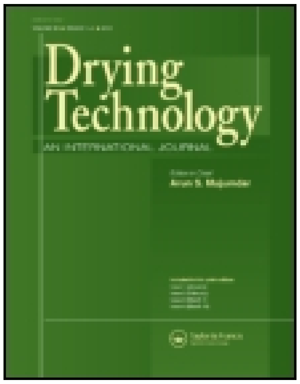

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Spray-Drying Microencapsulation of Anthocyanins by Natural Biopolymers: A Review

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Spray-Drying Microencapsulation of Anthocyanins by Natural Biopolymers: A Review

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There has been an increased interest in the development of food colorants from natural sources as alternatives to synthetic dyes because of both legislative actions and consumer concerns. Anthocyanins are of great interest for the food industry since they give a wide range of colors as well as nutraceutical activities. Nevertheless, due to their low stability to environmental conditions during processing and storage, introducing those compounds into foods is challenging. Microencapsulation may be an efficient way to introduce such compounds into those products. An important step in developing microcapsules is the selection of a biopolymer (wall material) which meets the required criteria. Hence, this review will focus on microencapsulation of anthocyanins with different biopolymers through spray drying to develop natural colorant pigments which possess high stability, solubility, and dispersibility. Our goal is to give updated information regarding microencapsulation of anthocyanins by spray drying, as well as its effectiveness, developments, and optimized conditions which will be discussed.

Keywords Anthocyanin; Biopolymers; Microencapsulation; Spray drying; Stability

INTRODUCTION

Color is one of the most important quality attributes affecting a consumer's acceptance of food, since it gives the first impression of food quality. There is a worldwide trend towards the use of natural additives in general, and food colorants in particular, in food applications. The interest of the food industry in natural colorants replacing synthetic dyes has increased significantly over the last few years, mainly due to safety issues. The use of natural pigments requires knowledge of chemical structure and stability in order to adapt them to the conditions of use during processing, packaging, and distribution.[1,2] The industry requires technologies which protect the natural pigments, due to their instability in the presence of light, air, humidity, and high temperatures. Currently, in order to provide this protection, one alternative is microencapsulation technology by applying different biopolymers.[3]

Microencapsulation is a rapidly expanding technology that is a unique way to package materials in the form of micro- and nano-particles and defined as a process to entrap one substance (active agent) within another substance (wall material).[4,5] In the food industry, it involves the incorporation of ingredients, polyphenols, volatile additives, colors, enzymes, and bacteria in small capsules to stabilize, protect, and preserve them against nutritional and health losses. In addition, microencapsulation can simplify the food manufacturing processes by converting liquids to solid powders and decreasing production costs.[6,7] Most microcapsules are small spheres with diameters of between 1 to 1000 microns.[8] In the simplest form, a microcapsule is a small sphere with a uniform wall around it. The material inside the microcapsule is referred to as the core, encapsulant, internal phase, payload phase or fill, whereas the wall is sometimes called the shell, coating, wall material, encapsulating agent or membrane shell, carrier material, external phase, or matrix.[9,10] In this review, only "core" and "wall" will be used to refer to the encapsulated ingredient and encapsulating agent, respectively.

The spray-drying technique has been widely used for drying heat-sensitive foods, pharmaceuticals, and other substances because of the rapid solvent evaporation from the droplets. Although most often considered a dehydration process, spray drying can also be used as an encapsulation method when it entraps "active" materials within a protective matrix, which is essentially inert to the material being encapsulated.[11] Compared to the other conventional microencapsulation techniques, it offers the attractive advantage of producing microcapsules in a relatively simple, continuous processing operation. Spray drying is the most common technique used to encapsulate anthocyanins and about 80–90% of encapsulates are spray-dried; however, there are several disadvantages of this technique. In this review, after a brief description of anthocyanins, microencapsulation and spray drying technique, optimum

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conditions, and some characteristics of spray-dried anthocyanin powders are discussed.

ANTHOCYANINS

Anthocyanins (Greek *anthos*, flower, and *kyanose*, blue) are the largest group in the plant kingdom and generally accepted as the largest and most important group of water-soluble pigments in nature. They are responsible for the color of many fruits, flowers, and other parts of plants.[12] Anthocyanins are glycosides of anthocyanidins (also called aglycones) and sugars. There are about 17 anthocyanidins found in nature, but more than 90% of all anthocyanins isolated in nature are based only on the following six anthocyanidins: pelargonidin (plg), cyanidin (cyd), peonidin (pnd), delphinidin (dpd), petunidin (ptd), and malvidin (mvd),[13,14] as shown in Table 1. The interest in anthocyanin pigments and scientific research has increased in recent years mainly due to their role in nutraceutical and health benefits given by natural antioxidants. Despite the advantages of anthocyanins as potential substitutes of synthetic colors, due to their particular chemical structure, anthocyanins are unstable and susceptible to degradation. The stability of anthocyanins is affected by pH, temperature, light presence, metallic ions, enzymes, oxygen, ascorbic acid, sugars and their degradation products, proteins, and sulfur dioxide.[15–17] More particularly, the bioavailability of anthocyanins is low due to their sensitivity to changes in pH. Anthocyanins are generally stable at pH values of 3.5 and below, and are therefore stable within stomach conditions. However, they degrade at higher pH values, such as those more typical for the intestinal tract (pH of 7), and thus their nutritional value is greatly reduced. Therefore, this high instability of anthocyanins has a direct consequence on possible color stabilization actions and needs to be stabilized to preserve the product's original color and its potential health benefits. For this reason, encapsulation is the best way to improve bioavailability of anthocyanins.[18–20]

ENCAPSULATION OF ANTHOCYANIN BY DIFFERENT METHODS

There are many encapsulation techniques, among which some have been successfully applied to anthocyanins (see Table 2). The selection of a microencapsulation method depends upon specific applications and parameters, such as required particle size, physicochemical properties of the core and wall materials, release mechanisms, process cost, etc.[21–23] In general, encapsulation has increased the stability of anthocyanins independent of the encapsulation technique used; in contrast, the degree of stabilization seems to be directly related to the employed encapsulation technique conditions.

Spray drying is the most common technique used to encapsulate anthocyanins and about 80–90% of encapsulates are spray-dried. Freeze drying is also an efficient method for anthocyanin encapsulation to produce a porous, non-shrunken structure especially useful for temperature-sensitive active agents like anthocyanins.[24,25] The major disadvantages of freeze drying are the high energy use, the long processing time, and the open porous structure obtained, which is in general not a very good barrier between the active core and its surroundings. Compared to spray drying, freeze drying is up to 30–50 times more expensive.[26]

MICROENCAPSULATION OF ANTHOCYANINS BY SPRAY DRYING

Spray drying is a unit operation which is the continuous transformation of feed from a fluid state into dried particulate form by spraying the feed into a hot drying medium.

TABLE 1
Chemical structures and characteristics of six naturally occurring common anthocyanidins

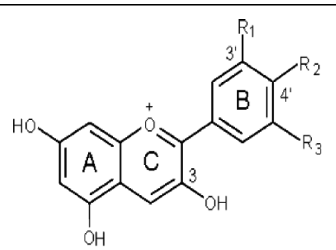
Anthocyanidin	Basic structure	R_1	R_2	R_3	Main color	Examples of sources
Cyanidin		–OH	–OH	–H	Reddish-orange	Apple, elderberry, blackberry, nectarine, plum, peach, red cabbage
Delphinidin		–OH	–OH	–OH	Purple, blue	Grapes, beans, eggplants, oranges
Pelargonidin		–H	–OH	–H	Orange	Strawberries, red radishes, some beans
Malvidin		$–OCH_3$	–OH	$–OCH_3$	Purple	Grapes
Peonidin		$–OCH_3$	–OH	–H	Purplish-red	Cranberries, blueberries, plums, grapes, cherries, purple corn
Petunidin		–OH	–OH	$–OCH_3$	Dark-red or purple	Grapes, red berries

TABLE 2
Overview of common microencapsulation processes for anthocyanins and their characteristics

Encapsulation technology	Process steps	Particle size (μm)	Advantages	Disadvantages	Ref.
Spray drying	1. Dissolve core material in aqueous wall material solutions 2. Atomize 3. Dehydrate	10–400	1. Low process cost 2. Wide choice of wall materials 3. Good encapsulation efficiency 4. Good stability of the finished product 5. Possibility of large-scale production in a continuous mode	1. Can degrade highly temperature-sensitive compounds 2. Control of the particle size is difficult 3. Yields for small batches are moderate	[29–37]
Freeze drying	1. Dissolve core material and wall material in water 2. Freeze the sample 3. Drying under low pressure 4. Grinding (option)	20–5,000	Thermosensitive substances that are unstable in aqueous solutions may be efficiently encapsulated by this technique	1. Long processing time 2. Expensive process costs 3. Expensive storage and transport of the capsules	[38]
Fluid bed coating	1. Fluidize active powder 2. Spray coating 3. Dehydrate or cool	20–200	1. Low cost process 2. It allows specific capsule size distribution and low porosities into the product	Degradation of highly temperature-sensitive compounds	[39]
Emulsification	1. Dissolve active and emulsifiers in water or oil phase 2. Mix oil and water phases under shear	0.2–5,000	Polar, non-polar (apolar), and amphiphilic can be incorporated	1. Limited number of emulsifiers that can be used 2. Difficult control of the capsule formation	[40]
Melt extrusion	1. Melt the wall material 2. Dissolve active in the coating 3. Extrude with extruder 4. Cool	300–5,000	1. The material is totally surrounded by the wall material 2. Any residual core is washed from the outside 3. It is a relatively low-temperature entrapping method	1. The capsule must be separated from the liquid bath and dried 2. It is difficult to obtain capsules in extremely viscous carrier material melts	[23]
Encapsulation by rapid expansion of supercritical fluid (RESS)	1. Create a dispersion of core material and dissolved or swollen wall material in supercritical fluid 2. Release the fluid to precipitate the shell onto the active	10–400	1. Non-toxicity and easy removal of the solvent 2. Operation at low temperatures and in an inert atmosphere that allows avoiding degradation of the product	1. Both the core and the wall material must be very soluble in supercritical fluids 2. Low or no solubility of high molecular weight, and polar compounds in CO_2 3. Poor control over the precipitated crystal morphology, size distribution	[41]

(*Continued*)

TABLE 2
Continued

Encapsulation technology	Process steps	Particle size (μm)	Advantages	Disadvantages	Ref.
Ionic gelation	1. Wall material with dissolved core material is extruded as drops within an ionic solution 2. The capsules are formed by ionic interaction		Organic solvents and extreme conditions of temperature and pH are avoided	1. Mainly used on a laboratory scale 2. The capsules in general have high porosity, which promotes intensive burst	[42]
Thermal gelation	The principle is almost the same as the ionic gelation principle; nonetheless, there is no necessity of an ionic solution to form a gelled drop; the gelation is only due to thermal parameters		The same of ionic gelation	The same of ionic gelation	[43]
Phase separation (coacervation)	1. Prepare o/w emulsions with lipophilic active in oil phase 2. Mix under turbulent conditions 3. Induce three immiscible phases 4. Cool 5. Crosslink (optionally)	10–800	Can be used to encapsulate heat-sensitive ingredients due to done at room temperature	1. Toxic chemical agents are used 2. The complex coacervates are highly unstable 3. There are residual solvents and coacervating agents on the capsules surfaces 4. Spheres low size range 5. Expensive and complex method	[44,45]
Emulsion method	Emulsification of a protein solution, which contains the core material, in an oil phase and heating of this emulsion to induce the gelation of the dispersed droplets	1–100	Micro-nanocapules with narrow size distribution can be obtained	1. Instable when exposed to environmental stresses, such as heating, drying, etc. 2. Limited number of emulsifiers that can be used	[40]

There are three fundamental steps involved in spray drying[27,28]:

1. Atomization of a liquid feed into fine droplets;
2. Mixing these spray droplets with a heated gas stream, allowing the liquid to evaporate and leave dried solids;
3. Separation of dried powder from the gas stream and collection.

Spray drying involves complex interactions of process, apparatus, and feed parameters, which all have an influence on the final product quality. The spray-dried products have important properties like uniform particle size, nearly spherical regular particle shape, excellent flowability, improved compressibility, low bulk density, better solubility, reduced moisture content, increased thermal stability, and suitability for further applications. Such product characteristics mainly depend on the physical properties of feed, equipment components, and processing parameters. By modifying the spray-drying process, it is possible to alter and control the mentioned properties of spray-dried powders.[46–48]

Spray drying is the most commonly used encapsulation technique in the food industry. It is also one of the oldest encapsulation methods and has been used in the food industry since the late 1950s. There are several advantages for this technique, such as low operating cost, high quality of capsules in good yield, rapid solubility of the capsules, small size, high stability capsules, and continuous operation.[49,50] Carbohydrates, milk proteins, and new emerging biopolymers make up the three main classes of wall materials generally available and suitable for spray-drying microencapsulation.[51,52] After selecting suitable wall material, it is hydrated in water. For water-soluble materials like anthocyanins, the ingredient to be encapsulated is added to the wall material and homogenized. The ratio of core to wall is usually 1:4,[3] but this can be optimized for each individual ingredient. This mixture is then fed into the spray dryer and atomized with a nozzle or spinning wheel. Water is evaporated by the hot air (100–160°C) and the small particles are deposited to the bottom of the spray dryer, where they are collected. The resulting microcapsules are then transported to a cyclone separator for recovery.[41] During the drying process, a film is formed at the droplet surface and the concentration of ingredients in the drying droplet increases. Finally, a porous, dry particle is formed. Critical parameters of spray drying are inlet and outlet temperatures of air, viscosity of feed, solid content, surface tension, feed temperature, volatility of solvent, and nozzle conditions.

Currently, the main emphasis of the microencapsulation of food components has concentrated on improving the encapsulation efficiency during spray drying and extending the shelf-life of the products. This is intended to produce high-quality encapsulated powders. Successful encapsulation of anthocyanins should result in an encapsulated powder with minimum surface pigment content on the powder particles and maximum retention of the core material. The properties of the wall and core materials and drying parameters are the factors that can affect the efficiency of encapsulation.[48,51]

Although spray dryers are widespread in the food industry, there are several disadvantages of this technique, such as [26–28]:

- Production of no uniform microcapsules;
- Limitation in the choice of wall materials (low viscosity at relatively high concentrations);
- Production of very fine powders which need further processing;
- Not good for heat-sensitive materials.

Different Biopolymers in Spray-Drying Encapsulation of Anthocyanins as Wall Materials

Encapsulation facilitates light- and heat-labile molecules like many pigments, such as anthocyanins, to maintain their stability and improve their shelf-lives and effects. It is a rapidly expanding technology, highly specialized, with affordable costs. Microencapsulation efficiency and microcapsules' stability are largely dependent on wall material composition. This biopolymer could act as a barrier and it may protect the core against oxygen, water, and light or could avoid contact with other ingredients or control diffusion. Overall, materials for microencapsulation have to fulfill all or some of the following requirements[7]:

- Have good rheological properties at high concentration (if needed) and easy workability during the encapsulation; Do not react with the material to be encapsulated; Seal and hold the active material within its structure during processing or storage; If applicable, completely release solvent or other materials used during encapsulation under drying or other solvent-removing conditions; Provide maximal protection of the core against environmental conditions; Be inexpensive; Be food-grade and legally allowed; Be available in large quantities and constant quality.

A number of commercially approved biopolymers are available to produce microencapsulated anthocyanins like gum Arabic, maltodextrin, inulin, tapioca starch, citrus fiber, glucose syrup, soy protein isolate, whey proteins, and other wall materials like cold-set glucan gel or a heat-set curdlan gel. Not all biopolymers meet the properties needed, so they are often used in combination with other wall materials and other modifiers such as oxygen scavengers, antioxidants, chelating agents, and surfactants.[53,54]

The choice of a biopolymer for microencapsulation by spray drying is very important for encapsulation efficiency and microcapsule stability. Typical biopolymers generally available and suitable for spray-drying microencapsulation include natural gums (gum Arabic, alginates, carrageenans, etc.), proteins (dairy proteins, soy proteins, gelatin, etc.), carbohydrates (maltodextrins and cellulose derivatives) and/or lipids (waxes, emulsifiers).[55] According to Shahidi et al.,[24] maltodextrin is extensively used as a wall in spray drying to satisfy demand and low cost. Maltodextrins turned out to be essential to preserve the integrity of the anthocyanins during their encapsulation.[56,57] Nowadays, maltodextrin is commonly mixed with gum Arabic. A mixture of maltodextrin (60%) and gum Arabic (40%) has been used for encapsulation of procyanidins from grape seeds.[58] No change of procyanidins was observed during the critical drying stage, the rate of encapsulation was around 85%, and stability was improved. Another wall material successfully used for encapsulation of anthocyanins was protein-lipid (sodium caseinate-soy lecithin) emulsion, which was used in spray drying of grape seed extract.[59] Chiou and Langrish[60] introduced citrus fruit fiber as a wall material for spray drying of bioactives extracted from *Hibiscus sabdariffa L.* The main bioactive

TABLE 3
Experimental conditions recently optimized for the encapsulation of different anthocyanins by spray drying

Anthocyanin's source	Wall material	Operation conditions: Inlet air T (°C)	Outlet air T (°C)	Feed flow rate	Encapsulation efficiency (%)	Reference
Black carrot	A range of maltodextrins [Stardri 10 (10DE), Glucodry 210 (20–23DE) and MDX 29 (28–31 DE)]	160, 180, 200	107, 118, 131	5 ml/min	NR[a]	[56]
Garcinia indica	Maltodextrin of various dextrose equivalents (DE 06, 19, 21, and 33) and gum acacia and tricalcium phosphate	150	80	NR	NR	[64]
Berberis	Maltodextrin, β-cyclodextrin, gum acacia	160	80	NR	90–95	[65]
Opuntia stricta	Glucose syrup (DE 29)	160	Variable: 50–68	0.72 l/h	NR	[66]
Blueberry	Mixture of soybean protein isolate (SPI)-maltodextrin and β-cyclodextrin-maltodextrinn-arabic gum	120	80	400 r/h	92.48	[67]
Andes berry	Maltodextrin DE 20	230	150	10 mL/min	NR	[68]
Butterfly pea	Hydroxyl propyl methyl cellulose (HPMC) and gelatin	130	80	10 ml/min	NR	[69]
Pomegranate	Maltodextrin (MD) or soybean protein isolates (SPI)	140 to 160	100 to 140	10 mL min)1	SPI = 35.8–100% MD = 89.4–100	[57]
Proanthcyanidins	Arabic gum and maltodextrin	180	88	NR	88.84	[70]
Roselle-pineapple juice	Three different maltodextrin DE 10 concentrations (3%, 5%, and 10% w/w)	140, 160, 180, and 200	80	NR		[71]
Tamarillo	Maltodextrin DE 20	230	150	10 mL/min	NR	[68]
Red prickly pear	Glucose syrup	120–160	120	0.72 l/h	NR	[72]
Açai juice	Maltodextrin 10DE, maltodextrin 20DE, and gum Arabic	140, 170, and 200C	82, 97, 112	15 g/min	NR	[36]

[a]NR: Not reported.

compounds in *H. sabdariffa* L. extract are polyphenols; more specifically, the anthocyanin complexes. The presence of the bioactive material in the fibers did not appear to significantly affect the product size or shape. The results demonstrated that natural fruit fibers might be a potential replacement carrier for spray drying of sticky materials. Murugesan and Orsat[61] used five different wall materials (i.e., soya milk powder, soya protein powder, isolated soya protein, gum acacia, and maltodextrin) for encapsulating elderberry. They reported that gum acacia and maltodextrin gave better results. Ge et al.[52] microencapsulated red pigments from a hybrid rose with oil-soluble wall materials (mixture ratio of beeswax:stearic acid was 1:1), showing promising embedding rate and reporting that the stability of the product was significantly enhanced.

Spray-Drying Conditions

Encapsulation efficiency could be maximized by the right choice of spray-drying parameters, including inlet and outlet drying air temperatures, infeed temperature, atomization type and conditions, drying air flow rate, and humidity and powder particle size.[62] According to Liu et al.,[63] the optimum inlet air temperature for anthocyanin microencapsulation was 120°C and outlet air temperature was 80°C. Table 3 summarizes experimental conditions which have been recently optimized for the encapsulation of different anthocyanins by spray drying. The best spray-drying conditions are a compromise between high air temperature, high solid concentration of the solution, and easy pulverization and drying without expansion and cracking of final particles.

Physical Properties of Anthocyanin Microcapsules

In microencapsulation, some physical and morphological parameters of powders, such as low moisture content and a_w values, as well as better solubility and lower hygroscopicity, are essential for powder stability, powder storage, and powder reconstitution.[73,74] The use of different carrier agents for powder production can result in different physicochemical properties, depending on the structure and the characteristics of each agent.[74] Independent from the type and ratio of the carrier, the microparticles could have similar appearances. The external surfaces should show continuous walls with no fissures, cracks, or interruptions, which is an attribute that is essential for better protection and core materials retention.[75] Smooth spheres are desirable for the stability of encapsulated ingredients and also for the controlled release. This concept is one of the main purposes of microencapsulation of food ingredients because it can improve the effectiveness of food

TABLE 4
Examples of stability improvement of anthocyanins by spray-drying encapsulation

Anthocyanin source	Stabilization improvement	Reference
Blackberry	Stability of microcapsules using maltodextrin, gum Arabic, or a blend of both carrier agents over a period of five months at 25 or 35°C and at relative humidity of 32.8% was improved.Anthocyanin degradation followed the first-order kinetic model. Temperature negatively influenced the stability of anthocyanins.	[82]
Apple pomace	The stability of anthocyanins increased. The improvement in the shelf-life was attributed to reduction of water activity.	[83]
Black currant	High storage stability at 8°C and 25°C for 12 months.	[29]
Opuntia stricta fruits	The stability of anthocyanins increased.	[66]
Berberis kaschgarica	Athocyanins showed an increase in stability towards light, temperature, carbohydrates, reducing agents, oxidants, and metal ions after microencapsulation.	[65]
Black carrot	Storage at 4°C increased half-life of spray-dried anthocyanin pigments three times according to 25°C storage temperature.	[56]
Hybrid rose	Stability of the pigments under different pH, light, and heat was significantly enhanced.	[52]
Grape	An increase in the storage temperature from 4 to 25°C led to a change in the characteristic color index (bright red) of anthocyanins, and a darkening to brick red was noted.	[84]
Acai (*Euterpe oleracea* Mart.) juice	Stability at different temperatures (25 and 35°C) and water activities (0.328 and 0.529) was improved. Anthocyanin degradation exhibited two first-order kinetics: the first one, with higher reaction rate constant, up to 45–60 days of storage; and the second one, after this period, with lower degradation rate.	[74]
Pomegranate	Microcapsules with maltodextrin (MD) or soybean protein isolates (SPI) were stored at 60°C and in absence of light for 56 days. The polyphenols' encapsulating efficiency was significantly better in the SPI matrix, but for anthocyanins it was in the MD matrix. On the other hand, during storage, the MD microcapsules provided a significantly greater protective effect on the polyphenols and anthocyanins than SPI, as was shown by the lower degradation rate constants. When the microcapsules were added to yogurt, the stability of the bioactive compounds followed a similar behavior to those without encapsulation.	[57]
Garcinia indica	Storage at 4°C increased the half-life two-fold compared to that of the spray-dried product kept at ambient temperature (25°C).	[64]

additives.[76] However, in anthocyanin encapsulation, some studies have reported that the outer surfaces of the capsules had irregularities (some dents) and a few pores or cracks. The presence of these dents could have an adverse effect on the flow properties of microencapsulated product powders, but they do not affect the core material's stability.[77] These dents are formed by shrinkage of the particles during drying.[78] In many cases, these droplets, spherical in the beginning, form particles with irregular surfaces (folds).

The particle size and particle size distribution also play an important role in flowability, powder handling, processing, and other powder properties, such as bulk density, angle of repose, and compressibility of bulk solids.[45,79] The differences between the particle size distribution could affect the core material retention and other microcapsule properties.[77] The particle size mainly is influenced by spray nozzle size, nozzle position, liquid delivery rate, atomizing pressure, and solution concentration (viscosity).

Spray-drying conditions, such as air inlet temperature, air outlet temperature and nozzle size, affects the microencapsulated powder properties.[80] According to Ferrari et al.,[81] a higher inlet air temperature significantly increased the hygroscopicity of the powder, decreased its moisture content, and led to the formation of larger particles with smooth surfaces.

Stability of Microencapsulated Anthocyanins

Degradation kinetics and color stability of spray-dried encapsulated anthocyanins from roselle (*Hibiscus sabdariffa*) were studied by Idham et al.[85] In this study, three different biopolymers (i.e., maltodextrin, gum Arabic, combination of maltodextrin and gum Arabic, and soluble starch) were used as wall materials. The stability of encapsulated pigments was investigated during storage under three different storage temperatures (4, 25, and 37°C) for 105 days. The biopolymers largely increased the half-life of the pigments during storage, especially at 37°C ($P < 0.05$), compared with the non-encapsulated roselle extract. Degradation studies in many other works indicated that encapsulated extract by spray drying was more stable to light and temperature than the free extract, thus stability of encapsulated anthocyanins was improved. Burin et al.[86] used maltodextrin, maltodextrin/c-cyclodextrin and maltodextrin/Arabic gum as wall materials for Cabernet Sauvignon grapes. They found that the combination of maltodextrin/Arabic gum presented the longest half-life time and lowest degradation constant for all the conditions evaluated. The stability of the anthocyanins added to the isotonic soft-drink system was also studied under different temperature and light conditions. The degradation of the anthocyanins fit a first-order reaction model under all evaluated conditions. Radical scavenging activity studies demonstrated a significant retention of antioxidant activity after encapsulation by the spray-drying process.[64,68]

Table 4 summarizes some examples of anthocyanin encapsulation stability from diverse sources utilizing spray drying.

CONCLUSION AND FUTURE TRENDS

The use of anthocyanins may show benefits over that of synthetic colors. However, the use of these colorants in food products may face some problems due to their instability during storage caused by temperature, oxygen, and light. In order to overcome the instability problem, which results in restricted commercial applications, it is clear from the literature that the utilization of encapsulated anthocyanins can help to increase shelf-life and protect the biological properties of the anthocyanins. In this review, the results of recent studies implementing spray-drying techniques applied to anthocyanins extracts confirmed that encapsulation is an interesting means to potentialize their activity. Spray drying is the most common technique used to encapsulate anthocyanins and about 80–90% of encapsulates are spray-dried. Other techniques include freeze drying, emulsification, gelation, etc. There are still some technologies not being applied for these special anthocyanins, including spray cooling/chilling, inclusion complexation, liposome entrapment, melt injection, rotational suspension separation, and nanoencapsulation. The reason could be due to the hydrophilic nature of anthocyanins. It is possible to formulate them within emulsions such as multiple emulsions and then apply the above-mentioned techniques for encapsulation.

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