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REVIEW ARTICLE

Stabilization of betalains by encapsulation—a review

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Abstract Betalains are pigments that have properties that benefit health, such as antioxidant, anticancer, and antimicrobial activity, and they also possess a high ability to provide color. However, these pigments, although used as colorants in certain foods, have not been able to be potentialized to diverse areas such as pharmacology, due to their instability to physicochemical factors such as high temperature, pH changes and high water activity. For this reason, different stabilization methods have been reported. The method that has presented best results for diversifying the use of betalains has been encapsulation. Encapsulation is a method of entrapment where the objective is to protect a compound utilizing more stable matrices from encapsulation technologies. This method has been employed to provide greater stability to betalains, using different matrices and encapsulation technologies. However, a review does not exist, to our knowledge, which analyzes the effect of matrices and encapsulation technologies on betalains stabilization. Therefore, the objective of this review article was to evaluate the different matrices and encapsulation techniques that have been employed to stabilize betalains, in order to arrive at specific conclusions concerning the effect of encapsulation on their stabilization and to propose new techniques and matrices that could promote their stabilization.

Keywords Betalains · Encapsulation · Matrix · Stabilization · Effects

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Introduction

Betalains are pigments found in fruits, flowers, roots, and leaves of plants (Gengatharan et al. 2015). They are synthesized from the amino acid tyrosine into two structural groups, betacyanins, and betaxanthins, it being the nature of the additional residue that determines the classification of the pigment (Gandía-Herrero and García-Carmona 2013). Betalains have interesting properties, such as high water solubility and color intensity, and they possess antioxidant and anticancer effects (Stintzing and Carle 2007).

However, one of the main problems that limit the application of betalains is their instability (Castellar et al. 2003). Due to the latter, investigations of betalains have focused on searching of ways to stabilize them and to increase their applications. Some of the stabilization methods that have been studied include the addition of antioxidants, chelating agents, and encapsulation (Herbach et al. 2006a, b; Azeredo 2009).

In recent years, encapsulation has been studied as a promising method for stabilizing betalains using different matrices (polysaccharides, proteins, and carbohydrates) and techniques (spray-drying, emulsions, ionic gelation, etc.) (Chong et al. 2014; Kaimainen et al. 2015a, b; Otálora et al. 2016). Encapsulation can be defined as a method of entrapment in which a compound is encapsulated by a more stable physical barrier, the compound localized in the center of the barrier that protects it. The encapsulated compound may be called core, active phase, or load; while the encapsulating agent usually is termed matrix, membrane, wall, coating, or capsule (Nedovic et al. 2011). Some researchers have evaluated the effect of different matrices and encapsulation techniques in the stabilization of betalains, allowing compilation of this information and reaching objective conclusions. The objective of this review was to propose best method of betalains encapsulation for their stabilization, evaluating the different matrices and encapsulation techniques that have been utilized, and to reach specific conclusions on the effect of encapsulation in the stabilization of betalains.

Overview and betalain properties

Betalains are hydrophilic vacuolar pigments that accumulate in the leaves, roots, stems, fruits, flowers, bracts, petioles, and seeds of plants of the order *Caryophyllales*. The only exception to this order are the families *Caryophyllaceae* and *Molluginaceae*, here the color is due to anthocyanins (Gandía-Herrero and García-Carmona 2013). Betalains in the 1950s were denominated nitrogenous anthocyanins; it was not until years later, that evidence that they comprised a set of different pigments from those of the anthocyanins was provided (Piattelli et al. 1964; Miller et al. 1968; Impellizzeri and Piattelli 1972). It was then that Mabry and Dreiding in (1968) coined the term "betalains".

Betalains are naturally synthesized from the amino acid tyrosine into two principal structural groups: betacyanins and betaxanthins, betalamic acid their biosynthetic precursor. Betacyanins exhibit a red–violet color with an absorbance spectrum (λ_{max}) of 541 $\pm$ 9 nm, and their basic structure consists of betalamic-acid condensation with the DihydrOxyPhenylAlanine cycle (the DOPA cycle). Additionally, betaxanthins show a yellow–orange color with an absorbance spectrum (λ_{max}) of 471.5 $\pm$ 13.5 nm and their structure consists of the conjugation of betalamic acid with amino acids or amines (Fig. 1) (Strack et al. 2003; Khan et al. 2015). To date, about 70 betalains have been identified in nature, comprising approximately 50 betacyanins and 20 betaxanthins. They can be found in fruits and seeds such as beet (*Beta vulgaris*), amaranth (*Amaranthus* spp.), pear (*Opuntia* spp.), and pitaya (*Stenocereus* spp.), among others (Cai et al. 2005; Stintzing and Carle 2007).

Investigations on betalains have been few, to our knowledge, compared with anthocyanins. This is due to their limited presence in nature. However, the study of betalains has increased over the past 15 years, generating more knowledge on their biosynthesis, structures, and properties. The importance of research on betalains lies mainly in their properties, such as water solubility, color intensity, and their antioxidant, antibacterial, and anticancer properties (Stintzing and Carle 2007; Cejudo-Bastante et al. 2014). Therefore, researchers in medicine and food areas have shown interest in studying betalains and in their potential use.

Betalain properties in food

At present, with the advancement of the study of betalains, their possible applications have been diversified. One of the main applications is their use as natural dyes. The use of natural dyes in food has grown, due to the alternative that it represent to the use of artificial dyes, which present harmful effects to health. Betalains are the most natural dyes used in food (Obón et al. 2009). The main source of betalains is red beets; however, the disadvantage of using betalains extracted from red beet is the earthy smell due to geosmin and pyrazines, which are undesirable when applied in food at high concentrations (Stintzing et al. 2000). Thus, novel sources of betalains are necessary for their application in foods. Some sources of betalains, which have encouraged food scientists to study them from a technological, and nutritional point of view include amaranth and cactus fruits, revealing great potential for employment as natural dyes (Cai et al. 2003; Moßhammer et al. 2005; Robert et al. 2015).

Another important contribution of betalains has been in the development of the packaging of food with natural polymers. These provide properties to food packaging, such as color, antioxidant capacity, stability in terms of photodegradation, and greater flexibility (Akhtar et al. 2012; Gutiérrez et al. 2016). Therefore, betalains, in addition to being used as dyes can favor the physicochemical properties of food packaging and provide added value. The relevance of betalains in foods and their properties has increased the interest of scientists to continue looking for ways to incorporate them into food and thus promote human health (Choo 2017).

Biological properties of betalains

Betalains present properties that promote health, primarily for their antimicrobial antioxidant, activity and anticancer (Vulić et al. 2013; Gandía-Herrero et al. 2016; Khan 2016a, b; Belhadj et al. 2017; Miguel 2018; Yong et al. 2018). Betalains show strong antioxidant activity, up to 7 times higher than vitamin C which is a very effective natural antioxidant, and up to 3–4 times higher than the ascorbic acid and catechin (Cai et al. 2003). The antioxidant activity of betalains has been studied from various

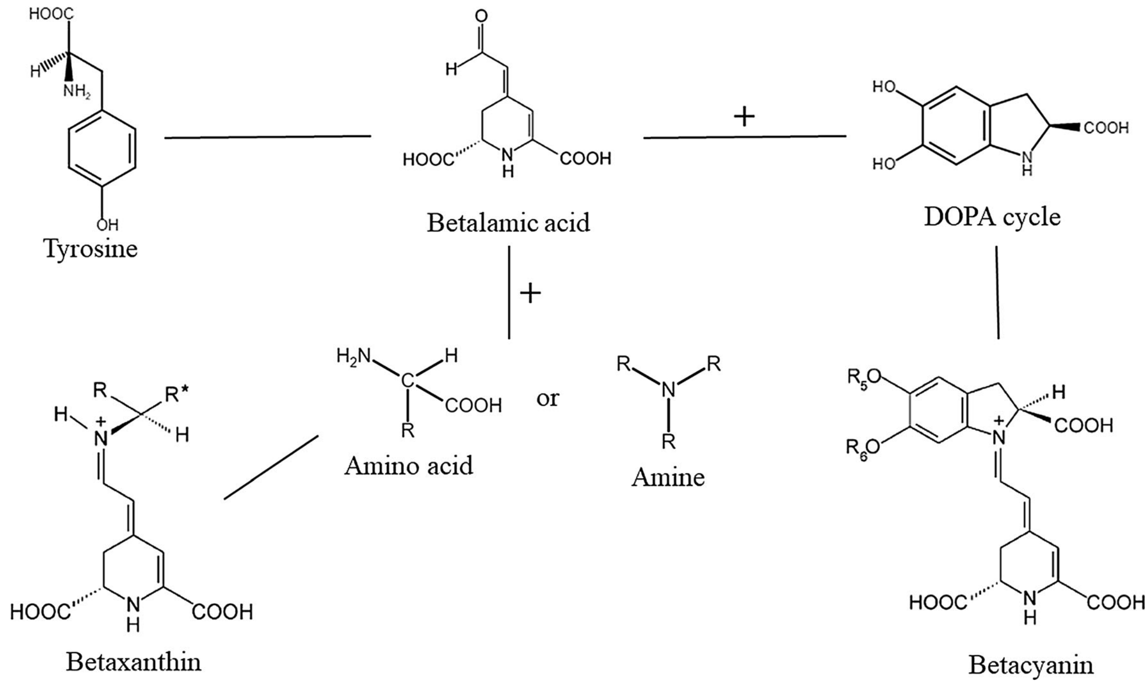

Fig. 1 Schematic diagram of the route to obtaining of betacyanins and betaxanthins

sources such as fruits, leaves, flowers, and seeds. However, not all sources of betalains present the same antioxidant activity due, to the number and position of hydroxyl/imino groups and of the aglycones glycosylation in the structure of betalains (Cai et al. 2003).

Betalains due to their effect actively against free radicals can prevent the onset of cancer. The literature has reported its antiproliferative effect on human colon carcinoma, showing that betalains can stop and efficiently inhibit the cell cycle of cancer cell (Serra et al. 2013). Also, they have been tested in ovarian cancer cells, immortalized cells of cervical epithelium and cervical cancer cells, presenting a significant inhibitory effect of 40–60% (Zou et al. 2005). Another less studied property is the antimicrobial effect of betalains. It has been reported that betalains exhibit antimalarial properties, being capable of chelating the essential interior cations and transport block intracellular parasites (Hilou et al. 2006). Also, betalains have shown inhibitory effects against Gram-negative bacteria such as *Pseudomonas aeruginosa* and *Salmonella typhimurium*, among others, and Gram-positive bacteria, such as *Staphylococcus aureus, Enterococcus faecalis,* and *Listeria monocytogenes* (Čanadanović-Brunet et al. 2011; Tenore et al. 2012). Although it is known that betalains show antimicrobial effects, the literature has reported very little about its mechanism of inhibition, therefore, it can be a topic of opportunity for future research.

Despite the interesting food and medical properties that betalains exhibit, one of the main constraints that prevent their potential use has been their instability. Therefore, in recent years several studies have been search ways to stabilize them, and to increase their commercial applications taking advantage of benefits.

Betalain stability

Several factors affect the stability of betalains and have to be considered to ensure their properties. The stability of betalains is influenced by the presence of high temperature, $pH < 3$ or > 7, light, oxygen, and high water activity (StStintzing and Carle 2007; Cejudo-Bastante et al. 2014). In addition, it has been observed that the structure is also important in the stability of betalains. For example, the betacyanin and betaxanthin structural groups show different stabilities. Betacyanins exhibit higher temperature stability, acidic pH and are less prone to oxidation than betaxanthins, but betaxanthins show higher stability at pH 7, and hydrolytic enzymes. The higher stability of betacyanins about betaxanthins may be due, to the fact that some of them have a glycosylated structure, which has a high oxidation–reduction potential (Herbach et al. 2006a, b; Azeredo 2009).

The physicochemical factors that compromise the stability of betalains, on their own, do not greatly influence their degradation, except for water activity, which is an important factor due to hydrolytic reactions. Temperature, oxygen, light, and pH have been shown to act in synergy, favoring further degradation of betalains (Fig. 2) (Azeredo 2009; Reshmi et al. 2012).

Due to the easy degradation of betalains, the objective-of-study in recent years has been based on finding ways to stabilize them in order to increase their commercial applications and to take advantage of their benefits. The literature has reported the use of additives, such as antioxidants, chelating agents and, in recent years, encapsulation, which represents a promising method for the stabilization of betalains.

Extraction methods of betalains

The extraction of betalains is the first step for its study, therefore, it is an important and crucial step in the final result. In the extraction of betalains, conventional and non-conventional methods have been used (Barba et al. 2017). The conventional methods are those that use solvents with and without thermal treatment such as maceration, hydrodistillation, and Soxhlet, while non-conventional methods are modern and ecological technologies with low energy consumption, some of these promising techniques are ultrasound-assisted extraction, microwave-assisted extraction, supercritical fluid assisted extraction, pulsed electric field assisted extraction and pressurized liquid extraction (Azmir et al. 2013; Soquetta et al. 2018). Conventional methods have been the most used in the extraction of betalains due they are simple methods and do not require sophisticated equipment, however, the extraction time is very long with low yields, and use high temperatures can degrade betalains (Tiwari and Cullen 2013; Celli and Brooks 2017). That is why in recent years, betalains extraction processes have been optimized using non-conventional methods. Laqui-Vilca et al. (2018) optimized the extraction of betalains from the quinoa husk by the ultrasound method and compared it with the maceration method, where they obtained by ultrasound 96.477 mg of betacyanins/100 g of fresh sample (FS) in 9.2 s and betaxanthins 201.01 mg/100 g of FS in 40 s, while in extraction by maceration, 30 min were required at room temperature to reach similar yields, demonstrating that the unconventional method was better for the extraction of betalains. Koubaa et al. (2016) they evaluated the potential of the previous treatments of ultrasounds and pulsed electric field to improve the extraction of betalains from the rind and pulp of the prickly pear, they performed a supplemental aqueous extraction. The results showed that the treatments used significantly improved the extraction of betalains, concluding that the pulsed electric field induces the permeability of the cellular wall without disintegrating the cellular tissue, which facilitates the recovery of intracellular compounds. Roriz et al. (2017) optimized the extraction of betacyanins from *Gomphrena globose L.* using microwave-assisted extraction and ultrasound where they reported a higher extraction yield using ultrasound with 46.9 ± 4.8 mg/g, validating that the ultrasound method is more suitable to obtain betacyanins from *Gomphrena globose L.* Thirugnanasambandham and Sivakumar (2017) optimized the extraction of betalains from the rind of the dragon fruit by the microwave method obtaining 9 mg/L of betalains in 8 min at 35 °C, they conclude that the result obtained shows the effectiveness of the microwave process in the extraction of betalains.

Some of the advantages and disadvantages of using these methods can be seen in Table 1, where the main disadvantage presented by conventional with respect to unconventional is time, temperature and the use of solvents. However, based on the above we can mention that although conventional methods may have limitations in the extraction of betalains, they are methods that can be combined with non-conventional methods to improve the extraction process without affecting the natural properties of betalains.

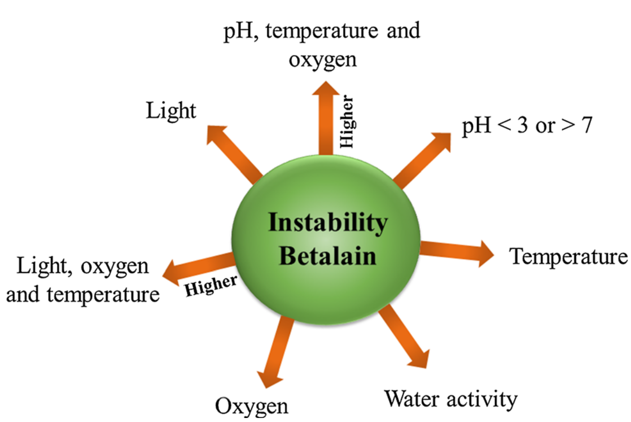

Fig. 2 Physicochemical factors, alone and in combination, which provide instability to betalains

Stabilization of betalains

One of the different ways of stabilizing betalains is with the use of antioxidant compounds, especially ascorbic acid and isoascorbic acid. These antioxidants have demonstrated beneficial effects in crude extracts of betalains, such as in purified betalains (Khan and Giridhar 2014). Isoascorbic acid has exhibited greater potential in stabilizing betalains than ascorbic acid, due to its greater redox potential (Azeredo 2009). However, more study is required on the optimal amounts of ascorbic acid or isoascorbic acid for betalain stabilization, since there are discrepancies. Chelating agents have also shown a stabilizing effect on betalains. These act by partially neutralizing the

Table 1 Advantages and disadvantages of conventional and non-conventional extraction methods

Methods	Advantages	Disadvantages
Conventional		
Maceration	Simple method and low cost	High extraction time, low yields and use of organic solvents
Soxhlet	Simple method	High energy consumption and use of organic solvents
Hydrodistillation	Organic solvents are not required	Hgh temperatures, high energy consumption and high extraction time
Non-conventional		
Supercritical fluid	Extraction is rapid, selective and does not require additional cleaning	Temperature changes and specialized equipment
Pressurized liquid	Rapid extraction and reduced consumption of solvents	High temperatures and pressure
Ultrasound assisted	Low extraction time, low energy consumption and high yields	Use of organic solvents
Microwave assisted	It can be done with or without the addition of solvents	Specialized equipment
Pulsed electric field	Low extraction time and high yields	Use of solvents and energy consumption

electrophilic center (positively charged N) present in the structure of the betalains. Citric acid and EDTA (EthyleneDiamineTetraacetic Acid) are chelating agents that have been utilized to improve the stability of betalains, avoiding their oxidation and increasing their useful life (Herbach et al. 2006a, b). However, the use of citric acid at high concentrations can affect sensory characteristics in foods. Other methods of stabilization of betalains less studied and with great opportunity to develop new research can be seen in Table 2.

Another of the main methods for stabilizing betalains is encapsulation. Encapsulation has been a subject of investigation in recent years to stabilize, improve bioavailability, and facilitate the administration of betalains (Khan 2016a, b). One of the most important reasons for the use of encapsulation in betalains is to provide greater stability during processing and final products (Nedovic et al. 2011). Encapsulated betalains may present a storage stability of up to 6 months, stability that could not be obtained with other methods (Gandía-Herrero et al. 2013). This is due to the matrix that protects them from physicochemical factors that accelerate their degradation. Another advantage of encapsulation of betalains is that these latter can be added to liquid or solid substances without their degradation (Ravichandran et al. 2014; Pitalúa et al. 2010). Therefore, stability of betalains deriving from encapsulation comprises one of the most important objectives in their study today. However, the effect of the different encapsulation techniques and matrix types, which may be important factors in determining greater or less betalains stability, is also important.

Encapsulation of betalains

Encapsulation is a method of trapping solid, liquid, and gaseous materials in small capsules that can be of nanometric or micrometric size (Fang and Bhandari 2010). The contents of the capsule are isolated from the environment and their contents can be released at controlled rates for prolonged time periods by means of the action of pH, enzymes, temperature, among others (Augustin and Hemar

Table 2 Other betalain stabilization methods: advantages and disadvantages

Methods	Observations	Advantages/disadvantages	References
Complex formation (inorganic matrices such as γ-alumina)	Stabilize the pigment for more than twenty months	High stability / lower solubility and possible aggregate formation	Pérez-Ramírez et al. (2015), Lima et al. (2009), Molina et al. (2014)
Copigmentation (metals, phenols, alkaloids, and organic acids)	Promotes color retention for up to 6 months at 5 °C	Increase color intensity and stability / Low stability in purified pigments	Khan et al. (2015), Khan and Giridhar (2014), Trouillas et al. (2016)

2009; Gouin 2004). This method is of interest to the pharmaceutical sector with respect to the release of drugs and vaccines. It is also of interest the food industry with respect to the addition of functional ingredients such as antioxidants, antimicrobials, and for controlling taste, texture, and color (Champagne and Fustier 2007; Vinceković et al. 2017).

Encapsulation is based on the protection of compounds sensitive to external factors, covering them with a more stable matrix such as polysaccharides, lipids, and proteins. These so-called core–shell systems are formed from the protective compound termed the core, and a shell or matrix that covers the compound (Fig. 3) (Janiszewska 2014).

Encapsulation is currently used to stabilize betalains. In the literature, several encapsulation and matrix technologies have been reported that have been used in the encapsulation of betalains. However, to our knowledge, there is not a review work that analyzes together the effect of matrices and encapsulation technologies on the stability of betalains.

Effect of the matrix and encapsulation technology on the stability of betalains

There are several factors that can contribute to the degradation of betalains into an encapsulated form. The main factors include the type of matrix, the technology of encapsulation, and the porosity of the matrix. This is because they are principally exposed to physicochemical factors mainly oxygen, that can easily enter the matrix and affect the betalains (Serris and Biliaderis 2001). The matrix is a physical barrier that is also frequently called a coating, capsule, membrane, or barrier (Fang and Bhandari 2010). These may be composed of carbohydrates, polysaccharides, lipids, proteins, and synthetic polymers, or may perhaps even be in combination, improving their barrier properties. Selection of the matrix is very important, since on it will depend the final application of the encapsulated compound and an efficient result (Chranioti et al. 2015). Currently, several matrices have been employed to encapsulate betalains as polysaccharides, proteins or in combination with polysaccharides. The reasons for this may be due to their ability to protect betalains from oxidation and the high solubility of the majority of polysaccharides (Gandía-Herrero et al. 2013; Robert et al. 2015; Chranioti et al. 2015; Otálora et al. 2016).

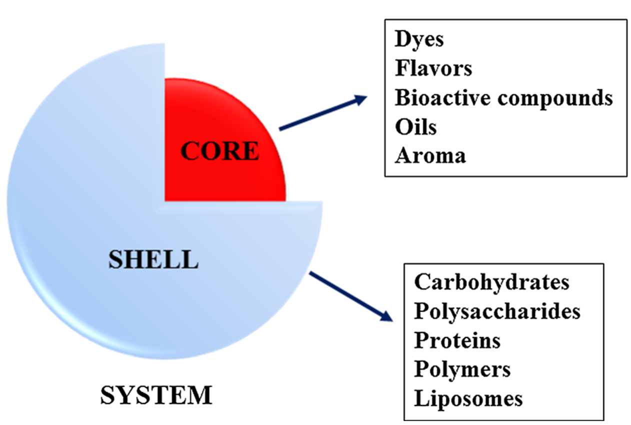

Fig. 3 Schematic of the core–shell system with examples

Maltodextrin is a polysaccharide obtained from the hydrolysis of starch. This polysaccharide is that which is most used as matrix to encapsulate betalains. In the literature, it has been reported that the use of maltodextrin, as an encapsulation matrix, increases the stability of betalains (Gandía-Herrero et al. 2013). Therefore, maltodextrin has been used alone and in combination with other polysaccharides. Ravichandran et al. (2014) reported the encapsulation of betalains from red beet. These authors employed maltodextrin and its combination with guar gum, gum Arabic, xanthan gum, and pectin. They found that encapsulation of betalains with maltodextrin and its combination with other polysaccharides increases their stability. Janiszewska et al. (2014) encapsulated beet juice employed maltodextrin and gum Arabic as matrix. These authors investigated the effect of the matrix on the stability of the pigments, demonstrating that gum Arabic possesses higher adsorption of water than maltodextrin, observing that the gum Arabic matrix degrades faster, exposing the pigment. These results are in agreement with the results obtained by Pitalua et al. (2010). These authors encapsulated betalains in gum Arabic by evaluating the matrix at different values of water activity, finding that the matrix dissolves in a short time period when it is exposed to high water activity. However, it has been found that when maltodextrin and gum Arabic are combined, they maintained their structural integrity in the presence of water, revealing their effectiveness for the encapsulation of pigments (Chranioti et al. 2015). Maltodextrin has also been combined with proteins. Castro-Muñoz et al. (2015) encapsulated tuna fruit juice utilizing a gelatin matrix, maltodextrin and a combination of gelatin/maltodextrin. The authors reported high hygroscopicity in the matrix; maltodextrin has a high capacity to absorb water of 72–83 g/100 g. Therefore, they mentioned that the properties of the matrix depend on the gelatin: maltodextrin ratio. These authors concluded that the compound can be used in food compounds. Robert et al. (2015) encapsulated betalains using soy proteins combined with maltodextrin or inulin, observing lower beta-lactam degradation when the matrix comprised a protein-polysaccharide. The maltodextrin-protein matrix was that with lower beta-lactam degradation compared with protein-inulin. In terms of this difference in betalain stability with respect to polysaccharide type the authors attributed this to the structural

Table 3 Main techniques and betalains encapsulation matrices that have promoted its stabilization

Encapsulation techniques	Matrices	Source of betalains / extraction method	Encapsulation efficiency	Stability after encapsulation	Applications	References
Hydration-sonication	Lecithin (nanoliposomes)	Betanin (red beet extract diluted with dextrin)/commercial	80.35%	Improved the in vitro digestion stability of betanin	Diabetes treatment	Amjadi et al. (2019)
Spray dried	Cactus mucilage	Pulp and skin of *Escontria chiotilla* and *Stenocereus queretaroensis* /magnetic stirring and maceration	Information not presented	Betalains retention was more than 90% after three months of storage	Food coloring	Delia et al. (2019)
Ionic gelation	Calcium alginate	Betalain-rich extract of *Opuntia ficus-indica* fruit/maceration	Information not presented	After 30 days, the sample colour change	Natural colorant in gummy Candies	Otálora et al. (2019)
Gelation	Sodium alginate	Bougainvillea bracts (*Bougainvillea spectabilis*)/maceration	88.63–89.82%	The encapsulation is efficient to protect and release the bioactive compounds from bougainvillea extracts	Bioactive pigments for applications in food	Orozco et al. (2019)
Ionotropic gelation	Ca(II)-alginate with sucrose and dextran	Stems/leaves of *Beta vulgaris*/maceration	15–60% (depends on the formulation)	Good conservation of the antioxidant activity (up to 70%)	Antioxidant	Calvo et al. (2018)
Spray drying	Modified potato starch and commercial starch	Fruit of pitaya (*Stenocereus pruinosus*)/maceration	Information not presented	Modified starch-based microcapsules showed better potential pigmentation and greater stability during storage for 32 days at 4 °C in yogurt with pH 4.6 than commercial starch-based microcapsules	Pigmenting agent of yogurt	Vargas et al. (2018)
Hydration-sonication	Lecithin (nanoliposomes)	Betanin/commercial	80.35%	Betanin stability decreases by approximately 10% for 60 days of storage	Gummy candies as a food model	Amjadi et al. (2018)
Spray dried	Maltodextrin, inulin, and whey protein isolate	Beetroot (*Beta vulgaris* L.)/ juice was obtained with a food processing centrifuge	Information not presented	The use of whey protein isolate together with inulin achieved high stability	Food coloring	Do Carmo et al. (2018)
Spray drying and ionic gelation	maltodextrin-cactus cladode mucilage and sodium alginate	Orange pulp fruits *Opuntia megacantha*/maceration	Information not presented	Betaxanthins encapsulated with maltodextrin-cactus cladode mucilage by spray drying were more stable at 18 °C and 57% RH for 62 days	Natural colorant	Otálora et al. (2018)
Microchannel emulsification	Soybean oil	E162, red beetroots (*Beta vulgaris*, *subsp*. *vulgaris*) and Fresh beetroot juice/commercial, mechanic, mechanic	Information not presented	Betanin from different sources encapsulated in W/O/W emulsion showed to be temperature sensitive	Information not presented	Pagano et al. (2018)
Spray drying	Maltodextrin	Quinoa (*Chenopodium quinoa* Willd.)/mechanic	100%	The oxygen consumption of the microparticles with betacyanin was higher when the temperature increased (80–90 °C) accompanied by a decrease in color intensity causing pigment degradation	Information not presented	Aguilar et al. (2018)

Table 3 continued

Encapsulation techniques	Matrices	Source of betalains / extraction method	Encapsulation efficiency	Stability after encapsulation	Applications	References
Freeze drying	Gum arabic and maltodextrin	Air parts of *S. fruticosa*	86.50–92.30%	After the 8 weeks storage to 60 °C, 25.87% of the betalains was lost	Information not presented	Mohamed et al. (2018)
Freeze dried and spray dried	Combination of maltodextrin and xanthan gum	Red beetroot (*Beta vulgaris* L.)/mechanic	Information not presented	Stable for 7 days at different pH and dried by freeze dryer	Suggested as colorants for use in food products	Atigo et al. (2018)
Spray drying	Maltodextrin	Yellow pulp fruits of *Opuntia ficus-indica*	Information not presented	Excellent preservation in the dark, even after 28 days at 4 °C. However, the presence of light contributed to betaxanthin deterioration	Natural colorant in yogurt and soft-drink	Fernández et al. (2018)
Spray drying	Maltodextrin and pectin	Pitaya juice (*Stenocereus griseus*)/mechanic	Information not presented	The particles have critical values at a storage temperature of 25° C. Below these conditions, the particles can be stored while maintaining their stability	Functional foods as a colorant	García et al. (2017)
Spray drying	Maltodextrin and resistant maltodextrin	Pitaya juice (dragon fruit)/ mechanic	Information not presented	Storage for 3 months at 4 °C, 25 °C and 40 °C exhibited higher betanin degradation in resistant maltodextrin at all temperatures with corresponding lower half-lives compared to maltodextrin	Natural colorant in sweets	Shaaruddin et al. (2017)
Spray drying	Maltodextrin	Red-violet fruits of *Basella rubra L./* maceration	Information not presented	Stable after two years of storage without light at 4 °C	Use in food industry as a natural colourant	Kumar and Giridhar (2016)
Freeze drying	Soy protein	Beetroot pomace (*Beta vulgaris* L., cv. 'Bicor')/ ultrasonic bath	86.14%	Stability was reduced by 24% after three months of storage at 25 °C	Could be used in the pharmaceutical industry and as food additives	Tumbas Šaponjac et al. (2016)
Emulsion	Sunflower oil and whey protein isolate	Beetroot juice/Mechanic	98–100%	The stability of the double emulsions prepared from beetroot juice, sunflower oil, and whey protein isolate is related to their high viscosity that prevents creaming and coalescence	Meat products	Eisinaite et al. (2016)
Freeze drying	Maltodextrin-gum Arabic and maltodextrin-pectin	Red dragon fruit (*Hylocereus polyrhizus*) peels	90–95%	The encapsulation of betalains in carbohydrate matrices stabilizes them in addition to preserving and improving their biological activities	In vitro evaluation as an antioxidant, anti-inflammatory and antiangiogenic	Rodriguez et al. (2016)

Table 3 continued

Encapsulation techniques	Matrices	Source of betalains / extraction method	Encapsulation efficiency	Stability after encapsulation	Applications	References
Freeze drying	Maltodextrin (MD), gum Arabic (GA), gum Arabic-midified starch (GA-MS), modified starch-chitosan (MS-CH) and modified starch-maltodextrin-chitosan (MS-MD-CH)	Beetroot coloring extracts/ beetroots extract were extracted with water in a commercial juice extractor	Information not presented	MD with GA proved to be effective agents for beetroot coloring extracts microencapsulation with a high half-life period, while that the incorporation study demonstrated higher stability for food model of low moisture such as chewing gum prepared with extracts encapsulated in GA–MS	Natural colorants in a chewing gum model system	Chranioti et al. (2015)
Spray drying	Gelatin and maltodextrin	Purple cactus pear fruits (*Opuntia stricta*)	18.07% to 57.30% depending on the ratio of gelatin and maltodextrin	The use of the maltodextrin-gelatin complex generated directly microcapsules with better stability to the temperature greater than 200 °C which provides a good protection to the bioactive components	Information not presented	Castro et al. (2015)
Spray drying	Maltodextrin and cladode mucilage and maltodextrin	Purple fruits of *Opuntia ficus-indica*/maceration	Information not presented	The encapsulation of betalains in maltodextrin was more stable at 57% and 75% RH, with a half-life of 117.4 and 103.4 days	Natural colorant	Otálora et al. (2015)
Spray drying	Soybean protein isolate, maltodextrin, inulin and mixtures	Cactus pear fruits (*O. ficus-indica*)/Pressing	99%	The protein and polysaccharide blends used as encapsulating agents for cactus pear pulp improved the polyphenol encapsulation and betalain stability at 60 °C as shown by the lower degradation rate constant	Food ingredients for functional foods	Robert et al. (2015)
Spray drying	Soluble fiber [(1 → 3) (1 → 4) β-d-glucan]	Juice of red cactus pear/ Information not presented	Information not presented	The addition of encapsulated betalains to extrudates showed greater pigment retention at 80° C-100° C at a cutting speed of 225 rpm	Extruded products	Ruiz et al. (2015)
Spray dried	Capsul	Pear fruits *(Opuntia ficus-indica)*/Maceration and clarified by microfiltration and ultrafiltration	98%	Microparticles with ultrafiltrated extract had better betanin stability 60 °C	Natural colourants for healthy foods	Vergara et al. (2014)
Spray drying and freeze drying	Maltodextrin, guar gum, gum Arabic, pectin and xanthangum with different concentration	Red beet roots/Maceration	Freeze drying results from showed higher recovery of betalains. Variation with xanthan gum showed increase up to 65% of betalains content than the control	Betalains with xanthan gum showed 21% more stability than the control (maltodextrin) Freeze drying encapsulation with xanthan showed a higher recovery of betalains by up to 1.3 times than spray drying encapsulation	Powdered food grade colorant	Ravichandran et al. (2014)

Table 3 continued

Encapsulation techniques	Matrices	Source of betalains / extraction method	Encapsulation efficiency	Stability after encapsulation	Applications	References
Spray drying	Maltodextrin, Arabic gum and a mixture of both	Beetroot juice/Information not presented	The highest content of pigments was observed for microcapsules obtained by the feed flux of the raw material 0.3 cm^3/s and Arabic gum as a carrier	The gum arabic microcapsules with beet pigments were more stable compared to maltodextrin	Natural colorant	Janiszewska, (2014)
Spray drying	Maltodextrin and chitosan	Violet flowers of *Lampranthus Productos* and *Beta vulgaris* roots/Mechanical and membrane separated	Information not presented	Maltodextrin encapsulation strongly increased the stability of the pigment, which remained stable for months in the absence of light, at temperatures of − 20 and 4 °C	Food applications	Gandía-Herrero et al. (2013)
Spray drying	Gum Arabic	Beetroot juice/commercial juice extractor	Information not presented	The powder stored at aw < 0.521 to 30 °C presented the greatest stability	Antioxidant and as a red colorant	Pitalua et al. (2010)
Spray drying	Maltodextrin and inulin	Cactus pear fruits (*Opuntia ficus-indica*)/maceration	Information not presented	Indicaxanthins in all systems showed a slow degradation during storage at 60 °C and were more stable than betacyanins	Incorporation into functional foods	Saénz et al. (2009)
Spray drying	Dried glucose syrup	Fruit juice of *Opuntia stricta*/mechanic	Information not presented	The encapsulated dye stored at room temperature maintained 98% of its color after one month	Natural colorant	Obón et al. (2009)
Freeze drying	Pullulan and maltodextrin samples of different molecular weight	Beetroot pigment/commercial	Information not presented	The wall materials used for encapsulation of the pigment were effective in decreasing the rate of degradation, however the most stable among the three matrices was pullulan	Natural colorant	Serris and Biliaderis (2001)

differences between both polysaccharides. In the literature, different betalain encapsulation technologies, such as spray-drying, freeze-drying, ionic gelation, and emulsions, have been reported (Vergara et al. 2014; Kaimainen et al. 2015a, b; Chranioti et al. 2015; Otálora et al. 2016). The most used technology for encapsulation of betalains is spray-drying, due to its low cost, simple processing, and its rapid obtaining of encapsulated betalains. However, the main disadvantage of spray-drying is that the matrix has to be soluble in solvents that can easily evaporate with temperature and that, due to the use of high temperatures, some bioactive compounds may degrade. Ravichandran et al. (2014) studied the effect of different matrices in the encapsulation of betalains by spray-drying and freeze-drying. These authors concluded that with the freeze-drying technique, higher loading and stabilization efficiency of betalains was obtained than with spray-drying. In addition, they mentioned that guar gum can be employed to encapsulate betalains with the freeze-drying technique, but that this is not suitable for spray-drying. There are other authors who also showed the limitations of the spray-drying technique (Gandía-Herrero et al. 2013). These authors encapsulated betalains in a matrix of maltodextrin and chitosan, revealing problems for the chitosan processing in this technique due to its viscosity and low solubility. Chranioti et al. (2015) reported that the dye of beet and saffron was encapsulated in matrices of maltodextrin, gum Arabic, modified starch, chitosan, and in combination, concluding that the technique is suitable for color stabilization. In Table 3 we can see an updated summary of the main encapsulation methods, matrices used and their effects on betalains stability.

From the abovementioned findings, we can conclude that the matrix type exerts an important effect on the stability of betalains. Polysaccharides are those most used, showing great potential to increase the stability of betalains, mainly maltodextrin. However, the combination of other polysaccharides can provide different characteristics for the matrix and contribute greater protection for the betalains. Nonetheless, the combination demonstrating greatest stability for betalains is the protein-polysaccharide combination. The increase or decrease in the stability of betalains will be related to the type of polysaccharide used because, due to their structure, they possess different properties. The type of encapsulation technology also appears to exert an effect on the stability of betalains that, in our view, requires more detailed studies in this regard. However, although the spray-drying technique is the most commonly used today, this does not infer that it is the best technique for stabilizing betalains. In general, the greater or lesser stability of betalains will be influenced by the matrix, the encapsulation technology, and also by the storage conditions, mainly by water activity. The latter has displayed a problem in matrix stability, as in the betalains.

Future perspectives

Encapsulation for the stability of betalains will continue to be one of the current study objectives. The effect of the matrix on betalains stability should be further investigated, and future research should be directed toward the combination of protein–polysaccharides. These are a very interesting source of research, especially in the study of betalains stability. Proteins such as those of gluten have exhibited good barrier properties, and polysaccharides such as pullulan demonstrate greater stability than maltodextrin under storage conditions, which could favor the stability of betalains (Serris and Biliaderis 2001). The coaxial techniques of encapsulation could be used. This technique ensures that betalains will be found in the nucleus and not dispersed in the matrix, as in the majority of the aforementioned techniques. The technique that could offer this characteristic is that of coaxial electrospray, which, to date has not been used, to our knowledge, for the encapsulation of betalains.

Conclusion

The best way to stabilize and potentiate the use of betalains derives from their encapsulation. The matrix type exerts an effect on the stability of betalains, providing greater stability of the protein-polysaccharide combination; however, betalain stability will be influenced by the chemical structure of the polysaccharide and the protein's physicochemical characteristics. These types of combinations require greater attention if one wishes to increase the stability of betalains. The use of novel encapsulation technologies with fewer conditions-for-use could diversify the employment of encapsulated betalains. In general, the best way to stabilize betalains is by the encapsulation method, utilizing polysaccharide-protein matrices by means of techniques such as freeze drying or techniques in which the betalains are found in the nucleus and not spread throughout the matrix.

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