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REVIEW

Protein-fatty acid complexes as delivery agent for fat-soluble vitamin: a review

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Abstract

Fat-soluble vitamins such as A, D, E, and K have an essential role in maintaining health. Deficiencies of vitamins A, D, E, and K are commonly known to cause night blindness, osteomalacia, increased oxidative cell stress, and hemorrhage. Vitamins are chemically reactive compounds that are fragile due to their sensitive and unstable nature. Aside from being prone to degradation due to environmental factors, the vitamins encounter various digestion factors that potentially affect their bioaccessibility and bioavailability when ingested. During digestion, the low pH environment of gastric juice may affect the bioavailability of vitamins. Decreasing vitamin bioavailability may lead to vitamin deficiency. Many methods are used for maintenance and improving vitamin bioavailability in the body. Using an encapsulation system can be helpful because it can maintain the vitamin's properties in the digestion system to optimize their benefits/uses and their bioavailability. The encapsulated substance is referred to as the core material, active agent, internal phase, or payload phase. The substance encapsulates is a coating, membrane, shell, carrier material, wall material, external phase, or matrix. It is important to use the transport medium as food and to create a barrier between the active agent and its environment. Proteins and fats are biomacromolecules that are good candidates for vitamin encapsulation. This article reviewed the protein-fatty acid complex (liprotides) potencies as a protecting and delivery agent for fat-soluble vitamins.

1. Introduction

Vitamins are small organic compounds that perform various biological roles in the body, including disease prevention, metabolic and cellular regulation, growth and development support, and reproduction support, promoting health in general (Leskova *et al.,* 2006). Since humans cannot synthesize vitamins, they must receive them through food intake. There are thirteen known vitamins, namely vitamins A, eight types of vitamin B, C, D, E, and K. B1 (thiamine), B2 (riboflavin), B3 (niacin), B5(pantothenic acid), B6 (pyridoxine), B7 (biotin), B9 (folate), B12(cobalamins) are all forms of vitamin B. These vitamins are categorized per their fat or water-soluble (Dhakal and He, 2020). Vitamins A, D, E, and K are fat-soluble, whereas the rest are water-soluble. During the digestion phase, fat helps in the absorption of fat-soluble vitamins.

Deficiencies of vitamins A, D, E, and K are commonly known to cause night blindness, osteomalacia, increased oxidative cell stress, and hemorrhage (Albahrani and Greaves, 2016), respectively, but studies have shown that low intake of these vitamins is often found in degenerative diseases or is indirectly associated with various diseases (Combs and McClung, 2017). For example, vitamin D and vitamin A deficiency are indirectly linked to the incidence of noninsulin-dependent diabetes mellitus, immune system disorders, and cancer (Albahrani and Greaves, 2016; Yosaee *et al.,* 2016; Jain *et al.,* 2017). Based on research, consumption of vitamin D can help the body fight against heart disease, autoimmune diseases, fractures, falls, cancer, influenza, type-2 diabetes, and depression (Nair and Maseeh, 2012).

Vitamins are chemically reactive compounds.

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During digestion, the low pH environment of gastric juice may affect the bioavailability of vitamins (Maurya and Aggarwal, 2017). There are several advantages of using an encapsulation system, such as maintaining and improving the natural properties of the material it protects over time, extending shelf life, control delivery, and preventing side effects (Gonnet *et al.,* 2010).

Proteins and fats are bio-macromolecules that are good candidates for vitamin encapsulation. Numerous studies have found that whey protein, including β-lactoglobulin and α-lactalbumin, bind many hydrophobic molecules (Livney, 2010), particularly vitamin D (Forrest *et al.,* 2005), retinol, oleic acid (Casbarra *et al.,* 2004), palmitic acid (Livney, 2010). Fatty acids and protein complexes, called liprotides, are complexes formed between different proteins and free fatty acids. Liprotides are composed of a core-shell form, consisting of a micelle-shaped fatty acid core coated by partially denatured proteins (Frislev *et al.,* 2018). The protein layer functions are to improve the solubility of fatty acids and carry and deliver fatty acids to the target cell or a hydrophobic surface (Kaspersen *et al.,* 2014). Such ability makes liprotides potential to carry hydrophobic molecules in a hydrophilic environment. The intestine more easily absorbs hydrophobic particles than hydrophilic particles (McClements, 2013). However, an *in vivo* study has shown that during digestion, a hydrophilic polyethylene glycol coating improves stability and bioavailability (Bellmann *et al.,* 2015). This study aimed to review different liprotides materials and explore the possibility of utilizing liprotides to deliver and protect liposoluble vitamins during digestion to improve the vitamin's bioavailability.

2. Liposoluble vitamins

Vitamins are organic molecules with a small molecular weight that play critical roles in metabolism (Combs and McClung, 2017). Vitamins are categorized as water-soluble or lipid-soluble based on their physical characteristics (Dhakal and He, 2020; Combs and McClung, 2017). Vitamins A, D, E, and K are nonpolar-solvent soluble vitamins or lipid-soluble (Combs and McClung, 2017), and will be the focus of this study. The quantities of lipid-soluble vitamins in nature and feed are likely to vary due to their stability being significantly influenced by the conditions in food production and processing (Combs and McClung, 2017). Table 1 shows the characteristics of liposoluble vitamins.

2.1 Vitamin A

Vitamin A is a vital micronutrient. In general, people associate vitamin A with eye health. However, it also plays a role in preserving the integrity of the epithelium and mucus and fostering growth and development (Huang *et al.,* 2018). Humans obtain vitamin A from their diet. Vitamin A naturally has several chemical forms such as retinal, retinol, retinoic acid, and retinyl esters. It varies depending on its function and location. In animal tissue, vitamin A is stored as provitamin A. While in green, orange, and yellow plant tissues, there are substances called carotenoids that are called preformed retinoids, meaning with a specific process, it can turn into vitamin A. Vitamin A is primarily found in milk, beef, and eggs as long-chain fatty acid esters of retinol, the most abundant of which is retinyl palmitate (Plack, 1965; Combs and McClung, 2017). Vitamin A regular consumption recommendations in Indonesia are 600 RE/day for women and 600-700 RE/day for men (Health Ministry of Republic Indonesia. 2019). In the body, retinol, retinyl esters, or provitamin A molecules such as β-carotene are the forms that vitamin A is usually absorbed. Intestinal mucosal cells take up free retinol (Dew, 1994). Any types of carotenoids ingested are either broken down to form retinol or absorbed unchanged. Additionally, free retinol may be produced in the intestinal lumen by the hydrolysis of retinyl esters. This hydrolysis process requires lipase activity. Free retinol is then included in mixed micelles and taken up by enterocytes through passive diffusion or a specific transporter such as the type 1 scavenger receptor class B (SR-B1) (Iqbal and Hussain, 2009; Gonnet *et al.,* 2010).

Although vitamin A supplementation has been considered a success, subclinical vitamin A deficiency case (<0.7 μM) has increased. Research shows that roughly 254 million individuals suffer from low serum retinol levels and or eye disorders with this deficiency. Southeast Asians account for 69% of the total (Combs and McClung, 2017). According to evidence from 122 nations, subclinical vitamin A deficiency is linked to an elevated risk of child mortality. Vitamin A deficiency has long been linked with high morbidity and mortality rates; recent intervention studies have shown that supplementing with vitamin A will minimize infant mortality by around 25% and maternal mortality by 40% (Combs and McClung, 2017). According to a study reported in 2013, the incidence of vitamin A deficiency in Indonesia was higher in the age group 9.0-12.9 years, 4.9% in urban areas and 4.8% in rural areas, relative to the age group 1.0-2.9 years, 3.1% in rural areas but not seen in urban areas (Ernawati *et al.,* 2013). Active infection tends to modify vitamin A utilization or, at the very least, distribution within tissues. During malaria outbreaks, chickenpox, diarrhea, measles, and respiratory illness, plasma retinol concentrations decrease (Combs and McClung, 2017). The risk of infection-related death increases fivefold in women suffering from night blindness in Nepal. Vitamin A in low doses intake

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Table 1. Characteristics of liposoluble vitamins.

Component	Characteristics	Stability
Vitamin A	Vitamin A naturally has several chemical forms such as retinal, retinol, retinoic acid, and retinyl esters. It varies depending on its function and location. Primarily found in milk, beef, and eggs as long-chain fatty acid esters of retinol, the most abundant of which is retinyl palmitate (Plack, 1965; Combs and McClung, 2017). Vitamin A regular consumption recommendations in Indonesia are 600 RE/day for women and 600-700 RE/day for men (Health Ministry of Republic Indonesia, 2019).	Vitamin A is degraded in the presence of prooxidant agents, heavy metals, free radical-generating agents, and radiation (Burri *et al.,* 2011).
Vitamin D	Vitamin D is generated in the skin as a result of sun exposure. Vitamin D is available only in trace quantities in nature in the form of vitamin D2 or vitamin D3 (Combs and McClung, 2017). Some invertebrates, plants, lichens, molds, and fungi contain ergocalciferol and ergosterol (precursor of ergocalciferol) (Lehman *et al.,* 2015; Jäpelt and Jakobsen, 2013). Vitamin D regular consumption recommendations in Indonesia are 15-20 mcg depending on age (Health Ministry of Republic Indonesia, 2019).	Vitamin D is a hydrophobic substance composed of a big sterol molecule that is light-sensitive, heat-sensitive, and oxidatively degraded (Pedersen *et al.,* 2016). Vitamin D is unstable in the stomach's acidic environment (Berdainer and Zempleni, 2009).
Vitamin E	Vitamin E is essential for the proper metabolism of all of the body's cells as an antioxidant. The need for vitamin E for a person depends on one's exposure to antioxidants and prooxidants (Combs and McClung, 2017). Humans and livestock get vitamin E mainly from vegetable oil. Other sources such as plants, cereal grains, and seeds also contain vitamin E, although only in smaller quantities (Maras *et al.,* 2004). Vitamin E intake is recommended at 11-20 mcg/day in Indonesia, depending on age and gender (Health Ministry of Republic Indonesia, 2019).	Vitamin E is somewhat unstable in aerobic environments. They are easily oxidized and damaged by peroxides, ozone, and permanganate in a process intensified by PUFAs and metal salts (Combs and McClung, 2017).
Vitamin K	Vitamin K is involved in bone formation, blood clotting, and a variety of other functions. Humans obtain vitamin K from plants and bacteria that can synthesize it. Vitamin K is often referred to as phylloquinone and menaquinones (MK). Vitamin K is most often present in foods such as phylloquinone. Green vegetables (e.g. kale and mustard green), margarine, and vegetable oil are examples of sources of phylloquinone. Vitamin K consumption is advised around 35-65 mcg/day in Indonesia, based on gender and age (Health Ministry of Republic Indonesia, 2019).	Vitamin K is partially soluble in ethanol but easily dissolves in ether, chloroform, fats, and oils. The vitamers are light and alkali sensitive but are relatively stable in hot and oxidizing conditions (Combs and McClung, 2017).

decreases perinatal and postnatal death in women. This finding is consistent with vitamin A's function in infection prevention (West *et al.,*1999).

Vitamin A supplementation reduces more than 30% the prevalence of malaria (without complication). Serum retinol deficiency is more prevalent in HIV+ individuals than in non-infected individuals. Individuals who are overweight or obese have elevated plasma apo-RBP4 levels (Yang *et al.,* 2005) but normal levels of retinol (Mills *et al.,* 2008). Individuals with long periods of elevation in RBP are at high risk of developing type 2 diabetes (Sun *et al.,* 2014). Plasma retinol levels are negatively correlated with the incidence of brain ischemia, while low-plasma β-carotene levels are linked to an elevated risk of heart attack (Hak *et al.,* 2003). One of the ways to increase the nutritional value of food is by fortification. An example of a program carried out in the United States is the "golden rice" program, where the use of technology, rice varieties containing β-carotene are produced (>35 g/g). In addition, the US government also conducts biofortification on certain types of maize, cassava, sweet potatoes, and carrots (Combs and McClung, 2017).

In Indonesia, the government has implemented various programs to address vitamin A deficiency, especially in children, including vitamin A supplementation every six months for children under the age of five, food diversification, yard use, and fortification (Achadi *et al.,* 2010). In 1978, Indonesia's first nationwide study revealed a prevalence of xerophthalmia (X1B) of 1.33%, ranging from 0.55 to 2.34%, significantly higher than the WHO comparison for measuring clinical vitamin A deficiency issues (Muhilal *et al.,* 1994). Indonesia then launched a scheme to administer vitamin A capsules at a high dosage to children aged six to nine years and postpartum mothers (Health Ministry of Republic Indonesia, 2009). A 1992 nationwide study found that the incidence of xerophthalmia decreased from 1.33% in 1978 to 0.34% after a high-dose vitamin A capsule policy was implemented for children aged 6-59 months and postpartum mothers (Muhilal *et al.,* 1994; Health Ministry of Republic Indonesia, 2009; Sandjaja and Sudikno, 2015). In terms of fortification, producers in Indonesia have been needed or voluntary to add vitamin A to cooking oil (Rokom, 2019). Numerous pilot experiments and trials have been conducted with positive

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outcomes to bolster the cooking oil fortification scheme (Achadi *et al.,* 2010; Sandjaja *et al.,* 2015).

2.2 Vitamin D

Vitamin D, also known as the "sunshine vitamin," is a hormone generated by sterol in the body in response to ultraviolet light's photolytic action on the skin. With moderate amounts of sunlight, people will develop vitamin D on their own (Combs and McClung, 2017). Vitamin D is generated in the skin as a result of sun exposure. This process converts 7-dehydrocholesterol to cholecalciferol. Then cholecalciferol is converted into 25 -hydroxycalciferol in the liver and 1,25-dihydroxycholecalciferols in the kidneys. While the human body can synthesize vitamin D, it will fall short of everyday needs, especially for people with a dark complexion, who spend little time outdoors, or who reside in northern latitudes. These people need to receive vitamin D from food consumption; it is a vitamin for them in the familiar context (Combs and McClung, 2017).

Vitamin D is present in nature in the form of provitamin rather than ergocalciferol (vitamin D2) or cholecalciferol (vitamin D3), typically found in supplements. Vitamin D is available only in trace quantities in nature in the form of vitamin D2 or vitamin D3 (Combs and McClung, 2017). Some invertebrates, plants, lichens, molds, and fungi contain ergocalciferol and ergosterol (precursor of ergocalciferol). Ergosterol is found in higher vertebrates only in trace concentrations as they eat it. Vitamin D3 can be present in animal tissue, but only if the animal's diet contains vitamin d3 and or the animal receives sufficient sunlight exposure. Therefore the vitamin d3 concentration in animal tissue is varied. Fish, liver, and oils contain vitamin D in the free form and long-chain fatty acid esters. They are the richest form of vitamin D found in nature. Being on top of the food chain, fatty fish can provide significant amounts of vitamin D because of the accumulation of vitamin D from consuming organisms that feed on ergosterol-containing microalgae (Jäpelt and Jakobsen, 2013; Lehmann *et al.,* 2015). Vitamin D regular consumption recommendations in Indonesia are 15-20 mcg depending on age (Health Ministry of Republic Indonesia. 2019).

Vitamin D deficiency affects over a billion people worldwide of all ethnic backgrounds and ages, rendering it a global public health problem (Nair and Maseeh, 2012). Vitamin D deficiency affects between 40% and 75% of the adult population, depending on the country (Palacios and Gonzazel, 2014; Hilger *et al.,* 2014; Combs and McClung, 2017). Infants are also susceptible to vitamin D deficiency. Although not all countries have data on infant vitamin D status, countries such as Iran, Turkey, India, and Pakistan reveal that nearly all infants are vitamin D deficient (Combs and McClung, 2017). According to studies conducted in Indonesia, the incidence of vitamin D deficiency (serum 25 (OH) D 25 nmol/L), insufficiency (25-49 nmol/L), inadequacy (50-74 nmol/L), and desirable (> 75 nmol/L) in children aged 2-12.9 was 0%, 45.1%, 49.3%, and 5.6%, respectively (Ernawati and Budiman, 2015). From different studies, based on the deficiency standard of WHO (< 50 nmol/L), the prevalence of vitamin D deficiency was 38.76% in children aged 2-12 (Valentina *et al.,* 2014)

Vitamin D deficiency has the most significant effect on osteoporosis, bone diseases, and rickets (Combs and McClung, 2017). Vitamin D, together with magnesium, phosphorus, and calcium, is vital for mineral and bone metabolism in the body. Therefore, it is also essential for maintaining healthy bones and teeth (Combs and McClung, 2017). Besides rickets and osteomalacia, vitamin D inadequacy is associated with a vast range of acute and chronic diseases, including type-2 diabetes, heart disease, cancer, pregnancy complications, respiratory infections, influenza, asthma, early death, depression, fractures and falls, and autoimmune disorders (Nair and Maseeh, 2012; Pliz *et al.,* 2018). Vitamin D has a role in how autoimmunity is regulated. Some research, but not all, has linked depleted 25-OH-D3 concentration to an elevated risk of asthma (Kerley *et al.,* 2015). Vitamin D may aid in the prevention of type 1 diabetes. It has been shown that a large dosage of 1,25-(OH)2-D3 will halt diabetes in nonobese diabetic mice (Combs and McClung, 2017). Vitamin D's efficacy in preventing type 2 diabetes can differ due to a person's extent of fat mass in the body. The association between vitamin D status and risk of type 2 diabetes is most substantial in individuals with obese or overweight (Isaia *et al.,* 2001). Vitamin D levels in food are low, making it extremely hard to fulfill vitamin D needs even when consuming the recommended amount of food. To address this problem, the governments of numerous countries fortified foods frequently eaten in their respective countries. Vitamin D fortification in the diet can be a cost-effective way to improve public health (Pilz *et al.,* 2018). Fortification of vitamin D can be done by adding vitamin D2 and or vitamin D3 to food or animal feed. Certain nations require vitamins D and A to be included in margarine and arrange voluntary additions to orange juice, milk, cheese, yogurt, baby food, baked goods, and breakfast cereals (Combs and McClung, 2017). A meta-analysis showed that consuming 1 μg vitamin D3 from fortified foods resulted in an average rise of 1.2 nM in plasma 25-OH-D3 concentration (Black *et al.,* 2012; Combs and McClung, 2017).

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2.3 Vitamin E

Vitamin E is essential for the proper metabolism of all of the body's cells. In the process of metabolism, the body will produce reactive oxygen species. This substance has potentially damaging effects on the body. Apart from metabolic products, these substances can also be found in the environment. Vitamin E with other nutrients forms a multi-component system to protect the body from the effects these substances produce. The need for vitamin E for a person depends on one's exposure to antioxidants and prooxidants. The same factors also determine the effects of deficiency. Vitamin C and selenium are examples of antioxidants, while ultraviolet (UV) rays, air pollution, and polyunsaturated fatty acids (PUFAs) are examples of prooxidants (Combs and McClung, 2017).

Humans and livestock get vitamin E mainly from vegetable oil. Other sources such as plants, cereal grains, and seeds also contain vitamin E, although only in smaller quantities (Maras *et al.,* 2004). Vitamin E may also be found in animal meat, but only from vitamin E-supplemented animals. Vitamin E supplementation at a dose of 10-50 times the standard practice of beef, swine, and poultry diet effectively increases vitamin E content in the animal's tissues (Sales and Koukolová, 2011). Vitamin E intake is recommended at 11-20 mcg/day in Indonesia, depending on age and gender (Health Ministry of Republic Indonesia, 2019).

Vitamin E has been shown in recent research to play a non-antioxidant function in controlling gene expression and cell signaling. High-dose consumption of vitamin E has helped reduce low-density lipoproteins (LDLs) oxidation, helping to decrease the chances of developing atherosclerosis (Combs and McClung, 2017). Vitamin E plays a significant function in cell metabolism. Its deficiency can thus impact various organ systems. The deficiency of vitamin E in adults is uncommon. Clinically, it presents as hemolytic anemia, a condition in which destroying red blood cells is faster than the process of making it after prolonged phases of body store exhaustion. Long-term deficiency may result in damage to the spinal cord and cerebellar, manifesting as weakened reflexes, weakened proprioception, and ataxia. Pregnant women who have a subclinical vitamin E deficiency raise their chances of miscarriage since they are more susceptible to oxidative hemolysis induced by the deficiency (Shamim *et al.,* 2015). Vitamin E deficit manifests as edema and bleeding in ventricular membrane in premature babies. Vitamin C and vitamin E deficiency are contributing factors for elevated bilirubin levels in neonates (Sareharto *et al*., 2016).

Oxidative stress is implicated in several disorders linked with insufficient vitamin E levels. Vitamin E has repeatedly been shown to decrease the likelihood of developing cardiovascular disease risk in observational studies (Cordero *et al.,* 2010). Vitamin E consumption is inversely correlated with the likelihood of Alzheimer's disease, cognitive impairment (Mangialasche *et al.,* 2013), and Parkinson's disease, all of which are believed to be caused by oxidative stress. High O2 gases, oxidants, and irritants of the environment can be harmful if continuously exposed to the lungs. Vitamin E has protective effects against this as well as from chronic smog exposure (Radhakrishnan *et al.,* 2014). Vitamin E has been proven in a randomized experiment to protect against the development of type 2 diabetes in participants with impaired glucose tolerance (Mayer *et al.,* 2002), and high-dose vitamin E supplements (e.g., 900 mg α-tocopherol per day) have been demonstrated to enhance insulin responsiveness in both ordinary and patients with type 2 diabetes (Combs and McClung, 2017).

Fortification of foods is beneficial in rising circulating α-tocopherol concentrations in experimental studies (Van Het *et al.,* 1998; Hayes *et al.,* 2001; Leonard *et al.,* 2004). Natural (RRR-) and synthetic (all-rac-) α-tocopherol are vitamin E forms that have been widely studied for supplementation and fortification in adult subjects. Some breakfast cereals, fruit juice, margarine, and milk are fortified with α-tocopherol (Dror and Allen, 2011).

2.4 Vitamin K

Vitamin K is involved in bone formation, blood clotting, and a variety of other functions. Humans obtain vitamin K from plants and bacteria that can synthesize it. Vitamin K is often referred to as phylloquinone and menaquinones (MK). Vitamin K is most often present in foods such as phylloquinone. Green vegetables (e.g., kale and mustard green), margarine, and vegetable oil are examples of sources of phylloquinone. Meanwhile, MK is derived from foods fermented by bacteria (cheese, yogurt, and natto (Agricultural Research Service, 2021)) that produce long-chain MK (MK-8 and MK-9) (Morishita *et al.,* 1999). Vitamin K can also be found in animal tissues if the animals are given vitamin K supplements such as menadione in their feed (Combs and McClung, 2017). Vitamin K consumption is advised around 35-65 mcg/day in Indonesia, based on gender and age (Health Ministry of Republic Indonesia, 2019).

Asymptomatic deficiency of Vitamin K has been associated with an increased risk of hemorrhagic illness in up to a third of Americans, including premature babies, born with inadequate Vitamin K levels. Hematologic disorders, such as intracranial bleeding, are usually linked with IMR 10-50% owing to vitamin K

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insufficiency (Hanifa *et al.,* 2017). Vitamin K seems to work in conjunction with other vitamins to regulate intracellular Ca^{2+} metabolism, signal transduction, and cell proliferation, both of which significantly impact health status (Combs and McClung, 2017).

Obesity has been linked with vitamin K deficiency since adipose tissue absorbs relatively high amounts of the vitamin (Shea *et al.,* 2010). The glucose metabolism parameters are inversely related to serum levels of total osteocalcin but not undercarboxylated osteocalcin (Booth *et al.,* 2013). In women, phylloquinone levels are inversely related to body fat percentage (Shea *et al.,* 2010); higher levels correlate with improved insulin sensitivity and glycemic regulation as measured by oral glucose tolerance tests (Yoshida, Booth, Meigs *et al.,* 2008). A three-year intervention research discovered that supplementing phylloquinone decreased insulin resistance in males (Yoshida, Jacques, Meigs *et al.,* 2008). However, neither the trial nor another discovered any significant advantages for women (Kumar *et al.,* 2010). The fortification for vitamin K was not very common, and only a limited number of topics were examined. Administering fortified menaquinone-7 yogurt in a healthy population indicated an increase in vitamin K levels after three months (Knapen *et al.,* 2015). Additionally, fortification with phylloquinone was attempted on oil, but the findings were inconclusive (Booth *et al.,* 2002).

3. Liposoluble vitamins stability

Liposoluble vitamins are very fragile antioxidants. Environmental factors including oxidation, light and high temperatures will deteriorate their efficiency significantly. Since they are liposoluble, they interfere with phospholipid membranes and thereby affect the chemical and physical stability of biological membranes (Gonnet *et al.,* 2010). Stability is a significant issue whether vitamins are used as food sources, nutritional supplements, or medications. The stomach is usually found to be very acidic with a pH of 2 to 3 or higher during the ingestion of food (Boland, 2016). This poses a challenge, since retinol, retinal, Vitamin D2, Vitamin D3, tocopherols, and tocopherol esters are all unstable in an acidic setting (Combs and McClung, 2017).

Other lipid materials dissolve lipid-soluble vitamins and other hydrophobic substances (e.g., cholesterol and carotenoids) (Combs and McClung, 2017). As a consequence, on a low-fat diet, lipid-soluble vitamins are poorly absorbed. Vitamin D3 absorption from fat-free meals is significantly lower than from fat-containing meals, according to studies.[71] Because fat-soluble vitamin absorption depends on micellar dispersion, it is hindered in lipid malabsorption or low dietary fat intake (<10 g/day) (Combs and McClung, 2017).

3.1 Vitamin A

Vitamin A naturally has several chemical forms such as retinal, retinol, retinoic acid, and retinyl esters. It varies depending on its function and location (Gonnet *et al.,* 2010). Vitamin A is degraded in the presence of prooxidant agents, heavy metals, free radical-generating agents, and radiation. A study calculated the bioconversion efficiency of β-carotene to retinol is roughly 50%, while intestinal absorption is roughly 33%. Additional research has shown that the bioconversion of dietary carotenoids to Vitamin A varies widely (10–90%) (Burri *et al.,* 2011). Low bioconversion is a typical occurrence in resource-poor nations, where children acquire vitamin A virtually exclusively via the conversion of β-carotene from fruits and vegetables (de Pee *et al.,* 1995). Apart from vitamin A status, which has an inverse relationship with carotenoid conversion performance, many other factors may impair conversion efficiency, including tropical enteropathy, intestinal roundworms, low-fat diets, chronic diarrhea, and other factors affecting the intestinal epithelium's absorptive role and transit period (Combs and McClung, 2017).

3.2 Vitamin D

Vitamin D is a cholesterol derivative that comes in a variety of bio equivalents; the most often used in dietary supplementation and fortification are Vitamin D2 (ergocalciferol) and Vitamin D3 (cholecalciferol). Vitamin D3, on the other hand, has a greater capacity for increasing serum 25 [OH] D than vitamin D2 (Kennel *et al.,* 2010; O'Mahony *et al.,* 2011). Vitamin D is a hydrophobic substance composed of a big sterol molecule that is light-sensitive, heat-sensitive, and oxidatively degraded (Pedersen *et al.,* 2016). Additionally, vitamin D is unstable in the stomach's acidic environment (Berdainer and Zempleni, 2009). This situation can impair the body's Vitamin D stability and bioavailability. The bioavailability of Vitamins D varies due to their biopotency variability, but a recent meta-analysis discovered that bolus doses of Vitamin D3 provided more substantial 25-OH-D responses in humans than Vitamin D2 (Tripkovic *et al.,* 2012).

3.3 Vitamin E

Vitamin E is somewhat unstable in aerobic environments. They are easily oxidized and damaged by peroxides, ozone, and permanganate in a process intensified by PUFAs and metal salts (Combs and McClung, 2017).

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3.4 Vitamin K

The K and MK vitamers, as well as the majority of menadione types, are insoluble in water. They are partially soluble in ethanol but easily dissolve in ether, chloroform, fats, and oils. The vitamers are light and alkali sensitive but are relatively stable in hot and oxidizing conditions (Combs and McClung, 2017).

4. Liposoluble vitamins encapsulation

Encapsulation is a process in which one substance is encased within another, resulting in particles with diameters ranging from a few nanometers to a few millimetres. The encapsulated substance is referred to as the core material, active agent, internal phase, or payload phase. The substance encapsulates is a coating, membrane, shell, carrier material, wall material, external phase, or matrix. It is important to use the transport medium as food and to create a barrier between the active agent and its environment. Encapsulates are classified into two broad categories: reservoirs and matrixes. The reservoir is encased in a shell. Additionally, this type is referred to as a capsule, a single -core, a mono-core, or a core shell. Pressure applied to a reservoir form can cause it to rupture, thereby releasing its contents. The matrix-type encapsulates contain several reservoir chambers within a single particle. The active agent in the matrix type is much more dispersed throughout the carrier material; it may be as small as droplets or as uniformly distributed throughout the encapsulation. In general, active agents in the matrix type are present on the surface (unless they are coated), in comparison to those in the reservoir type (Zuidam and Shimoni, 2010).

During digestion, the lipid content of meals has a significant effect on the intestinal absorption of liposoluble vitamins (Huo *et al.,* 2007; Dawson *et al.,* 2015). Encapsulation should prevent vitamins from complexing in the gastrointestinal tract or limit their release in oral administration applications (Gonnet *et al.,* 2010). Encapsulation may also be used to improve their bioaccessibility and bioavailability. If the carriers are not digestible, they may be absorbed in enterocytes or via paracellular pathways such as gap junctions. Alternatively, a lipidic fraction derived from degraded carriers could be incorporated into mixed micelles and followed through their normal absorption pathway (During *et al.,* 2005). Particle characteristics are determined by the process chosen, the excipients' physicochemical properties, and the excipients' interactions with the encapsulated vitamin (morphology, surface charges, permeability, and encapsulation efficiency). There are two major types of particles that have emerged: (i) lipid-based formulations in which vitamins are solubilized; and (ii) vitamins matricial entrapment by a polymer. These particles are formed by physicochemical or mechanical processes (Gonnet *et al.,* 2010). Encapsulation may improve efficacy by allowing for lower administration doses, thereby minimizing the appearance and side effects of hypervitaminosis syndrome. For instance, vitamin E encapsulated in NanoSolve® was found to be tenfold more bioavailable than the same oil in commercial gelatin capsules (Wajda *et al.,* 2007). Vitamin A and E bioavailability were increased by three and five to eightfold, respectively using Aqua-biosorb® when compared to capsules filled with oil, tablets, or water-dispersible capsules were used (Gonnet *et al.,* 2010). Vitamin A fortification is not straightforward due to these compounds' low polarity, which makes them insoluble in aqueous systems such as beverages. By incorporating colloidal nano lipid carriers, vitamin A's dispersibility and stability can be enhanced (Pezeshki *et al.,* 2014). Microdispersion of α-tocopheryl acetate in a fat emulsion appears to be especially advantageous in nutrient stability and impact on plasma α-tocopherol (Leonard *et al.,* 2004).

5. Encapsulation materials

Numerous substances can be used to trap, wrap, or bottle various types of liquid or gaseous substances. While a number of these substances have been approved for use in food, the vast majority have not. Should be mentioned that food additives are subject to stricter regulations than pharmaceuticals or cosmetics. As a result, certain well-established encapsulation techniques remain unapproved for use in the food industry. Additionally, each food producer must adhere to unique regulatory requirements when exporting or expanding their respective markets. While microencapsulation has found applications in the food industry, it is still far from being fully exploited. Exciting new techniques such as co-crystallization and liposome formation will significantly increase both the quantity and quality of encapsulated ingredients. Numerous encapsulation techniques have encountered limitations as a result of their high manufacturing costs and scarcity of food-grade materials. Liposomes in the food industry require significant research. In comparison to the pharmaceutical industry, which can afford high manufacturing costs, food applications will require cost reductions (Gibbs *et al.,* 1999). The food industry's most frequently used microencapsulation material is biomolecules. Along with carbohydrate polymers/polysaccharides, the most abundant of the four major biomolecular groups, proteins and lipids are also suitable for microencapsulation in the food industry.

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5.1 Protein

Proteins are naturally occurring macromolecules consisting of amino acid chains. The potential sequences and frequencies of the chain's twenty current amino acids, or more specifically 19 amino acids and one imino acid, result in their enormous variety. Proteins perform a wide variety of roles in all living species. Proteins are used directly as food in large quantities. The application's scope for non-traditional uses is being expanded. Along with water, lactose, fat, and other minor components, bovine milk contains approximately 3.0–3.6 weight percentage proteins. Two significant fractions are caseins and whey proteins. The purpose of this review is to increase our understanding of the potential of whey protein, specifically α-lactalbumin and β-lactoglobulin. Whey is a by-product of the cheese or casein manufacturing processes and has a variety of commercial applications. Additionally, the whey proteins fraction is highly heterogeneous, consisting primarily of α-lactalbumin, β-lactoglobulin, immunoglobulins, and serum albumin, but also a variety of minor proteins (O'Regan *et al.,* 2009). Table 2 shows the comparison of material and properties of protein and liprotides as delivery and protective agent.

5.1.1 α-lactalbumin

α-lactalbumin is a whey protein consisting of 123 amino acids, with a molecular weight of 14.2 kD. Human milk contains most of this α-lactalbumin, while cow's milk contains approximately 1.0-1.5 g/L or 3.4% of the total protein. The α-lactalbumin is present in 17% of whey protein isolate. Bovine α-lactalbumin's natural structure is composed of a large helical domain and a small beta layer domain connected by a loop. The α-lactalbumin contains a spacer between two domains, four disulfide bridges, and a single hydrophobic pocket (Delavari *et al.,* 2015). This hydrophobic sac gives α-lactalbumin a binding site that can be used to bind other compounds, like Vitamin D3. Native α-lactalbumin is highly affected by calcium ions, where the release of calcium ions alters the tertiary structure of α-lactalbumin. Oleic and palmitic acids cannot bind to holo -lactalbumin, but apo-lactalbumin has a binding site for oleic acid and another for palmitic acid (Delavari *et al.,* 2015).

Certain pH, temperature, and ionic conditions can influence the solubility of α-lactalbumin (Zadow, 2003). The α-lactalbumin has a single Vitamin D3 binding location based on Delevari et al (Delavari *et al.,* 2015). Its secondary structure changes when Vitamin D3 is present. The random spinal increase indicates a decrease in the structural order when Vitamin D3 is binding (Delavari *et al.,* 2015). Additionally, α-lactalbumin has the ability to bind hydrophobic ligands such as retinol (Livney, 2010), hydrophobic peptides, bee venom melithin (Barbana *et al.,* 2006), and oleic acid (Gustafsson *et al.,* 2005). Hydrophobic interactions alter the protein's conformation and increase the hydrophobic surface area of α-lactalbumin. The amino acid α-lactalbumin, which includes 48 mg of tryptophan per gram of protein (Layman *et al.,* 2018), increases blood tryptophan levels, thereby facilitating serotonin synthesis and availability in the brain. The scalding protein can help in the digestion, absorption, and utilization of amino acids by generating a cysteine from α-lactalbumin and various lower-methionine cysteines. The α-lactalbumin also forms complexes with oleic acid (OA), resulting in tumor cell cytotoxicity (Casbarra *et al.,* 2004; Pedersen *et al.,* 2016). Cysteine is required in sufficient amounts through diet and supplementation to promote glutathione and methionine production. It is well-known that cysteine and methionine are the two whey protein composites with a ratio of 5:1. For the methylation cycle and nucleotide synthesis of the building blocks of DNA, methionine is essential, along with folate, Vitamin B12, and choline. Too much methionine can inhibit the remethylation of homocysteine, which leads to the blood formation of homocysteine. Cardiovascular disease, osteoporosis, and other chronic health problems have included elevations of homocysteine.

5.1.2 β-lactoglobulin

The most prevalent protein in whey is β-lactoglobulin. It comprises 10% of the total milk protein or about 58% of the whey protein. The properties of whey protein concentrate are in fact the properties of β-lactoglobulin because of its prevalence in bovine milk. β-lactoglobulin is the primary component of milk skin, a thin gelatinous layer that forms on the surface of milk as a result of denaturation when the milk begins to boil. β-lactoglobulin dissolves in a solution of sodium chloride. Although many have speculated some biological roles for β-lactoglobulin, none has entirely been accepted to date by the scientists. β-lactoglobulin is made up of 162 amino acids and has a molecular weight of 18.4 kDa. β-lactoglobulin has an anti-parallel beta-barrel with three alpha-helix loops on the outer surface beta-helix strand that surrounds the first strand. The structure of β-lactoglobulin can fold into eight strands (Kontopidis *et al.,* 2004). β-lactoglobulin is a member of the lipocalin protein family (Magdalini *et al.,* 2013) that binds hydrophobic ligands such as fatty acids, retinol, and Vitamin D (Diarrassouba *et al.,* 2014). It also binds iron through siderophores (Roth *et al.,* 2014). β-lactoglobulin seems to have more than one binding spot. However, the precise position of the weaker site is yet to be determined. The molecule has a hydrophobic area that

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Table 2. Comparison materials and properties.

Wall Materials	Core Particles	Properties as		Source
		Protective agents	Delivery agents	
Protein				
α-lactalbumin	Oleic and Palmitic Acids	HOLO α-lactalbumin exhibited no interaction with any of the two fatty acids (oleic or palmitic acids) tested under non-denature conditions. The interaction between APO α-lactalbumin and fatty acids was observed because of the conformational changes in α-lactalbumin caused by calcium elimination.	The low pH of the stomach is known to allow α-lactalbumin to partially unfold to become the active apoptotic shape. Hydrolysis of lipids results in the release of oleic acid by acid lipases.	Barbana *et al*. (2006)
α-lactalbumin	Oleic Acid		The research observed a wide range of human benefits. When HAMLET is present in the stomach of a breastfed child, the low pH causes the protein to unfold by the release of calcium, and acid-sensitive lipases hydrolyze milk triglycerides to form oleic acid. We speculate that HAMLET may kill virus-transformed disease.	Gustafsson *et al.* (2005)
α-lactalbumin	Vitamin D3	Van der Waals, hydrogen bond, and hydrophobic interactions are essential in binding Vitamin D3 to the α-lactalbumin hydrophobic pocket. The α-lactalbumin and vitamin D3 complex have a much larger particle size than the native protein. In the presence of vitamin D3, the thermal stability of the protein decreases. The resulting complex is a promising candidate for enhancing low-fat foods and non-alcoholic beverages.		Delavari *et al.* (2015)
β-lactoglobulin	Palmitic acids	The globular structure of β-lactoglobulin enables it to spontaneously attach hydrophobic ligands such as fatty acids. The β-lactoglobulin calyx is the main binding site for hydrophobic ligands. A secondary binding site is situated next to the dimer interface on the surface of the protein. Palmitic acid is the fatty acid that is most closely attached to the β-lactoglobulin structure.	As β-lactoglobulin interacts with a ligand, such as fatty acids, it alters the ligand's bioavailability. The low solubility of fatty acids increases β-lactoglobulin bioaccessibility and vice versa. This finding establishes a mechanism for regulating fatty acid absorption during digestion. As such, β-lactoglobulin can be used in food matrices to modulate fatty acid bioavailability.	Maux *et al.* (2014)
β-lactoglobulin	Oleic acid and linoleic acid	LA binding to β-lactoglobulin improves its thermostability, while OA binding has no impact. On β-lactoglobulin, there are more binding sites for OA than for LA, despite the fact that their binding constants were similar i.e. both acids interact with the protein through van der Waals and hydrogen bonding.		Fang *et al.* (2015)
β-lactoglobulin	Fish oil	Complex coacervates consisting of gelatin or beta-lactoglobulin, gum Arabic, starch and glutaraldehyde were shown to reduce fish oil oxidation.		Friedmann *et al.* (2005)

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Table 2 (Cont.). Comparison materials and properties.

Wall Materials	Core Particles	Properties as		Source
		Protective agents	Delivery agents	
β-lactoglobulin	DHA	Excess pectin resulted in the formation of negatively charged particles containing 166 times the amount of DHA contained in the surrounding serum. This process resulted in the development of dilutable nanoparticle dispersions that shaped clear solutions comprising 0.05% β-lactoglobulin and DHA in a 1 to 2 molar ratio (β-lactoglobulin to DHA) with excellent colloidal stability and particle size of 100nm. The encapsulation of DHA by β-lactoglobulin and the development of nanocomplexes with pectin offered adequate defense against DHA degradation during an accelerated shelf-life stress test. The study demonstrates a novel method for nanoencapsulation of long-chain polyunsaturated fatty acids such as DHA, which is advantageous for enhancing transparent acid beverages.		Zimet and Livney (2009)
Bovine β-lactoglobulin A Bovine β-Casein	Vitamin D	Vitamin D3 was binding to β-lactoglobulin A and β-casein was found to be pH and ionic strength dependent. Binding happened under the normal conditions found in milk (pH 6.6). Vitamin D3 is thought to bind β-lactoglobulin A following the processing of fermented milk goods (i.e., cheese and yogurt) or inside the acidic stomach, as Vitamin D3 was tightly bound in all experimental conditions. β -lactoglobulin A and β-casein would maintain the whey or casein fraction since these proteins would shield Vitamin D3 from an otherwise polar environment.	If Vitamin D3 stability is preserved, it can be concluded that Vitamin D3 is available for human absorption.	Forrest *et al.* (2005)
Protein-Lipid (Liprotides)				
α-LA or BSA with different cis UFA	Vitamin D	Transparent and water-soluble liprotides protect Vitamin D from exposure to heat and ultraviolet light. Vitamin D did not degrade significantly in the presence of different fatty acid-derived liprotides, meaning that they all have the same protective hydrophobic condition. Liprotides are not stable below pH 6 but can stabilize Vitamin D in solutions above neutral pH. Due to the strong stability of Vitamin D in liprotides, UHT treatment is feasible with just a small loss of Vitamin D, allowing for the production of goods with a long shelf life. Vitamin D most likely binds to the liprotide's hydrophobic interior, protecting it from the surrounding media and thus preventing oxidative degradation. The structure and binding/sequestering environment of Vitamin D in liprotides are currently being investigated to better understand how the molecule is preserved and to gain a better understanding of what molecules could be integrated into the structure in the future. The findings indicate that vitamin D may be encapsulated and stabilized to enhance the consumption and bioavailability of transparent beverages with a neutral pH. This procedure may be used in a low-fat nutritious water drink or in a high-concentration Vitamin D liquid as an alternative to Vitamin D pills to increase its absorption.		Pedersen *et al.* (2016)

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Table 2 (Cont.). Comparison materials and properties.

Wall Materials	Core Particles	Properties as		Source
		Protective agents	Delivery agents	
α-lactalbumin-oleic acid (Hamlet)	α-tocopherol, free tryptophan, and retinaldehyde	α-tocopherol solubility and chemical stability were improved following its uptake into liprotides. The liprotide-tocopherol complexes retained the typical liprotide configuration of a fatty acid center surrounded by protein. Additionally, free tryptophan and retinaldehyde may be integrated into the liprotides; however, the analysis concludes that effective integration involves a hydrophobic terminal moiety that fits inside the liprotides' micelle interior.	When inserted into the liprotide matrix, toc and fatty acid could be moved to artificial vesicles. The research indicates that liprotides can stabilize and carry a variety of small molecules that are normally insoluble, potentially providing major health benefits.	Pedersen *et al.* (2015)

binds retinol quite effectively. Additionally, some speculate on its critical role in Vitamin A binding in mammalian glands.

β-lactoglobulin has a secondary structure similar to that of retinol-binding proteins. It is made up of nine strands of β-structure, eight of which are arranged in a β-barrel configuration. On the surface of the molecule, there is a single α-helix. The center of the barrel is hydrophobic and may interact with hydrophobic molecules to facilitate their binding. β-lactoglobulin is structurally similar to plasma retinol-binding protein in three dimensions (Kilara and Vaghela, 2018). The structure of the tertiary structure shows some homology with the lipocalin protein (Rovoli *et al.,* 2014). There are more binding sites for oleic acid than linoleic acid, which interacts with van der Waals bonds (Fang *et al.,* 2015). Since β-lactoglobulin binds to various hydrophobic molecules, such as retinol and long-chain fatty acids (Maux *et al.,* 2014), it possesses the requisite biological properties for transporting those binding ligands (Sawyer *et al.,* 1998). The β-lactoglobulin's three-dimensional structure is identical to that of α-lactalbumin, especially the three-strand anti-parallel β-layer (Pettersson *et al.,* 2006). The β-lactoglobulin can also form complexes with fatty acids such as oleic and linoleic acids. Friedmann et al. found a reduction of complex coacervates consisting of gelatin or β-lactoglobulin, gum Arabic, starch, and glutaraldehyde, caused by oxidizing fish oil (Friedmann *et al.,* 2005) Complex coacervates are used to prepare nanoparticles containing DHA, β-lactoglobulin, and pectin. These nanoparticles remain colloidally stable and transparent in an aqueous solution and act as an antioxidant for DHA. However, in comparison to other microencapsulates, their load is relatively low (Zimet and Livney, 2009). Because milk is known as an allergen, manufacturers must demonstrate that β-lactoglobulin is present or missing to ensure its labeling complies with regulations. Food testing laboratories can employ immunosorbent testing methods for β-lactoglobulin testings and enzyme-based food product identifiers. Laboratory polymerization of β-lactoglobulin with microbial transglutaminase reduces allergy in children and adults with allergies to cow's milk (Olivier *et al.,* 2012).

5.2 Lipid

Lipids are a diverse class of hydrophobic compounds that involve oils, fats, waxes, and phospholipids. They are composed of fatty acids and are described by their insoluble nature in water. There are two subgroups of fatty acids: saturated and unsaturated acids, which differ in the type of molecule bond structure. Saturated fatty acids contain a single chain of carbon atoms with no double bond (C-C). Unsaturated fatty acids contain carbon chains with one or more double bonds (C=C). Saturated fatty acids are solid, while unsaturated fatty acids are liquid at room temperature. Additionally, short-, medium-, and long-chain fatty acids are distinguished based on their aliphatic tail carbon count, of fewer than 8, 8–14, and more than 16 carbons, respectively (Zuidam and Nedovic, 2010).

5.2.1 Oleic acid

Oleic acid is an easily available unsaturated fatty acid derived from a variety of sources, including olive oil (Soriguer *et al.,* 2004). Besides olive oil (which contains between 55% and 80% of this fatty acid), palm oil, sunflower oil, rapeseed oil, and grapeseed oil also produce this fatty acid. Oleic acid contains 18 carbon atoms and contains a double bond between the 9th and 10th carbon atoms. Oleic acid is composed of two functional groups, alkenes, and carboxylic acids. The inclusion of alkenes in the Z isomer causes an irregularity in the bonds between the oleic acid molecules. At room temperature, oleic acid converts to a liquid. Oleic acid can convert to oleyl alcohol through reduction and form methyl oleate by esterification. Moreover, the compound can form epoxistearate when it is epoxidized. Oleic acid is often used to make surfactants, soaps, plasticizers, and emulsifiers for food and pharmaceutically (Soriguer *et al.,* 2004). Oleic acid can be used as surfactant Fe_3O_4 because it has a stable

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bond between carboxylic acid groups and Fe_3O_4 . As part of liposomes, Oleic acid has limitations in its use due to its tendency to break down and cause detachment. One way to increase its stability is by coating using protein to form a complex known as liprotide (Casbarra *et al.,* 2004).

5.3 Protein-fatty acid complex (liprotides)

Liprotides are a class of lipids composed of α-lactalbumin and *cis* fatty acids. When two hydrogen atoms parallel to the double bond are on the same side of the strand, the fatty acid is in a *cis* arrangement. Liprotides have a heart-shell composition, as determined by the SAXS examination, consisting of a fatty acid core in the shape of micelles and a coating of partly denatured proteins (Kaspersen *et al.,* 2014). The protein coating or layer's primary role is to enhance fatty acid solubility. Liprotides are capable of transporting hydrophobic molecules in a hydrophilic system due to this property. In other words, the protein layer functions as a carrier and delivery system for fatty acids to target cells or hydrophobic surfaces (Kaspersen *et al.,* 2014). Liprotides can transport their fatty acid content through membranes. Additionally, prior research (Pedersen *et al.,* 2016) has shown that liprotides may stabilize tiny aliphatic molecules such as retinol and tocopherol by encapsulating them in the fatty acid center.

5.3.1 α-lactalbumin-oleic acid

Liprotides consisting of α-lactalbumin-oleic acid have been shown to increase α-tocopherol solubility and chemical stability. The liprotide-α-tocopherol complexes retained the characteristic liprotide structure with a core of fatty acid surrounded by protein. α-tocopherol and fatty acid could be transferred to artificial vesicles when incorporated into the liprotide complex. Free tryptophan and the vitamin A precursor retinaldehyde could also be incorporated into the liprotides (Pedersen *et al.,* 2015). Effective integration of α-lactalbumin and oleic acid involves a hydrophobic terminal moiety that fits within the liprotides' micelle interior. Liprotides are capable of stabilizing and transporting a variety of small molecules that are otherwise insoluble, with important possible health benefits (Pedersen *et al.,* 2015). Encapsulating Vitamin D using liprotides made from α-lactalbumin (aLA) and oleic acid (OA), specifically, oleate, showed the best result. The aLA-OA liprotides could fully solubilize Vitamin D, increase its resistance to UV light by ninefold, and increase its long-term stability at 37°C by up to a thousandfold. As α-lactalbumin naturally binds Ca^{2+}, it makes Ca^{2+} a possible liprotide disruptor. However, liprotides prepared at 80°C were more stable against Ca^{2+} than those prepared at 20°C.

The liprotides were able to release their Vitamin D content, as demonstrated by the transfer of Vitamin D encapsulated in liprotides to phospholipid vesicles. Liprotides were not stable at pH 6 and below, limiting the acceptable pH range of the liprotides. Results indicate that Vitamin D may be encapsulated and stabilized to enrich clear beverages at neutral pH to improve the intake and bioavailability of Vitamin D (Pedersen *et al.,* 2016). The binding and membrane delivery properties of aLA-OA are similar to those of the commonly used chol transporter methyl-β-cyclodextrin (mBCD). It improves chol solubility by 50% more than mBCD and delivers chol to membranes with comparable performance. While OA is cytotoxic at high concentrations, its effects are lessened by chol. Furthermore, cytotoxicity is significantly decreased as OA is substituted with cis-palmitoleic acid or cis-vaccenic acid. The aLA la-OA is a useful method for delivering chol to membranes and cells (Frislev *et al.,* 2018).

6. Conclusion

Liposoluble vitamins are important to human health and can contribute to many illnesses due to their deficiency. Though vitamin fortification is an effective technique for combating vitamin deficiency, several vitamins are degraded during food processing and digestion. Encapsulation can enhance vitamin stability, aid in their survival during food processing and storage, and ensure that they are released in the most desirable area of the human digestive system. Protein-fatty acid complexes can be an attractive delivery vehicle for liposoluble vitamins. While protein and fatty acids are deemed “generally known as safe” (GRAS) materials for food applications, additional research is needed to determine their encapsulation quality, vitamin retention under a variety of food processing conditions, validation of retention in food applications, and release rate in a human gastrointestinal tract-like setting. Prospect has shown that encapsulation methods for liposoluble vitamins could be an effective way to improve vitamin fortification or supplementation in food and beverage. It will contribute to maintaining many illnesses due to vitamin deficiency and improve health throughout the world.

Conflict of interest

The authors declare no conflict of interest.

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REVIEW

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