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Leguminous fractions as encapsulating agents of fat-soluble vitamins

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Abstract

Vitamins are essential micronutrients for the functioning of the human body. Vitamins can be classified as water-soluble and fat-soluble, and are obtained through diet or supplementation. Fat-soluble vitamins include vitamin A, vitamin D, vitamin E, and vitamin K. These compounds are very sensitive to external factors, including light, oxygen, pH, and temperature. Lack of compound stability, poor solubility, and low permeability can compromise the bioavailability and usefulness of fat-soluble vitamins. The methodology of encapsulation of vitamins is currently being widely studied in order to improve their transportation and usage. Proteins (including protein isolates and concentrates) and carbohydrates derived from legumes are very interesting materials to coat compounds, considering their functional properties, and the fact that they are beneficial for the environment and human health. This review describes in detail the current knowledge about the use of legume protein and carbohydrates as materials for the encapsulation of fat-soluble vitamins. The functionality, health, and environmental advantages of legume fractions (particularly soy and pea fractions) as wall materials are also discussed. Future use of legume wastewater (soaking and cooking water derived from the treatment of legumes) as wall materials is evaluated as well. The study of encapsulation of fat-soluble vitamins by leguminous fractions is mainly focused on soy and pea protein isolates and concentrates and can still be expanded, considering the numerous benefits of encapsulation they provide. Research on encapsulation using legume carbohydrates is scarce and may be interesting due to their high encapsulation efficiency and easy digestibility. Saponins, proteins, and carbohydrates present in legume wastewaters could offer useful properties to encapsulation processes, while benefiting the environment.

Keywords

Legume protein, fat-soluble vitamins, protein isolates, legume wastewaters, compound stability, soy, wall materials, environment

Introduction

Vitamins are micronutrients that the human body needs for proper growth, development, and functioning. Vitamins can be classified as water-soluble or fat-soluble. The latter includes vitamins A, D, E, and K [1, 2]. The incorporation of these substances in the human body is extremely important due to the functions that they fulfill [1]. Vitamin A is a group of organic compounds belonging to the retinol family known primarily for being a good agent for the treatment of eye and skin disease [3, 4]. Vitamin D is a steroid involved in bone metabolism which can be synthesized in the human skin when exposed to the ultraviolet (UV) rays of sunlight [1, 5]. The rest of fat-soluble vitamins including vitamin E and vitamin K are terpenes [1]. The former has several functions, including antioxidant and immune properties, while the second one participates in coagulation and bone processes [1, 2, 6]. In order to avoid pathologies related to vitamin deficiency, they must be included in the diet in sufficient quantities or through supplementation [1, 7]. The diseases and health problems caused by the deficiency of fat-soluble vitamins are diverse and vary from minor problems to serious and irreversible pathologies [8]. The deficiency of these substances represents a problem but their overabundance can also lead to several complications [9]. When incorporated in excess, water-soluble vitamins are efficiently eliminated. However, fat-soluble vitamins cannot be excreted and tend to accumulate in adipose tissue and in the liver [2]. Prolonged or excessive incorporation of these vitamins can cause various health complications [7].

Microencapsulation technology is generally used to protect several compounds from external environmental factors and also, it allows releasing them into the active site in a controlled manner. Fat-soluble vitamins are substances that are highly sensitive to various environmental factors, which can change their functionalities. The low water solubility of these vitamins makes their incorporation difficult in several systems [10]. Therefore, over the years, various technologies and methods have been developed to improve their application in the pharmaceutical, food, and cosmetic industries, thus preserving their structure and keeping their multiple health benefits. Microencapsulation based on the coating of substances was one of the more efficient processes for such purposes. The protective coating or film can be made up of various materials or mixtures of different coating agents, depending on the type of substance to be protected [10].

The technology to achieve encapsulation has evolved significantly throughout the years. Currently, various methodologies are employed to encapsulate fat-soluble vitamins, among which the following stand out: physical methods (spray drying, extrusion, electrospinning) and physicochemical methods (emulsification, coacervation, solvent evaporation, inclusion complexes), emulsification and spray drying the most prominent methods [10, 11]. Among these materials, proteins and carbohydrates of animal and plant origin have been evaluated by various authors [10]. Legume proteins may be useful for encapsulation processes, considering the multiple properties they have, their benefits for the environment and their low price.

The purpose of this review is to summarize the latest information on the use of proteins and carbohydrates from legumes for the encapsulation of fat-soluble vitamins. Special attention is paid to the functionality and advantages of these encapsulation materials.

Functional aspects of fat-soluble vitamins

The structure, functions, and effects of low consumption of these vitamins are widely detailed in the literature [1, 7]. However, taking into account certain general characteristics of these vitamins is important to evaluate the main aspects of their metabolism and, therefore, the encapsulation processes. Thus, a brief summary of the main aspects of each fat-soluble vitamin is presented below.

Vitamin A and provitamin A

Vitamin A is found in a variety of foods, including carrots, cheese, egg yolk, liver, milk, kale, pumpkin, sweet potato, and spinach [7, 10]. The functions of vitamin A are diverse, encompassing the proper functioning of vision, respiratory, urinary, reproductive, and immune systems, as well as the promotion of skin cells, hair, and bone growth, and support in wound healing [1, 7]. Besides, vitamin A is considered an antioxidant. Vitamin A can be found as retinol, retinal, and retinoic acid, which are its three active forms [4, 7], and it comes from two main sources: provitamin A and preformed vitamin A. On one hand, provitamin A is in the form of carotenoids (including α- and β-carotenes). This form of vitamin A is found in plant sources and is converted into retinol. On the other hand, preformed vitamin A is in the form of retinol, which is the most readily usable form of vitamin A and the most commonly found form in animal-sourced foods [3, 4]. As mentioned before, the accumulation of fat-soluble vitamins in the body can generate several health issues. Excess in vitamin A can lead to symptoms such as headaches, vomiting, enlarged liver, hair loss, and skin problems, as well as birth defects due to teratogenic effects [4]. Nevertheless, these cases are considered rare and are likely to occur only with high doses of vitamin A ingested through supplements. Tolerable upper intake levels of preformed vitamin A are 600–2,800 μg/day for children (from birth to 18 years old), whereas the limit for adults is 3,000 μg/day [12].

Vitamin D

Vitamin D includes ergocalciferol (vitamin D2) and cholecalciferol (vitamin D3) [2, 10]. The latter is synthesized by human skin when exposed to UV rays of sunlight. When the epidermis is irradiated by light UV, a sterol compound is activated in order to form vitamin D [10, 13]. Vitamin D sources are not abundant. Among them, mushrooms, some dairy products, meats, and fortified foods can be mentioned. Regarding the functions of vitamin D, these include the hormonal balance of calcium and phosphorus metabolism, the correct functioning of the nervous system and the formation of ribonucleic acid (RNA), and the participation in the immune system and in cardiovascular health [1, 13]. Small amounts of vitamin D in the body can lead to the appearance of rickets or osteomalacia, while an excess of this compound can lead to mental disorientation, weight loss, and lack of appetite and, in some cases, it can cause death; hence, the maximum amounts suggested for adults are 50 μg/day [12].

Vitamin E

Vitamin E has different isoforms, including tocopherols and tocotrienols [8]. This vitamin plays a crucial role in antioxidant, anti-inflammatory, and neuroprotective functions, supporting the proper functioning of the immune system and aiding in the formation of red blood cells [1, 7]. Sources of vitamin E include oils from soy, corn, palm, peanut, sunflower, nuts, almonds, and fish, as well as wheat germ, and some vegetables like broccoli, spinach, and pumpkin [7, 14]. The recommended dietary allowance (RDA) for vitamin E is usually covered by food ingestion, therefore problems related to its shortage are not so common [13]. However, intake of vitamin E under the RDA can lead to neurological pathologies, including Parkinson's disease and Alzheimer's disease, whereas an excess of this vitamin (above 1,000 mg/day for adults) may cause some types of cancer [12].

Vitamin K

Correct blood coagulation depends on the presence of vitamin K [15]. In addition, this vitamin participates in calcium metabolism [16]. It can be obtained through the diet or by bacterial production in the intestine. There are different forms of vitamin K: vitamin K1, which is especially found in plants (in the forms of phytonadione and phylloquinone) and, other parts of vitamin K are produced in the human and animal gut (often known as vitamin K2, in the form of menaquinone) through the intestinal microbiota [10, 17, 18]. Vitamin K1 is found in high concentrations in dark leafy plants, such as spinach, collards, soybean, and olive oil [6, 19]. Besides, another form of vitamin K (known as vitamin K3) is a synthetic compound that can be transformed into K2 in the intestinal tract [15]. If supplementation with vitamin K is high, this vitamin could inhibit the action of some medicines. The characteristics such as source, functionality, and recommended intake of fat-soluble vitamins are summarized in Table 1.

Table 1. Source, functionality, and recommended intake of fat-soluble vitamins

Vitamin	RDA	Sources	Functions	Reference
A	Children: 400–600 µg/day; adults: 800–1,300 µg/day	Plant sources: broccoli, carrots, kale, mangoes, pumpkin, red peppers, spinach, sweet potato Animal sources: dairy, egg yolk, fish oil, liver	Antioxidant, bone development, eye integrity, growth of epithelial tissue, immunity, reproductive functions	[4, 7, 12]
D	Children: 10–15 µg/day; adults: 15–20 µg/day	Plant sources: mushrooms, dark chocolate Animal sources: cheese, eggs, fish, liver	Bone mineralization, calcium and phosphorus absorption, cardiovascular health, immunity	[7, 12, 20]
E	Children: 4–11 mg/day; adults: 16 mg/day	Plant sources: almonds, asparagus, broccoli nuts, oils (corn, palm, peanut, sunflower, soy), pumpkin, spinach, wheat germ Animal sources: fish	Antioxidant, anti-inflammatory, atherosclerosis prevention, calcium and phosphorus homeostasis, erythropoiesis, immunity, neuroprotective	[1, 7, 12, 14, 16]
K	Children: 30–75 µg/day; adults: 90–120 µg/day	Plant sources: asparagus, broccoli, cabbage, spinach Animal sources: beef, egg, fish, liver	Bone metabolism, prevention of calcification of blood vessels	[6, 7, 12]

It is possible to cover the recommended intake of vitamins through the consumption of a wide variety of fresh foods that include the listed fruits and vegetables, nuts, legumes, and foods of animal origin. However, it is known that the current dietary patterns of the majority of the population are associated with the deficiency of various nutrients, little variety of ingredients and consumption of highly processed foods, with decreasing intake of fresh products [21]. The combination of these factors can contribute to the development of hidden hunger, defined as "insufficient intake or poor biological use of micronutrients" [22]. Deficiencies in fat-soluble vitamins may occur in these cases, bringing about problems that may not be easily observable; if left untreated, these deficiencies could lead to more serious illnesses [23]. In addition, lack of natural light and high exposure to screens can be associated with a deficiency in vitamin D, considering that this compound is produced when the sterols present in the skin are exposed to UV rays [5, 24]. In this sense, vitamin D deficiency has become a highly prevalent condition in the general population [5, 21]. Considering this scenario, it is possible to identify that vitamin supplementation is presented as a necessary strategy to be implemented in a great part of the population, possibly as part of health policies, in order to contribute to the prevention of diseases.

Absorption and transportation of fat-soluble vitamins

Fat-soluble vitamins have diverse structures, which makes the absorption process complex. Like other lipophilic compounds, these vitamins must be transferred to specific organs to be able to perform their functions. These vitamins, unlike water-soluble ones, must be linked to carrier proteins (or lipoproteins) in order to be transported into the blood circulation system. Certain characteristics of fat-soluble vitamins make it difficult for them to reach the target site or carry out their actions. Lack of stability to several factors (pH, light, temperature, and oxygen, among others), poor solubility, and low permeability can compromise the bioavailability and usefulness of fat-soluble vitamins [25], factors are summarized in Figure 1.

Vitamin absorption can be influenced by various factors, including the characteristics of the food matrix as well as individual physiological traits. Factors such as the presence of fat, dietary fiber, or certain micronutrients in the food matrix can change vitamin absorption. As well as other lipophilic compounds, the absorption of fat-soluble vitamins can be increased by consuming fat during meals. Lipids incorporated through foods can bind to fat-soluble vitamins, transporting them through the cell walls of the intestine and into the blood circulation system. These vitamins are then stored in the liver or adipose tissue [1, 7].

People who do not have an adequate intake of fat may have difficulties in absorbing fat-soluble vitamins, thus, it is necessary for those who follow a low-fat diet to reinforce the incorporation of these substances, considering the vital functions they fulfill. Other authors suggest that low-fat regimens should

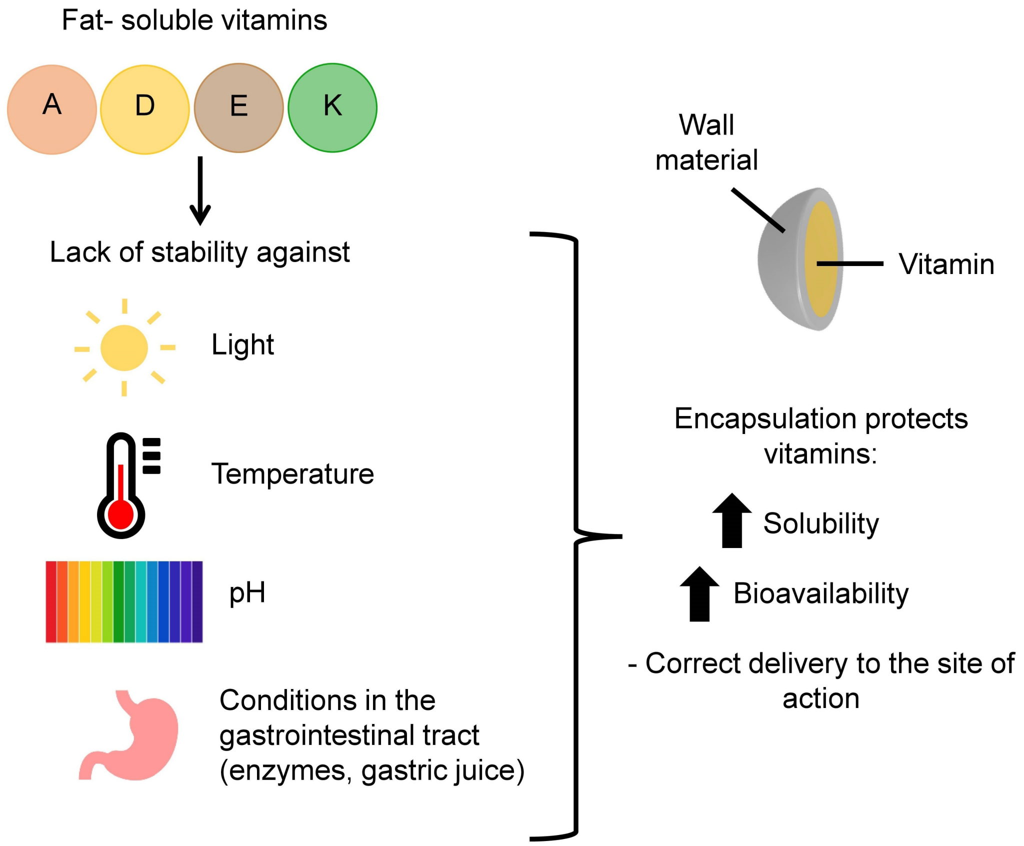

Figure 1. Factors affecting the stability of fat-soluble vitamins [25]. The upward arrow indicates "increase"

only be taken into account when there is low cholesterol consumption or when fatty foods are not absorbable [1]. Vitamin deficiency should also be considered in situations when malabsorption problems exist, like gastrectomy, cystic fibrosis, pancreatic pathologies, or fat malabsorption [7]. The amount of food ingested, bile secretion, alcohol consumption, and the age of the individual, can increase or decrease the absorption of fat-soluble vitamins [24]. Some authors have proposed that the proportion of adipose tissue in the individual can also condition the serum levels of vitamin D [24]. People with obesity may present differences in bioavailability, homeostasis, and/or requirements of fat-soluble vitamins in comparison with people without this condition [26, 27]. All the named factors must be considered when designing vitamin supplementation programs for the general population.

When foods or supplements with fat-soluble vitamins are ingested, they travel through the digestive tract until they arrive at the small intestine. Once in this organ, the fat-soluble vitamins cross the cell wall of the enterocytes, reaching the blood circulation system. Bile enzymes, fats, and the action of the pancreas are required for the digestion process. The storage of these vitamins occurs in the liver or adipose tissue, where they stay until they perform their functions [7].

Taking into account all the factors that can affect the absorption and bioavailability of fat-soluble vitamins mentioned, an adequate way to protect these compounds is through encapsulation with different matrices [11]. Encapsulation can be defined as "the entrapment of a substance (active agent) within a carrier material (wall material)" [28]. The trapped substance is called core material, whereas the protective compound is considered wall material, carrier, encapsulant, or coating material. Encapsulation methodologies are crucial techniques for protecting active ingredients from adverse environmental factors, the gastrointestinal tract, and potential damage during processing and storage [29]. When protecting fat-soluble vitamins, some properties of the wall material such as film-forming and emulsifying capacities are worth noting [30]. Through encapsulation, fat-soluble vitamins can increase their solubility and bioavailability, ensuring their precise delivery to their sites of action [10]. The recommended dietary amounts of fat-soluble vitamins could be enhanced through the ingestion of encapsulated supplements. Liposomes, films, micro or nanoparticles, or emulsions can be used for the encapsulation process.

According to Wijekoon et al. [10], when encapsulating fat-soluble vitamins or similar compounds, it is important to evaluate several factors, including the inherent characteristics of the fat-soluble compound, its compatibility and potential interactions with the chosen wall material, and the optimal form of encapsulation. It is also relevant to evaluate the ultimate intended application of the encapsulated compound (i.e., cosmetic or food products). Additionally, considering that fat-soluble vitamins must be consumed with some regularity, it is important to know whether or not individuals follow a supplementation plan using encapsulated vitamins [13]. It may be relevant to evaluate the cost of the final encapsulated product, the presence of unpleasant sensory characteristics (like undesirable flavor and aroma), or gastric adverse effects, as well as social factors such as beliefs and personal attitudes that may affect the use of these encapsulated supplements [31, 32].

Proteins and carbohydrates from legumes for the encapsulation of fat-soluble vitamins

Several food systems can be used as carriers for hydrophobic compounds. Proteins are an interesting material for the coating of substances, considering that they have emulsification properties and can form gel structures [33]. Proteins with hydrophobic regions have binding capacity for lipophilic substances. Besides, proteins can have antioxidant activity, film-forming capacity and ability to self-assemble into specific structures, and have high nutritional value [25]. Proteins provide benefits regarding encapsulation and carrying of substances, considering that they can circulate through blood during high periods of time, they present targeting ability, and they can bind to certain molecules [34]. Other advantages of using proteins for encapsulation include environmental benefits, since they are renewable and biodegradable [25, 35]. Besides, foods usually have a generally recognized as safe (GRAS) status, so they represent an advantage over other resources [30]. Food-grade delivery systems made of proteins have been evaluated, showing high potential as vehicles for bioactive ingredients [36]. The benefits of proteins as carriers of fat-soluble vitamins are summarized in Figure 2.

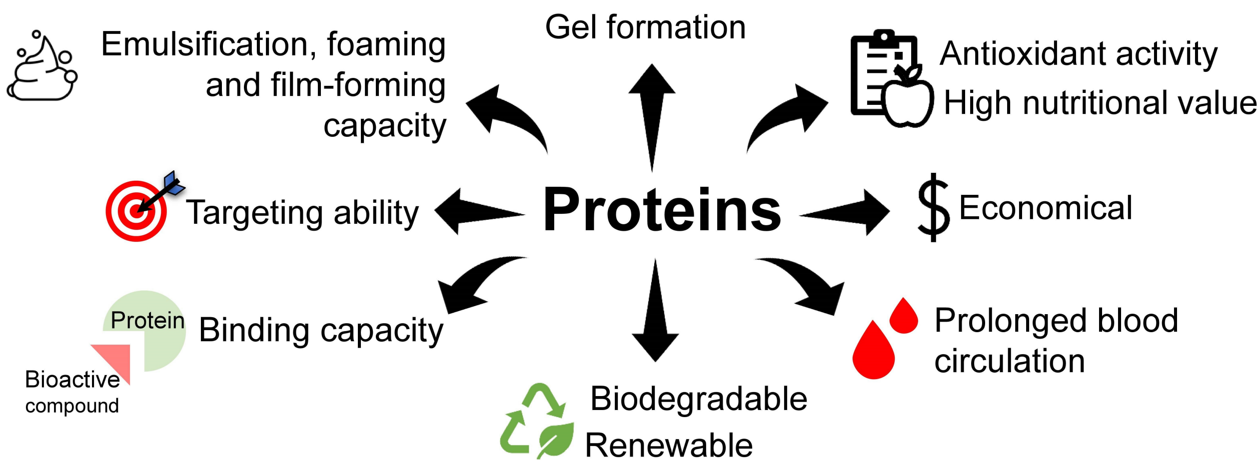

Figure 2. Advantages of proteins as carriers

Note. Adapted from "Plant protein-based delivery systems: an emerging approach for increasing the efficacy of lipophilic bioactive compounds," by Gomes A, Sobral PJDA. Molecules. 2021;27:60 (https://www.mdpi.com/1420-3049/27/1/60). CC BY.

Plant-based proteins are worth considering for compound encapsulation purposes, due to the positive attention they have received and the potential benefits (environmental, sustainability, health, and lower costs) that foods derived from plants may offer when compared to those of animals' origin [25, 37]. Besides, people who have personal or religious beliefs against animal consumption would benefit from the use of encapsulation materials with plant-based components [36]. However, there are some disadvantages in vegetable proteins compared to animal proteins, such as the presence of anti-nutritional factors, and the reduction of certain properties of interest (such as lower emulsifying or lower fat-binding capacities) [25].

Gliadin, which is present in wheat, zein, and maize, has been studied as a plant protein-based carrier [36]. These two proteins have a hydrophobic nature and are promising options to deliver fat-soluble vitamins.

Legume protein (as well as its concentrates or isolates) can represent a useful material for encapsulating compounds [29, 38, 35]. Extensive studies have been conducted on the encapsulation of water-soluble vitamins through legume proteins [29, 38], whereas the encapsulation of fat-soluble vitamins is not as well-developed. Most research regarding the protection of fat-soluble vitamins with legume proteins focuses on soy proteins [10]. Some procedures, including heat treatments, can impact positively on legume protein characteristics, making them more useful for microencapsulation processes [30, 35]. Nesterenko et al. [39] found that the acylation process applied to soy protein isolates (SPI) led to the enhancement of the retention of α-tocopherol, as it favored the amphiphilic character of SPI. This protein isolate has several useful encapsulation properties, including emulsifying, oil-binding, and high thermal stability [40]. Wang et al. [41] evaluated the potential of soybean lipophilic protein (found in SPI) for nano-emulsion delivery systems in neutral and alkaline environments. This lipophilic protein can be used as an emulsifier. The authors found that this fraction can be used as a stable wall material for the encapsulation of vitamin E. Vitamin D encapsulation was evaluated by Walia and Chen [42], Khan et al. [43], and Almajwal et al. [44]. All the studies presented positive results when pea or soy fractions were added to the encapsulation process. The current knowledge about the encapsulation of fat-soluble vitamins with legume fractions is summarized in Table 2. The encapsulation efficiency of a compound can be considered as the rate between the content of the compound in the emulsion (or form of encapsulation) and the total content of the compound initially incorporated [41].

Table 2. Characteristics of legume proteins as wall materials for the encapsulation of fat-soluble vitamins

Wall material	Core material	Encapsulation technique	Main findings	Encapsulation efficiency	Reference
PPC	Vitamin D	Nano-emulsion	PPC used as a surfactant improved vitamin absorption	94–96%	[42, 45]
PPI	Vitamin E (tocopherol)	Emulsions	Higher stability of PPI emulsions when compared with SPI emulsions	NI	[46]
	Vitamin D	Nano-emulsion created by ultrasound	PPI enhanced vitamin absorption	NI	[44]
SPI	Vitamin D	Microcapsules	Encapsulation has high vitamin retention and higher stability with respect to free vitamin D	> 82%	[43]
		Nano-emulsions	Protect vitamin D from UV exposure	> 70%	[47]
	Vitamin E (tocopherol)	Microencapsulation by spray-drying	SPI was modified by acylation, leading to a higher retention efficiency of vitamin E compared to native protein	Native SPI: 80%; modified SPI: 95%	[40]
		Emulsions	Stable delivery system at low temperatures (4°C)	NI	[46]
	Vitamin E	Nano-emulsion	Stable delivery system	60–90% depending on pH	[41]
	Vitamin A (β-carotene)	Nanoparticles	Successfully managed to preserve β-carotene inside the protein aggregates	> 93%	[48]

PPC: pea protein concentrate; PPI: pea protein isolate; NI: not informed

In addition to proteins, other components can be used for encapsulation and transport of functional ingredients. Among them, carbohydrate-based delivery systems have been evaluated by various authors. These systems can be made of carbohydrates coming from different animal, plant, or microorganism origins. Agar, xanthan gum, inulin, starch, and other materials can be used as encapsulation materials. Starches (including different fractions of starch such as resistant starch from roots and legumes) can be used as interesting encapsulation agents, considering that they are easily digestible, provide faster release than other encapsulating materials and present high encapsulation efficiency [36, 49, 50]. Many of the substances encapsulated with carbohydrates consist of water-soluble vitamins. Carbohydrates are highly hydrophilic substances, considering they contain -OH group, thus, it is easy for them to bind water-soluble substances. The available literature shows research on encapsulations of bioactive compounds using starches or other carbohydrates derived from legumes [35]. Zhu [51] and Hasanvand et al. [52] evaluated the usefulness of corn starch as wall material for the protection of vitamin D. To date, not many studies have been found on the use of carbohydrates derived from legumes as wall material in encapsulation of fat-soluble vitamins. It could be of interest to take advantage of the carbohydrate fraction of legumes, considering that they make up a large part of these foods. Hydro-lipophilic agents, such as emulsifiers, can be used to enhance the capacity of carbohydrates for fat-soluble vitamin encapsulation. The hydrophilic part of the named agents would bind to carbohydrates, while the lipophilic part would bind to the fat-soluble compound.

Legume discards for the encapsulation of fat-soluble vitamins

As mentioned in the different sections of the current review, diverse plant-based coating materials have been studied for the encapsulation of substances. Proteins or carbohydrates present in food are two of the most studied compounds due to their multiple advantages as delivery systems. Among them, legume proteins stand out as relevant carriers. However, in order to be properly consumed, legumes need to go through soaking or cooking processes so as to enhance organoleptic characteristics and reduce the content of certain antinutritional compounds [53, 54]. The treatment of legumes before consumption represents an environmental problem, considering the amount of water used and its consequent discards. In this sense, waste from legume processing, such as aquafaba, has become relevant in recent years. Aquafaba is a diluted solution, usually obtained from canned or cooked chickpeas [55], and it is used as a substitute for eggs in the elaboration of different foods. Aquafaba has diverse properties, including foaming and gelation characteristics, as well as emulsification functions [55, 56]. Besides this case, water from the processing of legumes is not widely used. The composition of water coming from legumes is variable, and it depends on the type of grain and cooking conditions (temperature, pH, time, and ionic force, among others). Wastewater from legumes contains oligosaccharides and polysaccharides, low-molecular-weight proteins (that are water-soluble), saponins, fiber, and phenolic compounds, among others [57]. Martins et al. [58] evaluated the composition of water coming from the processing of legumes as a source of saccharides of different polymerization degrees and their revalorization in the context of the circular economy. According to Serventi et al. [59], wastewater from legumes can contain interesting amounts of different nutrients. Protein contents of these waters can be around 1 g/100 g aquafaba [59].

The application of legume wastewater is mainly carried out as an egg substitute. According to Mustafa and Reaney [57], new functions of this byproduct may include its use in the cosmetic sector, and certain functions in the pharmaceutical industry (such as the encapsulation of active ingredients). In this sense, and considering the presence of protein and other nutrients in legume wastewaters, these materials could be used for the preservation of fat-soluble vitamins. Additionally, these byproducts have the capacity to contribute to foam stability [57], a capacity that can be enhanced by the presence of saponins [59]. Saponins from legume wastewaters can be of great interest as nonionic surfactants. When elaborating micelles, liposomes, and microemulsions, surfactants can be used as carrier materials. Saponins as surfactants can enhance the bioavailability of compounds and avoid undesirable effects [60]. Encapsulation of vitamin K through micelles with saponins has been studied by Sun et al. [61], who stated that an efficient combination of protein and carbohydrates can help to achieve a good emulsifying and film-forming capacity while having a material supporting the formation of a matrix [62, 63]. All these factors would be useful to take advantage of a resource that is currently discarded, which would be economical and could provide certain properties of interest. The standardization of aquafaba and other legume wastewater as products with different applications could be very useful in order to reuse the water obtained from legume processing. No research was found at present on fat-soluble vitamin encapsulation with aquafaba from legumes.

Besides, byproducts from the elaboration of tofu or other "vegetable cheeses" made of legumes may be useful for the delivery of hydrophobic compounds. Soy whey, derived from tofu production, is an ingredient rich in proteins and carbohydrates that could be used for different applications [64]. The application of different technological processes to standardize the quality of legume wastewaters or discards increases their potential use as emerging natural ingredients in encapsulated products, foodstuff, and cosmetic and pharmaceutical goods.

Conclusions

Fat-soluble vitamins are necessary for the proper functioning of the human body, so their intake in adequate quantities is necessary. However, the current lifestyle, characterized by the lack of fresh foods, high consumption of highly processed meals and high exposure to screens instead of sunlight, can lead to a notable shortage of these vitamins in the general population. These substances are very sensitive to various environmental factors and those of the human organism, so their encapsulation is relevant to protect and transport them through the body. Various studies have been carried out on encapsulation strategies, as well as on the materials for said process. Among these, the use of vegetable proteins is of great interest due to various functional, health, and environmental advantages. The study in the encapsulation of fat-soluble vitamins with legume proteins can still be expanded, considering that studies tend to focus on proteins to protect water-soluble vitamins. The majority of the available works about the encapsulation of fat-soluble vitamins are usually carried out with soy or pea protein to protect vitamins D and E. Besides, carbohydrates can be used as wall materials, considering several interesting properties of these materials. However, to date, not much research has been conducted on the use of carbohydrates derived from legumes as encapsulating materials.

Legumes are usually soaked and/or cooked before being eaten, resulting in large volumes of water that are then discarded. These waters contain various components, such as proteins, carbohydrates, and saponins have relevant functional properties. From a future perspective, it would be interesting to evaluate the usefulness of these proteins as a means of encapsulation of fat-soluble compounds. Saponins could be used as surfactants. The reuse of water from the processing of legumes for encapsulation could be an innovative alternative for environmental care.

Abbreviations

NI: not informed

PPI: pea protein isolate

RDA: recommended dietary allowance

SPI: soy protein isolates

UV: ultraviolet

Declarations

Author contributions

ADC and JNP: Conceptualization, Investigation, Writing—original draft. MCP: Conceptualization, Writing—review & editing, Supervision. All authors read and approved the submitted version.

Conflicts of interest

The authors declare that they have no conflicts of interest.

Ethical approval

Not applicable.

Consent to participate

Not applicable.

Consent to publication

Not applicable.

Availability of data and materials

Not applicable.

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