidol (HP). The treatment of both acute and chronic psychosis with HP is common. The physiochemical characteristics of HP (haloperidol) also meet the requirements for general TDD design. HP partitions into the SC because of its low molar mass (375.9 Da) and high lipophilicity (log P = 3.36). Systemic TDD has gained significant traction thanks to penetration enhancers.[32]

Limonene PG/GP1 Organogels as a Vehicle in Transdermal Delivery of Haloperidol

Organogels containing 2.5 mg/mL HP in PG, 5% limonene, and 2-10% w/v GP1 were developed. For quick dissolution, the calculated amounts of GP1, limonene, and PG were combined and baked at 120°C. The temperature of the oven was then decreased below 90 C. Following the addition of HP, the liquid combination was kept at 90 C for an additional 30 min. The resultant drug-gel emulsion naturally cooled to room temperature, resulting in the emergence of a white gel. Limonene was chosen as the chemical enhancer because it improved *in vitro* therapeutic HP delivery, lowered the lag period, and boosted skin permeability. The GP1/PG organogels limonene addition resulted in higher gel moduli, which could be a sign of improved gel physical stability. By introducing impedance on the vehicle side, organogel as a drug delivery system decreased drug absorption. The effectiveness of using organogel to regulate drug release in maintenance therapy is demonstrated by the derived empirical correlations amongst gel resistance and gel rheology.[32]

Organogel as Oral Controlled Release Formulation for Lipophilic Compounds

Both the 12-HSA and ibuprofen were weighed and added to soybean oil for the formulation which contained ibuprofen in the organogel. Because of its high lipophilicity, ibuprofen is quickly dissolved in oil. This happens at room temperature. After then, the mixture was heated to 75°C while being gently stirred to melt 12-HSA. When 12-HSA was entirely melted, the liquid was placed into the body and covered of a gelatin capsule, where it was gently chilled to solidify the soybean oil. Just before the organogel had strengthened, the body and cap were attached to one another. It was discovered that the low mass gelators quantity may be changed to regulate the pace of ibuprofen release from organogels. This mechanism also accounts for the vast majority of variations in the rate of erosion of organogels. It was also made clear that taurocholate improved the lipolytic activity of lipase and that lipase is closely associated with the decomposition of organogel. For lipophilic substances, Organogel is unquestionably beneficial as an oral controlled dissolution formulation.[27] In the simulated intestinal fluid, which additionally contained lipase and sodium taurocholate, the rate of ibuprofen release from the organogel was assessed. When soybean oil did not have a gel-forming agent added, ibuprofen was immediately released. On the other hand, all of the organogels significantly lowered the rate of ibuprofen release.[27]

Rheology and Utilization of Gelatin-stabilized Micro Emulsion-based Organogels in Iontophoretic Transdermal Drug Administration

By infusing an aqueous sodium salicylate stock solution into a reverse micellar surfactant solution, clear solutions formed after a brief shake to create w/o microemulsions containing the model medication. MBGs were created by adding solid gelatin (up to 0.14 g/g) to a previously made w/o microemulsion that included 25% weight-for-weight surfactant, 25% weight-for-weight water, and 50% weight-for-weight IPM. Once the gelatin was completely dissolved, the temperature was increased to 558C while stirring continuously. The sample was subsequently given time to cool to room temperature once the agitation was stopped. Micro emulsion-based organogels are formulations that produce transparent, homogeneous, non-birefringent gels. (MBGs). These unique MBGs offer TDD matrices that are rheologically acceptable, and because they are electrically conducting, they may also be used in iontophoresis. In iontophoretic tests, sodium salicylate was utilized as a model drug, revealing that MBGs may be successfully adapted to this method.[33]

Oleogel Use for Encapsulation and Nutraceutical Delivery

Stephen DeFelice, MD, coined the phrase nutraceutical in 1989 as a mix of the words nutrition and pharmaceutical. A food (or component of a meal) that offers medical or health advantages, including the prevention and/or treatment of a disease, is referred to as a nutraceutical, according to Dr DeFelice. Numerous fat-soluble compounds that are categorised as nutraceuticals may be successfully encapsulated or given using an organogel. Β-carotene, lycopene, coenzyme Q10, docosahexaenoic acid (DHA), eicosapentaenoic acid (EPA), conjugated linoleic acid, tannins, plant sterols, and isoflavones are a few of these substances. Although many of these substances may already be present in a healthy diet, their levels are now too low to have any noticeable pharmacological effects. In addition, with an organogel might enhance how these effects manifest. If nutraceuticals are added to organogels, the degradation of such substances can be minimized by adding them after the material has cooled, minimizing their exposure to temperatures above 1008°C. Furthermore, the availability of accessible oil will help in the micellization of the chemicals, enhancing absorption by the intestinal lumen and maximizing delivery efficacy and any health advantages.[23]

Oleogel as a Curcumin and Resveratrol Co-delivery Vehicle

The importance of curcumin, a polyphenol isolated from turmeric rhizome, has long been recognised. It has great anti-inflammatory, antioxidant, and wound-healing properties. in addition, it has antibacterial properties against a range of yeast, molds, and gram-positive and Gram-negative bacterial species. Furthermore, it is said to have anti-cancer characteristics that, when coupled with micelles, show chemo-preventive effects. By putting curcumin in an appropriate delivery system made up of nanoparticles, nanostructured lipid carriers, liposomes, and an emulsion-based matrix, the instability of curcumin might be addressed. Similar to other polyphenols, resveratrol is a naturally occurring substance that can be discovered in foods such as grapes, peanuts, and blueberries. It has anti-inflammatory, antioxidant, and lipid, glucose, and inflammatory regulation capabilities, as well as advantages for the body's defences against heart disease, cancer, and liver disorders. Curcumin and resveratrol themselves have a variety of advantages, but when combined, they offer significant therapeutic advantages, notably for both the avoidance and treatment of various malignancies through a range of molecular processes. For instance, when used in combo, curcumin and resveratrol significantly increased the amount of apoptosis (300%) in colon cancer cells (HCT-116 cells). Combining curcumin and resveratrol targets a variety of carcinogenesis pathways, which include those that are important for the development of cancer cells, such as the epidermal growth factor receptor, nuclear factor kappa-light-chain-enhancer of activated B cells (NF-B), activator protein-1, and COX-2 inhibition. There are several biochemical routes and processes through which the combination of curcumin and resveratrol can cure various cancers, including lung, colon, breast, prostate, liver, and brain tumours. MCT oil was used to generate the emulsion-templated oleogel, which was built via the protein-polysaccharide interaction between gelatin and gellan gum transferring the lipophilic curcumin and resveratrol for a synergistic effect.[34]

Microstructure and Mechanical Properties of β-sitosterol Based Oleogels by Self-Assembly with Monoglyceride

Investigated the volatiles' release under control property. Glyceryl monostearate was often utilised as a surfactant in the food, drug, and cosmetic sectors. In refined oil from sunflowers (90 percent in the final system), different ratios of -sitosterol and monoglyceride were combined (10:0, 6:4, 4:6, and 0:10, wt%/wt%). The finished system's overall organogelator content was 10 weight percent. With a magnetic stirrer running at 250 revolutions/min, the samples were heated until completely dissolved (85°C, 30 min). The resulting translucent solutions were then kept cool for 24 h at room temperature to gel. Low molecular-weight organogelators (LMOGs) have drawn a lot of interest since they not only provide an alternative to saturated and trans fats but also have special encapsulation and delivery capabilities. Oleogels are produced by the intermolecular interactions of molecules. Oleogels based on-Sitosterol (Sito, the most prevalent phytosterols) have drawn attention as organogelators due to their natural, healthful, and biocompatibility. Monoglyceride-based oleogels based on phytosterols have been developed as a controlled flavour delivery technique. When compared to monocomponent gels, the form of the unique crystals in bicomponent oleogels was found to be spherulitic by microscopy.[35]

Encapsulation of β-carotene in Oleogel-in-water Pickering Emulsion with Improved Stability and Bio Accessibility

It is good for human health to consume beta-carotene (BC). Hydrophobic BC has limited bioavailability and oxidative stability, which restricts its use as a supplement in pharmaceutical and functional meals. Here, an oleogel-in-water Pickering emulsion (OPE-2) and a standard oil-in-water

Pickering emulsion (OPEs-1) were developed with the goal of enhancing BC's chemical stability and bioavailability. As the emulsifier, cellulose nanocrystals were employed. By structuring soybean oil with beeswax, oleogel was created. Finally, the OPEs-1 and -2 with BC loaded were built. Oleogel has the ability to convert visco-elastic emulsions into elastic materials as well as increase the viscosity of emulsions in which it acts as the dispersed phase (OPEs-2). The OPE-2 that was BC-encapsulated shown greater FT stability. Over a large pH (4.0–8.0) and salt concentration range, the OPEs -2 were demonstrated to be more stable than the OPEs -1. (0.05–0.60 M). It was additionally shown that the OPEs-2 increased BC's chemical stability during long-term storage. OPEs-2 considerably enhanced the chemical stability and bioaccessibility of encapsulating BC compared to OPEs-1. The findings might lead to a brand-new, fantastic design for distribution methods for lipophilic nutraceuticals in businesses, such as pharmaceuticals and functional meals.[36]

POTENTIAL APPLICATIONS OF OLEOGELS

Bioactive Delivery

The ability of oleogels to store and distribute lipid-soluble nutraceuticals in a controlled and focused way is being investigated by researchers. Carotene, lycopene, coenzyme Q10, DHA, EPA, tannins, and other bioactive substances that dissolve in lipids are being explored for integration into oleogel systems. These substances are known to have numerous health advantages, including reduced platelet aggregation, blood viscosity, and fibrinogen, antioxidant properties, and lower rates of chronic illnesses like cardiovascular disease and cancer. However, owing to their hydrophobic character, these bioactive are not very bioavailable in the body. By encapsulating them in oleogels, they become more accessible in the intestines. Spray drying is a method to encapsulate these beneficial substances in oleogels, which contain carbs such as modified and hydrolysed starches, cellulose derivatives, proteins such as whey proteins, caseinates, and gelatine, gums, and wall material such as cyclodextrins.[11] To accomplish desired functional advantages, molecular delivery methods are used to directly administer bioactive molecules to people. Because TAG molecules are hydrophobic, oleogel systems are a natural method to increase the bioavailability and bioaccessibility of hydrophobic bioactive molecules during oral administration. The liquid oil in the combination also contains TAG molecules, but these have modest melting temps. During digestion, the liquid oil tries to escape the gel network and spread in the body's watery phase. In this phase, the watery TAG molecules form micelles and serve as dispersing substances for the hydrophobic bioactive molecules.[3] The process of turning of hydrophobic bioactive compounds into micelles and rendering them soluble is critical in deciding their bioavailability.[5] The micelles formed during digestion travel throughout the body, serving as transporters for bioactive substances. These readily travel through hydrophobic barriers such as cell walls, which allows for better targeting and dissemination.[37]

Food Industry

Oleogel, which are semi-solid gels formed by the dispersion of a liquid oil phase in a structuring agent, have emerged as a promising alternative to traditional fats and oils in the food industry. The details are as mentioned below:

Breakfast spreads

Breakfast spreads, such as margarine and butter, can benefit from the use of oleogels to reduce the amount of saturated and trans fats, while maintaining the desired texture and flavor. The unique properties of oleogels, such as their ability to mimic the functionality of solid fats without the need for hydrogenation, make them an attractive ingredient for health-conscious consumers. Moreover, oleogels can improve the nutritional quality of breakfast spreads, as they can be formulated to contain high levels of unsaturated fatty acids, which have been associated with a lower risk of cardiovascular disease. Several studies have investigated the use of oleogels in breakfast spreads, demonstrating their potential to enhance the sensory properties and nutritional value of these products.[38,39]

Confectionery

The fat level of chocolate, compound, fillings, and other confectionery products has an enormous effect on their quality. Cocoa butter or its substitutes and milk fat are the two main fat groups used in chocolate manufacturing; these fats decide the hardness, tempering ability, and point of melting of chocolate goods. A cocoa product can contain up to 20% saturated fat on average, so alternatives that are better are in high demand.[15]

Meat products

Meat products contain naturally common trans-fats as well as high amounts of saturated fat (35%), both of which are detrimental to cardiovascular health. The beef industry's task then is to reduce these harmful fats whereas improving the fatty acid profile (a greater percentage of mono and polyunsaturated fatty acids) without compromising organoleptic properties. Oleogels are regarded as one of the most creative answers to this problem, and they have the potential to increase the nutritional content of meat products.[11] The cooking loss of the burgers was greatly decreased when beef tallow was replaced with hydroxypropylmethylcellulose oleogel, and the patties had a tender texture. The sensory rating also revealed that swapping oleogel in beef patties had no discernible effect on the sensory characteristics (e.g., color, flavor, and taste). Another group created beef patties with various amounts of oleogel and animal fat and tested their physicochemical characteristics. Although the burger containing oleogel did not have the same texture as a usual burger, the findings revealed that it had less oxidation and cooking shrinkage, as well as less cooking loss and fat absorption. Another research looked at the effect of switching pig back fat with RBW oleogels on the flavor characteristics of frankfurter-style sausages. The organoleptic evaluation scores and incisor probe analysis revealed that, while oleogels could not fully match the texture of frankfurters made with pork fat, the firmness and springiness of frankfurters made with oleogel and pork fat were nearly identical, whereas oil could not mimic those characteristics on its own. In addition, the adhesiveness of oleogels was similar to that of pig fat.[40]

Baked products

To keep their flavor, tenderness, and structure, cookies and pastries require a lot of saturated fat. One research investigated the possibility of using oleogels made from edible oil and natural waxes to substitute traditional margarine in cookie recipes to decrease the saturated fat in these pastry products. Although the kinds of oil and wax had an influence on the oleogel and cookie dough characteristics, the effect on the spread factor, hardness, and fracturability of the cookie was not worth noting. The cookies produced had qualities comparable to those of conventional margarine, implying that oleogels can be used to are substitutes saturated/trans fats in typical cookies with unsaturated fats. The physical characteristics of the biscuits improved when oleogels were used in place of shortening. An additional study found a similar result when shortening was substituted with oleogel in cookie formulations, which produced samples with high levels of unsaturated fatty acids and low levels of saturated fatty acids. The oleogel formula cookies had 92% unsaturated fatty acid concentration, whereas the shortening formula cookies had only 47.2%. The employing of oleogel instead of butter in cookie recipes reduced the viscoelasticity of the doughs, making the biscuits spreadable at heating temperature. Researchers also substituted butter with oleogel to see how it affected carbohydrate digestibility and the textural qualities of wheat sponge cake bread. The viscoelastic characteristics of the butter-fabricated blends have been lowered by increasing the oleogel concentration. This was consistent with the previous research, which found that incorporating oleogel improved the texture of the cookie. Furthermore, oleogel inclusion improved *in vitro* starch digestibility, raising the digestible starch portion from 70% to around 84%. However, this presented an issue as increased starch digestibility has been linked to a rise in metabolic syndrome-related health problems. When using oleogel for bread product composition, a trade-off between texture and carbs digestibility must be considered.[40]

Oleogel as Nutraceuticals

Oleogel have been used as a delivery system for lipophilic nutraceuticals such as vitamin E, carotenoids, and phytosterols. The oleogels provide a matrix for the incorporation of these nutraceuticals, protecting them from oxidation and degradation during storage and transportation.[41] Oleogels for Fortification of Omega-3 Fatty Acids: Omega-3 fatty acids are essential for human health, but they are not synthesized by the body and must be obtained through the diet. Oleogels have been used to fortify foods with omega-3 fatty acids such as EPA and DHA derived from fish oils. The oleogels provide a stable matrix for the incorporation of these fatty acids into food products.[42] oleogels for encapsulation of probiotics: Probiotics are beneficial bacteria that have been shown to have a positive effect on human health. However, their viability during processing and storage is a major challenge. Oleogels have been used to encapsulate probiotics, protecting them from environmental stresses and improving their survival during processing and storage.[43] Oleogels for Encapsulation of Bioactive Compounds: Oleogels have been used to encapsulate bioactive compounds such as polyphenols, which have been shown to have antioxidant and anti-inflammatory properties. The oleogels provide a stable matrix for the incorporation of these compounds into food products, protecting them from degradation during processing and storage.[44] Oleogels for Reduction of Saturated Fats: The consumption of saturated fats has been linked to an increased risk of cardiovascular disease. Oleogels have been used as a replacement for saturated fats in food products such as spreads and margarines, reducing their overall saturated fat content while maintaining their texture and sensory properties.[45] Oleogels for Encapsulation of Vitamins: Oleogels have been used to encapsulate vitamins such as vitamin D, which is important for bone health. The oleogels provide a stable matrix for the incorporation of these vitamins into food products, protecting them from degradation during processing and storage.[46] Oleogels for encapsulation of flavors and Aromas: Oleogels have been used to encapsulate flavors and aromas, which can be sensitive to oxidation and degradation. The oleogels provide a stable matrix for the incorporation of these compounds into food products, protecting them from oxidation and prolonging their shelf life.[47] Oleogels for improvement of texture and mouthfeel: Oleogels have been used to improve the texture and mouthfeel of food products, particularly in reduced-fat formulations. The oleogels can mimic the texture and mouthfeel of fats while reducing their overall fat content.[48] Oleogels for Encapsulation of Essential Oils: Essential oils have been used for their antimicrobial and antioxidant properties, but their volatility and sensitivity to oxidation can limit their use. Oleogels have been used to encapsulate essential oils, protecting them from environmental stresses and prolonging their shelf life.[49] Oleogels for reduction of cholesterol: Oleogels have been used as a replacement for animal fats, which are high in cholesterol. The oleogels can provide a healthy alternative to animal fats in food products, reducing their overall cholesterol content.[50] Oleogels for encapsulation of nutraceuticals in beverages: Oleogels have been used to encapsulate nutraceuticals in beverages, which can be challenging due to the sensitivity of the nutraceuticals to pH and temperature changes. The oleogels provide a stable matrix for the

Table 1: Several reported oleogel formulations with different polymers

S. No.	Oleogel	Excipient used	Purpose	References
1	Soya bean oil oleogel	Polymethylsilsesquioxane and Cetyl PEG/PPG-10/1 Dimethicon	To use in food and personal care products	[54]
2	Palm oil oleogel	Glycerol monostearate	To reduce the trans- fat content and improve the oxidative stability of food products	[55]
3	Olive oil oleogel	Hydroxypropyl methylcellulose	To reduce the fat content and improve the sensory properties of food products	[56]
4	Soya bean oil oleogel	Sorbitan monostearate	To improve stability and texture of products	[57]
5	Coconut oil oleogel	Xanthum gum	To improve the texture and stability of personal care products	[58]
6	Sunflower oil oleogel	Ethylcellulose	To improve the thermal stability and shelf life of cosmetic and pharmaceutical products	[59]
7	Canola oil oleogel	Hydrophobically modified starch	To reduce the fat content and improve the texture of food products	[60]
8	Palm oil oleogel	Glycerol monostearate	To reduce the trans -fat content and improve the sensory properties of food products	[61]
9	Grape seed oil oleogel	Beeswax	To improve the texture and stability of personal care products	[62]
10	Corn oil oleogel	Polyglycerol polyricinoleate	To improve rheological properties and reduce the crystallization rate in chocolate products	[63]
11	Avocado oil oleogel	lecithin	To improve the texture and mouth feel of food products	[64]
12	Fish oil Oleogel	Whey protein isolate and Candelilla wax	Health supplements	[65]
13	Rice brain oil oleogel	Stearic acid and lecithin	Antioxidant delivery	[66]
14	Hemp seed oil oleogel	Soy protein isolate and glyceralmonosterate	Health supplements	[62]
15	High oleic -sunflower oil oleogel	Sorbitan trioleate and candelilla wax	Fat replacement	[67]
16	Pumpkin Seed oil oleogel	β-Sitosterol and glyceralmonosterate	Health supplements	[68]

incorporation of these compounds, protecting them from environmental stresses and improving their bioavailability.[51] Oleogels for improvement of bioavailability: Oleogels have been used to improve the bioavailability of nutraceuticals, particularly lipophilic compounds. The oleogels can enhance the solubility and absorption of these compounds, improving their bioavailability and efficacy.[52] Oleogels for Encapsulation of Functional Ingredients: Oleogels have been used to encapsulate functional ingredients such as prebiotics and antioxidants. The oleogels provide a stable matrix for the incorporation of these ingredients into food products, protecting them from degradation during processing and storage [Table 1].[53]

CONCLUSION

Oleogels have undergone extensive development to deliver bioactive molecules. The majority of the studies concentrated on the use of oil-soluble compounds. Given their food-grade composition and tamper-proof structures, these oil-based gels might be used to regulate lipid digestibility and deliver lipid-soluble molecules. Edible oleogels have been proposed as a novel delivery material for lipid-soluble molecules. These gels may improve bioaccessibility of lipid-soluble molecules by delivering them in soluble form, as well as provide additional benefits such as protection and controlled release capabilities. Custom-made oleogel systems will be created in the future in order to control the lipolysis rate, the rate at which the oleogel structure breaks down, and the bioaccessibility of bioactive compounds all at once. However, it is crucial to fully comprehend these bioactive compounds' absorption mechanisms, and this issue needs to be dealt with in the years to come.

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