



Review

Food ingredient encapsulation using nanoliposome technology: a review study

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ABSTRACT

The nanoliposome is a microscopic vesicle containing a phospholipid bilayer that surrounds a fluid space. The thickness of this bilayer lipid is usually between 3 and 6 nm, but the liposomes formed from them can have a diameter between 50 nm to 50 μ m. Their unique properties have led to numerous applications in several scientific and technological fields. Nanoliposomes can cause controlled release of various biologically active agents, including food components and nutraceuticals at the right place and time. Therefore, nano-liposomes can increase the cellular uptake of encapsulated materials and increase their effectiveness. Food additives such as vitamins, enzymes, synthetic and natural antioxidants, synthetic and natural antibacterial compounds etc. can be converted to stable materials using nanoliposomes. As a result, this article reviews various aspects of nanoliposomes, including existing preparation techniques, and their various applications in food technology.

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1. Introduction

Nanotechnology has entered in all dimensions of human life. Undoubtedly, nanotechnology has entered in all sciences. In particular, this technology has had very significant impacts on nanomaterial production and food hygiene and safety. Design and fabrication coatings for biodegradable films with small particles is one of the most researched items. Recently, it can be said that nanoparticles are various bioactive components of food that play an important role in protecting food against adverse conditions created during the process and storage of food such as high temperature, high humidity, high oxygen, specific pH values and light exposure (1,2).

Also, this technology can be used to produce foods containing food additives with high shelf life (1,3). Another advantage of encapsulation is the controlled and targeted release of bioactive substances in commercial products or the delivery of drugs into the human body (4). One of the most popular, simple, economical, and common encapsulation methods is nanoliposomes. Nanoliposomes are bilayer compounds of polar lipids or phospholipids that contain food ingredients in nanoscale. One of the challenges facing nanoliposomes is their tendency to accumulate and increase in size during storage, so paying attention to this behavior of nanoliposomes during storage is of particular importance (5-7).

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Nanoliposomes have physical and structural properties similar to liposomes, but due to the reduction in size in the nano range, they have a higher surface area and their efficiency increases accordingly. Nanoliposomes often have a diameter range of 50-150 nm (8). Liposomes are classified by size and include MLV, MVV, ULV and DBV. ULV, Vesicles has a lipid layer that is divided into two categories: SUV and LUV, which are SUV vesicles smaller than 100 nm and LUV vesicles larger than 100 nm. MLV, multiple lipid vesicles (more than two layers), MVV vesicles are small vesicles surrounded by a single coating, and DBV is bilayer vesicles (Figure 1) (8,9).

Ultrasound and microfluidization methods transfer a lot of energy to liposomes, and this amount of energy produces smaller nano-liposomes, so more SUV is produced compared to other types of liposomes (10). By encapsulating compounds in the form of nano-liposomes, several food ingredients with synergistic effect can be encapsulated together (11). There has been an appreciable increase in the number of publications on the encapsulation of food bioactive ingredients by nano-liposome over the past 5 years. Nanoliposome encapsulation is convenient because it preserves compounds with different solubility (hydrophilic, hydrophobic and amphiphilic).

Using this method, two compounds with hydrophilic and hydrophobic properties can be encapsulated simultaneously or separately, when encapsulation occurs simultaneously, hydrophilic compounds in the nucleus of liposomes and lipophilic compounds are enclosed between membrane structures (12-14). These structures have low production costs and permeability. In addition, the ability of nanoliposomes to deliver encapsulated materials to specific target areas in food and within the body is another significant issue (15). They are also phospholipid compounds with food grade. By extracting phospholipids such as lecithin from the produced food compounds, they are approved for use in food and are safe. These nanoliposomes have the ability to be produced on a large scale.

They have health benefits due to their suitability lipid compounds. These compounds are also biodegradable (16-18). The nanoliposome encapsulation process is suitable and important for foods such as volatile compounds, oils and additives. Some additives such as some vitamins, oils, are added to enrich the food and must be delivered to certain areas of the body. These compounds are sensitive to acidic and alkaline conditions as well as the effects of enzymes in the body. The order must be maintained until it reaches the target

organ (19). For this purpose, nanoliposomes with smaller dimensions, high encapsulation efficiency and controlled release, retain the properties of encapsulated compounds in vivo for a longer period of time and release at a lower rate, in which case the use of polymers increases the stability of nanoliposomes under these conditions (20). The elements and important parameters of nanoliposome encapsulation are described in the section titled elements and parameters of nano-liposome preparation for encapsulation of food constituents. The most critical indices during nanoliposome encapsulation achieves high production efficiency with the highest encapsulation efficiency. Another important issue is the low stability of nanoliposomes at high temperatures and environmental conditions. One of the major problems in using this method which can be due to the oxidation of lipid compounds in the wall of nano-liposomes, which is vital in terms of using polymers to increase the stability of nanoliposome (21). This topic has been the focus of published works in recent years and thus it is briefly discussed in the section titled Nanoliposomes with a biopolymer coating. The aim of this study was to investigate the factors affecting the preservation of food ingredients, nanoliposomes and methods of production of nanoliposomes.

1. Elements and parameters of the preparation of nano liposomes process for encapsulating food ingredients

To prepare nanoliposomes, first liposomes are produced and then using energy-generating methods, their dimensions are reduced to nano-liposomes. The production of liposomes is done in a new and conventional way. Production of liposomes by conventional methods has disadvantages such as solvent retention, production of liposomes with larger dimensions, damage to lipid compounds, etc. Therefore, to preserve the compounds from the mentioned disadvantages, new methods can be used, which include supercritical fluid process, asymmetric double centrifuge, freeze-drying, thin-layer evaporation and membrane control technology (22). Then, to produce liposomes, first the phospholipids are hydrated with water and then, by applying sufficient energy, they produce liposome structures using vander waals force and hydrophilic-hydrophobic interactions (23).

Also, in order to apply energy for the production of liposomes, can be used from thermal methods. In this method, no solvent is used and it does not have the stress caused by pressure. In this method, the phospholipids are first hydrated and then placed on a heater store for 30 min, and to prevent heat damage, the materials to be encapsulated are added after the encapsulating liposomes are formed (24). Liposomes are then transformed into nanoliposomes using one of the methods of ultrasound, microfluidization (9), polyol dilution (25) and bubble method (26). The following is a summary of some of the more common methods for producing nano-liposomes: Ultrasound method is the simplest method of producing nano-liposomes. The ultrasound waves created by the probe can be between 16 to several hundred kHz and by creating holes in the structure of liposomes, it reduces their dimensions and turns them into nano-liposomes (27). In this method, phospholipids are first dissolved in solvents such as chloroform, then evaporated using a rotary evaporator under vacuum and the lipids are dried. The dried lipids are hydrated with the desired material for encapsulation and then stirred for 1-5 min, and finally exposed to ultrasound for 5-15 min and for 1 h at a temperature above the critical temperature in an environment with inert gas is placed to cool and stabilize (23, 28). Because it is possible to transfer titanium particles from the probe to the nanoliposomes, they are finally separated using a 0.45 μm membrane filter or centrifuge. In this method, ultrasonic bath can also be used to prevent the transfer of titanium particles (29, 30).

Microfluidization is a repeatable method, capable of producing large volumes of nanoliposomes and can also control particle size (9). The products of nanoliposomes in this way is without the use of solvent and high pressures are used to reduce the size of liposomes (31). In this case, the desired phospholipids are hydrated and then mixed using a homogenizer and converted into nano-liposomes in the microfluidizer, placed in an inert gas medium at a temperature above the critical temperature for 1 h to cool irrespective of the effect of ultrasound on a series of functional properties of food ingredients, this method for the production of nano-liposomes increases the encapsulation efficiency (32). As mentioned earlier, many studies have shown that the use of confinement of two compounds with simultaneous synergistic effect is a significant advantage of nanoliposomes. Encapsulation of nisin with garlic extract has been reported by a nanoliposome method, in order to study the

antimicrobial properties of these compounds in milk, It has been shown to have a synergistic effect in preventing the growth of microorganisms, and the remarkable point is that nisin alone has less effect on gram-negative bacteria, while in combination with garlic extract, this effect increased. The use of nanoliposome encapsulation has increased the antimicrobial effect of these compounds because it prevents interference with food compounds (43). Vitamin E (α -tocopherols), which have an antioxidant effect, oxidize themselves after neutralizing the radicals. In this case, CoQH₂ causes a synergistic effect by reducing tocopherol. Therefore, the α -tocopherol-encapsulating nanoliposomes along with CoQH₂ have been observed to increase the antioxidant effect, increase oxidative stability and control release (44). Due to the antioxidant effect of α -tocopherol and the susceptibility to oxidation of eicosapentaenoic acid (EPA) and docosahexaenoic acid (DHA), nanoliposomes are further studied together. The value of peroxide and oxidation by-products shows that in addition to the effect of nanoliposomes in preserving these compounds, the antioxidant effect of α -tocopherol also significantly reduces oxidation and loss of unsaturated fatty acids (45). Therefore, it can be concluded that nano-liposomes lead to better protection of antioxidant and antimicrobial activity against the process and storage conditions. A summary of the recent works in this field is presented in Table 1.

3. Nanoliposome encapsulation of different food bioactive compounds

Nanoliposome is a versatile process that can be used for encapsulation of almost all types of food ingredients, e.g., enzymes, bioactive peptides and molecules, phenolic compounds and antioxidants, vitamins, minerals, natural food colorants, omega-3 oils, flavors, essential oils, antimicrobial agents, and many other components. In this article, we focus on the encapsulation using nano-liposomes of several groups of bioactive food ingredients that have received much attention in recent years.

3.1. Encapsulation of antioxidant and antimicrobial compounds using nanoliposomes

Antioxidant and antimicrobial compounds are a group of food additives that are used chemically and microbes to produce foods with a long shelf life. Allicin (33), nisin (34), thymol and carvacrol (35), curcumin (36) and anthocyanins (37) are compounds with antimicrobial and antioxidant activity. These compounds, except for nisin, are essential oils and have health effects.

Some of these compounds together, such as nisin and garlic extract (38) or the use of thymol and carvacrol in combination with nisin has a synergistic effect (39). However, these compounds are highly sensitive to environmental conditions, food processing and storage, and bacteriocins and similar substances may lose their effect by reacting with food compounds and interfering with them, (40,41) so they need to be encapsulated. Nanoliposome compounding has been proven to be a popular way to protect antimicrobial and Rasti *et al* 2017, in their study on the effect of fish oil nanoliposomes on the taste of bread and fortified milk, they showed that EPA and DHA nano-liposomes encapsulated in soy phospholipids which are added to bread and milk and stored for 7 and 3 days, respectively. The rate of oxidation and loss of nanoliposomal fatty acids by measuring peroxide and anisidine is significantly lower compared to the free state and on the other hand nanoliposomes also mask the flavor of fish oil (59). The use of nanoliposomes containing DHA and EPA in yogurt shows little oxidation after 21 days of storage, while the addition of these free fatty acids is significantly oxidized and even on the first day of storage, this amount is significant (50). The data for this study was presented in Table 2. The studies on stability during storage show that omega-3 nanoliposomes produced by ultrasound are more stable, have a higher encapsulation efficiency, and a smaller average diameter than a nanoliposomes prepared by microfluidization (60).

If the oil in the nanoliposomes remains stable in the intestinal environment and is released in a way that is absorbable by the body, the encapsulation process is successful. A summary of the recent works in this field is presented in Table 2.

antioxidant compounds. A widely used compound for use in nanoliposomes is phosphatidylcholine.

Nanoliposome formation of compounds with antioxidant properties maintains the antioxidant effect for a longer period of time. Existing reports indicate that nanoliposomes have more antioxidant properties than the free form and with increasing concentration of nanoliposome extract added to DPPH solution, the amount of the mentioned property also increases significantly and the maximum value reported for it is at a concentration of 1000 µg/ ml. On the other hand, nanoliposomes will be able to maintain their antioxidant properties for a longer period of time than unenclosed extract. Also, a study has been performed on three beverages with different pH, which shows that the pH of the food composition also has a significant

effect on the stability and preservation of nanoliposomes added to the food. The encapsulated nanoliposomes are released into the food (42).

3.2. Nanoliposome Encapsulation of Omega-3

Omega 3 are a group of essential fatty acids that prevent many diseases such as cardiovascular disease (50).

This group of fatty acids includes eicosapentaenoic acid (EPA) and docosahexaenoic acid (DHA), which are abundant in marine oils. In addition, omega-3 fatty acids can be obtained from plant sources such as walnut. According to EFSA recommendations, the minimum required dose of omega-3 compounds is 250 mg per day (51). But the amount of omega 3 consumption is less than this amount and to supply this amount should be added to food products. However, these fatty acids have a long and unsaturated fatty acid chain (PUFA) which is sensitive to oxidation and also adding this compound directly to the food creates an unpleasant taste and aroma (52,53). Therefore, it is necessary to develop an effective protection strategy to facilitate their use in food products. Encapsulation of these compounds using spray drying method has been reported but has a destructive effect due to the use of high temperatures and air to dry Omega 3 fatty acids (54). Also, the use of larger scale encapsulation does not have a definite effect to prevent oxidation and does not cover the unpleasant flavors of fish oil (55). Therefore, nanoliposomes are one of the newest and most suitable technologies for encapsulating fish oils and fatty acids. The studies have shown that the use of nanoliposomization process increases encapsulation efficiency (83-95%) (56-58). There have been many related studies on the use of nanoliposomes to protect omega-3 compounds and prevent taste in products.

3.3. Nanoliposome Encapsulation of vitamins and carotenoids

The vitamins are nutrients that are not made in the body and when taken in sufficient quantities have health effects. Loss of vitamins in the structure of nutrients during food processing has led to their addition to various types of food and beverage products to create functional foods (64).

The carotenoids are one of the most important groups of natural colors that transmit yellow, orange, and red colors to vegetables. Conditions, low bioavailability, their reaction with other nutrients.

Table 1. A brief overview of recent nanoliposome encapsulation studies on antioxidant and antimicrobial compounds

Core material	Nanoliposome composition	Nanoliposome preparation method	Size (nm)	Encapsulation (%)	Results	References
Neohesperidin	soybean lecithin and cholesterol	ultrasound	92	64.25%	Increased antioxidant activity in nanoliposomes. DPPH free neohesperidin=15% DPPH nanoliposomes=25%	(46)
Turmeric extract	phosphatidylcholine	ultrasound	92	95±2%	at a concentration of 500 µg/ml DPPH free turmeric extract = 75% DPPH Nanoliposomes = 80% MIC of free extract in the case of <i>Staphylococcus aureus</i> = 20 mg/ml MIC of nanoliposomes for <i>Staphylococcus aureus</i> = 10 mg/ml MIC of free extract for <i>Escherichia coli</i> = 5 mg/ml MIC of nanoliposomes for <i>Escherichia coli</i> = 1.25 mg/ml	(42)
Betalain	soybean lecithin	ultrasound	55.35	74-76%	The results revealed that the DPPH radical scavenging activity of the samples increased by increasing the BNL concentration, when compared with blank NLS**	(47)
Allicin	Lecithin and cholesterol	ultrasound	145.25± 15.19	75%	The highest encapsulation efficiency is achieved during ultrasonication time of 3 minutes, lecithin to allicin ratio 1: 3, lecithin-cholesterol 1: 4 and PH = 6.81	(48)
Pistachio green hull extract	soy lecithin	-	90-102	52.93	Nanoliposomes composed of 1% lecithin with 1000 ppm of phenolic compounds had the highest EE***	(49)

*BNLS is betalain nanoliposomes

**NLS is nanoliposomes

***EE is Encapsulation efficiency

Table 2 . A brief overview of recent nanoliposome encapsulation studies on Omega-3

Core material	nanoliposome composition	nanoliposome preparation method	Size (nm)	Encapsulation (%)	Results	References
Fish oil	sunflower oil and lecithin	ultrasound	339	90.12±0.27	peroxide value of free fish oil on the first day=0.6 peroxide value of nano-liposomal encapsulated fish oil on the first day =0.5 peroxide value of free fish oil on the twenty-fifth day=4 peroxide value of nano-liposomal encapsulated fish oil on the twenty-fifth day=1.5	(61)
Shrimp Oil	Soy lecithin	ultrasound	104.7	93.64±0.98	The amount of peroxide after 15 days in the samples containing nanoliposomes was almost unchanged and equal to 4.6 and the amount of TBARS also changed slightly and remained approximately constant and equal to 35.	(62)
Shrimp Oil	phosphatidyl choline	ultrasound	104.7	95	The amount of peroxide of nanoliposomes produced by ultrasound method is significantly less than the number of nanoliposomes produced using microfluidization.	(63)
Fish oil	Soy lecithin	ultrasound	73.2 ± 18.1	-	significantly higher omega 3 PUFAs % recovery and lower peroxide and anisidine values were observed in nanoliposomal omega-3 PUFAs enriched samples in comparison with other samples.	(59)
Fish oil	sunflower oil and lecithin	ultrasound	400	92.22±0.19%	The value of yogurt peroxide containing free fish oil on the first day = 0.9 The value of yogurt peroxide containing fish oil freely on the twenty-first day = 1.6 The value of yogurt peroxide containing nanoliposomes of fish oil on the first day = 0.6 The value of yogurt peroxide containing nanoliposomes of fish oil on the twenty-first day = 0.7	(50)

Table 3. A brief overview of recent nanoliposome encapsulation studies on vitamins and carotenoids

Core material	Nanoliposome composition	Nanoliposome preparation method	Size (nm)	Encapsulation (%)	Results	References
Vitamin k	Cholesterol and Soy phosphatidylcholine	ultrasound	127	89.03	The highest encapsulation efficiency was obtained at a concentration of vitamin K 0.5 mg / ml, 15 minutes sonication and a ratio of phosphatidylcholine to cholesterol 1: 6	(73)
lycopene	Cholesterol and lecithin	ultrasound	40	-	activity of liver antioxidant enzymes was most strongly increased by treatment with lycopene embedded In nanoliposomes and that lycopene nanoliposomes were targeted to the liver.	(74)
Ascorbic acid	Marine phospholipids	ultrasound	236-279	55	In the ratio of 1: 3 phospholipid to vitamin C, the maximum EE is equal to 55%. This value is equal to 45% for 1: 4, 20% for 1: 5 and 40% for 1: 6.	(75)
Vitamin A	Lecithin and cholesterol	ultrasound	107	above 92%	The use of cholesterol in the preparation of nano-liposomes in the amount of 10-50 mg has reduced the particle size and stability of Nanoliposomes after 30 days of storage.	(18)
beta-carotene	soybean phosphatidylcholine	heating process	-	-	Beta-carotene nano-liposomes in polyvinyl alcohol and polyethylene oxide fibers are protected from ultraviolet radiation	(76)
Astaxanthin	soybean phosphatidylcholine	ultrasound	80.31 ± 1.80	97.49 ± 0.27	The solubility of nanoliposomes in water is 17 times that of free astaxanthin. In the free state it is 1.45 µg / ml while nanoliposomes are 25.12 µg / ml.	(77)

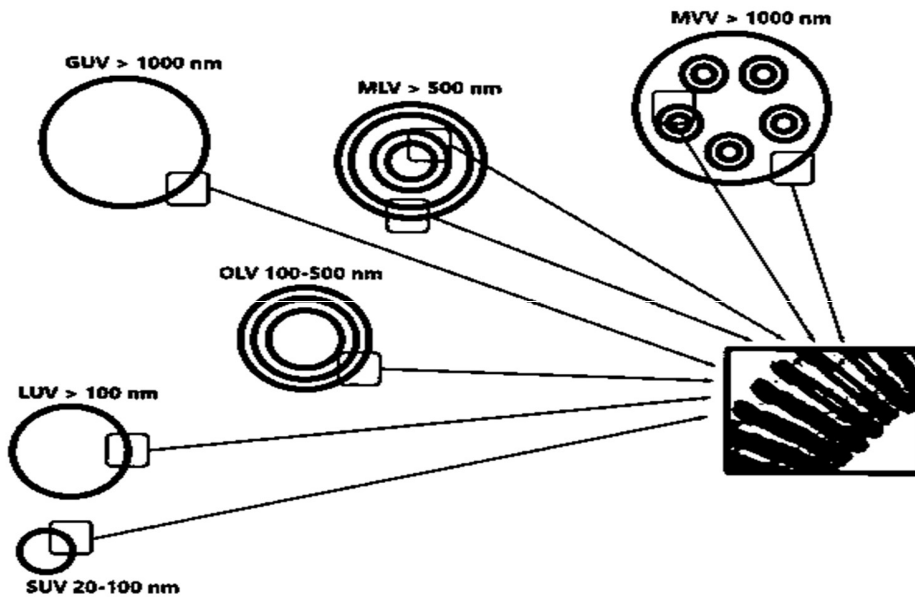


Figure 1. Different types of liposomes and nanoliposomes size

There is also the nature of hydrophobic or hydrophilic batch of these compounds. It is important to use an appropriate encapsulation method to produce and protect fortified compounds with improved stability of vitamins and carotenoids. The use of encapsulation of nano-liposomes has been a successful approach due to its ability to enclose hydrophilic and hydrophobic compounds as well as to be safe in this area (65).

Numerous studies have been performed on the effect of phospholipids of different origin used as wall materials in nanoliposomes, such as soy phospholipids and eggs on the stability of nanoliposome-encapsulated materials (66). However, some researchers have also studied the effects of milk phospholipids (67).

The vitamin C is one of the vitamins with high sensitivity to environmental factors and conditions. Also, nanoliposomes of this vitamin are less stable in acidic conditions than in neutral conditions. Use of phospholipids of milk fat globules to the wall of nanoliposomes containing vitamin C has been successful in maintaining this compound for 7 weeks, so that after this time, 67% of this vitamin is still recoverable (68).

On the other hand, other effective factors in preserving vitamin compounds in food products include the concentration of nanoliposome wall materials. In this regard, Pezeshky et al. 2016 reported that, when the concentration of lecithin-cholesterol is used in a ratio of 10-50 in the encapsulation of vitamins, an optimal result is obtained in the stability and particle size of nanoliposomes, but in this regard, vitamin A and its precursors are an exception and in any case have a lower encapsulation efficiency than other vitamins, which will be mentioned below (18). The studies have also shown that vitamin C, in addition to having health benefits, due to encapsulation with vitamin E can also enhance antioxidant activity and also alone control the oxidation process (44, 69).

The vitamins E and C have antioxidant properties and prevent damage to fatty acids by neutralizing free radicals and converting them to their oxidized state, due to the synergistic effect of these two compounds on each other and the ability of nanoliposomes to encapsulate two compounds with hydrophilic and hydrophobic properties. The use of this structure to maintain antioxidant properties and enhance this effect in food sensitive to oxidation can be significant (9). The most important carotenoids used in the food industry that are encapsulated by nanoliposomes are beta

carotene and lutein (70). The effect between carotenoids and the lipid layer and the physical stability of nanoliposomes, which affects the ability of nanoliposomes to carotenoids and, in fact, their encapsulation efficiency, largely depends on the type of wall material, the type of carotenoid and the particle size. In this case, the use of egg phospholipids with surfactant (Tween 80) have been studied in many studies and based on these studies, among carotenoids, the lutein encapsulation efficiency was higher than beta carotene, then lycopene and finally the least effect was related to canthaxanthin. This is due to their orientation in the membrane of nanoliposomes. In general, although among carotenoids the encapsulation efficiency of lutein and beta-carotene is higher, but the use of nanoliposomization process for carotenoids has a lower encapsulation efficiency than other food ingredients. It has been shown that with increasing concentration of carotenoids, particle size increases, and encapsulation efficiency decreases following this increase in concentration (71). The results of a study by Tan *et al.* in 2014 showed beta-carotene and lutein nanoliposomes showed significant antioxidant activity, while canthaxanthin and lycopene nanoliposomes had the opposite effect and acted as peroxidants. Also, the stability of nano-liposomes containing canthaxanthin and lycopene during storage is much lower than when nanoliposomes lack these compounds. Therefore, the use of Latin carota and beta-carotene nanoliposomes maintains its properties and stability in the gastrointestinal tract, while for the other group, the opposite is the case (72). A summary of the recent works in this field is presented in Table 3.

4. Nanoliposomes with polymer coating

Use of nanoliposomes is very important due to many of the mentioned benefits. It is also one of the newest methods of encapsulating food ingredients but finds these compounds have little stability in the environment and increase the size of liposomes during storage due to their interconnection (78). On the other hand, as mentioned, a number of carotenoids using conventional nanoliposomes have low encapsulation efficiency and are not able to maintain these compounds. To improve the encapsulation of carotenoids and increase the stability of nanoliposomes as well as to prevent them from binding to each other, a coating of natural polymers such as chitosan can be

used, Which is one of the newest unique bioactive formulations of food (79).

The use of chitosan due to its non-toxicity and increase in the stability of nanoliposomes has led to its widespread use in various industries. The preparation of nanoliposomes is made with a coating of a Chitosan biopolymer. After preparing the chitosan solution by dissolving chitosan in a buffer solution (acetic acid, phosphate, and sodium chloride) and stirring continuously and keeping it overnight, then nanoliposomes are added (80).

Chitosan biopolymers improve the thermal stability of nanoliposomes. Use of high concentrations of chitosan is successful in maintaining encapsulated carotenoids due to reduced membrane permeability, and this biopolymer improves the encapsulation efficiency and bioavailability of nanoliposomes in the gastrointestinal tract and in the body (81-84).

It has also been reported that chitosan coating in nanoliposomized peptides increases the encapsulation efficiency of peptides if the optimal concentration of chitosan is used, but the important point, in this case, if a higher concentration of chitosan coating is used, the diameter size of nanoliposomes increase and reduce their stability and accumulation, thereby reducing the encapsulation efficiency of nanoliposomes (21).

Following the use of polymers such as gums, after preparing nanoliposomes, it is added to the mixture at room temperature during continuous mixing. The use of guar and xanthan gums with a total concentration of 0.10% in beta-carotene encapsulation has been shown to preserve more carotenoids during 3 months of storage (85).

It can be predicted that the confinement of food ingredients with nanoliposomes coated with polymers will continue to grow as these compounds grow further in the food industry. Specifically and widely available, this new technology is very easy and very versatile, meaning that it should be suitable for use in heat-sensitive materials, bioactive peptides, and proteins, flavorings, enzymes, etc.

5. Conclusion

Nanoliposome encapsulation of food bioactive ingredients has advanced considerably in recent years, with the main goal of scientists being the optimization of the process for specific bioactive. Some carotenoids, such as lycopene and canthaxanthin, have a concern that they may cause excessive peroxidation of the nanoliposome membrane due to the encapsulated effect, which can be reduced by using biopolymer coatings, although in these cases the biopolymer

concentration should be controlled to prevent the accumulation and instability of nanoliposomes. Although the use of biopolymers cannot make the carotenoid encapsulation efficiency as significant as other food components, but it can improve this weakness to some extent. The use of nanoliposomes for omega-3 compounds has significantly reduced oxidation and has been successful in this regard. Finally, for antioxidant and antimicrobial compounds, the use of several synergistic compounds can be very significant.

Conflict of interest

Authors declare they have no conflict of interest.

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