J. Food Sci. Gastron. (January - June 2023) 1(1): 22-34
https://doi.org/10.5281/zenodo.13975102
ISSN: 3073-1283

JFSG
JOURNAL OF FOOD SCIENCE AND GASTRONOMY

REVIEW ARTICLE

Natural colorants in the food industry: the role of anthocyanins and their spray drying process

Colorantes naturales en la industria alimentaria: el rol de las antocianinas y su proceso de secado por aspersión

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Received: 9 December 2022 / Accepted: 13 January 2023 / Published online: 31 January 2023

Abstract The use of natural colorants in the food industry has garnered increasing interest due to the demand for healthier and safer products for consumers. Among these colorants, anthocyanins, compounds found in various fruits and vegetables, stand out for their ability to provide vibrant colors and their antioxidant properties. However, their industrial application faces challenges related to their stability against factors such as light, pH, and temperature. This review described the role of anthocyanins as natural colorants, addressing their properties, benefits, and limitations in food products. Additionally, spray drying was analyzed as a promising technique to improve the stability and shelf life of anthocyanins, facilitating their effective incorporation into the industry. Recent studies on the impact of this process on the bioactive properties of anthocyanins were reviewed, as well as their application in the development of food products utilizing natural colorants.

Keywords anthocyanins, natural colorants, food industry, stability, spray drying, antioxidant properties.

Resumen El uso de colorantes naturales en la industria alimentaria ha suscitado un creciente interés debido a la demanda de productos más saludables y seguros para los consumidores. Entre estos colorantes, las antocianinas, compuestos presentes en diversas frutas y hortalizas, se destacan por su capacidad para proporcionar colores vibrantes y por sus propiedades antioxidantes. Sin embargo, su aplicación industrial enfrenta desafíos relacionados con su estabilidad ante factores como la luz, pH y temperatura. Esta revisión describió el papel de las antocianinas como colorantes naturales, abordando sus propiedades, beneficios y limitaciones en productos alimentarios. Además, se analizó el secado por aspersión como una técnica prometedora para mejorar la estabilidad y la vida útil de las antocianinas, facilitando su incorporación eficaz en la industria. Se revisaron estudios recientes sobre el impacto de este proceso en las propiedades bioactivas de las antocianinas, así como su aplicación en el desarrollo de productos alimentarios que utilizan colorantes naturales.

Palabras clave antocianinas, colorantes naturales, industria alimentaria, estabilidad, secado por aspersión, propiedades antioxidantes.

How to cite
Rodríguez, D. (2023) Natural colorants in the food industry: the role of anthocyanins and their spray drying process. *Journal of Food Science and Gastronomy*, 1(1), 22-34. https://doi.org/10.5281/zenodo.13975102

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PUBLIS EDITORIAL

Introduction

Color is a quality characteristic of food products. Colorants are added to food for various functions: to make them more attractive, to counteract color loss during processing, to enhance quality, and to influence consumers to purchase them (Madhava & Sowbhagya, 2012). Color plays a fundamental role, as it is associated with a flavor threshold, a perception of sweetness, food preference, and acceptability (Clydesdale, 1993). According to Downham & Collins (2000), there are four types of colorants available in the food market: synthetic (42%), natural (27%), nature-identical (20%), and caramel (10%).

The use of synthetic colorants is supported by their lower cost, stability, and brightness compared to natural colorants. However, various studies have linked some of them to carcinogenesis, genotoxicity, and neurotoxicity (Kobylewski & Jacobson, 2010).

Natural colorants, on the other hand, are derived from inexhaustible sources, such as plant material, insects, algae, cyanobacteria, and fungi (Mortensen, 2006). Recent consumer trends demand natural products with therapeutic and medicinal properties, among other reasons, which are related to the toxicity attributed to synthetic colorants (Chaitanya, 2014).

Anthocyanins are pigments responsible for a range of colors that span from red to purple in flowers, fruits, leaves, stems, and roots of plants (Castañeda et al., 2009). These pigments are flavonoids with antioxidant activity that have been linked to the prevention of cardiovascular, and neurological diseases, cancer, and diabetes (Konczak & Zhang, 2004).

The color and stability of anthocyanins are affected by various extrinsic and intrinsic factors (Enaru et al., 2021). In this sense, spray drying is a cost-effective method that preserves the colorant by trapping the bioactive ingredient within the encapsulating material (Cai & Corke, 2000).

The objective of this article was to describe the use of anthocyanins as natural colorants in the food industry, with a particular focus on anthocyanins, evaluating their potential as alternatives to synthetic colorants. Additionally, the spray drying process will be examined as a key technique for preserving their bioactive properties and stability, highlighting its impact on the quality of the final product.

Food additives

A food additive is any substance that is not normally consumed as a food itself, nor is it used as a basic ingredient in food, whether or not it has nutritional value, and whose addition to food during its production, manufacturing, preparation, treatment, packaging, transport, or storage results (or can reasonably be expected to result) directly or indirectly in itself or its by-products becoming a component of the food or affecting its characteristics. This definition does not include contaminants or substances added to food to maintain or improve nutritional qualities (NC 277, 2008).

The use of additives must be regulated by professional ethics, as they must provide a benefit to the food, either by improving it or by extending its shelf life. An excess of them would transform them into contaminants or constitute fraud (Valle, 2000).

The search for a balance between the safety of their intake and the technological benefit they provide to foods is essential due to the need for their use (Parra, 2004).

There are different types of additives, including preservatives, colorants, enhancers, antioxidants, flavorings, nutritive and non-nutritive sweeteners, vitamins, amino acids, nucleotides, carbohydrates (gums, sugars, among others), stabilizers, thickeners, emulsifiers, enzymes, minerals, and others (Castillo, 2016).

Food colorants

Color is the first sensory impression of a product; it can even influence the perception of its smell, taste, temperature, texture, and even nutrient content (Valle, 2000; Lakshmi, 2014). Both color and its uniformity are important components in the visual quality of foods and play a crucial role in consumer choice (Brennan, 2008), and therefore in the success or failure of a product. Foods in their natural state have colors that vary both with the seasonality of the raw material and with the technological treatments applied during processing (Valle, 2000; Ibáñez et al., 2003).

Colorants are substances that can have either a natural or an artificial origin (Badui, 2006) and are used either to enhance the color of certain foods, those that have lost color during industrial treatment or to make them more attractive. They can also be defined as those substances that add color to a food, including natural components (Parra, 2004). In other words, they are the group of additives responsible for providing the desired and expected color of each food, that is, they provide, reinforce, or homogenize its color to make it more appealing to consumers (Cubero et al., 2002). Their use ensures a standardized tone in food products (Masone et al., 2015).

Synthetic colorants provide greater intensity of coloration (requiring a smaller amount of colorant to achieve the same effect), offer a wider range of colors, are more stable to light, pH, and temperature, are easier to reproduce the desired color, and have lower probabilities of interacting with other additives (Astiasarán et al., 2003).

Consumer concern about the safety of synthetic colorants has increased interest in using natural colorants as additives (Gil, 2010), making them increasingly popular (Martins et al., 2016) for being less toxic and harmful to health, as well as having a lower environmental impact (Silva, 2006). For this reason, the search for alternatives to synthetic colorants is a challenge in which the agro-industrial sector invests all its resources (Cano, 2011).

Parra (2004) conducted a comparative study between the use of synthetic and natural colorants, concluding that synthetic colorants have better functional and technological characteristics than natural ones, making them more suitable for use as additives in a wide range of foods. In other words, they are more stable, provide better color uniformity, and mix more easily, resulting in a wide range of shades.

In contrast, other studies have reported that synthetic colorants have numerous side effects. These include allergic reactions, such as allergic gastroenteritis (Prado et al., 2012). Recent studies focus primarily on the connection between these colorants and behavioral disorders in children (Amchova et al., 2015). Some even promote hypersensitivity reactions causing urticaria, angioedema, and asthma (Vidotti et al., 2006).

This has favored interest in obtaining colorants from natural sources as possible substitutes for synthetic colorants, as there is currently no evidence of their toxicity in humans (Soria et al., 2007). Anthocyanins have thus become an interesting option in this regard due to their antioxidant and cytotoxic activities (Kong et al., 2003).

Natural Dyes

Most natural dyes are of plant origin; they can be pure compounds or products of extraction. The latter are obtained from food raw materials and may be associated with other molecules. The main natural pigments belong to three major categories: porphyrin pigments, which include chlorophylls and heme pigments; carotenoids, which include β-carotene, lycopene, and xanthophylls; and finally, flavonoids and their derivatives (Linden & Lorient, 1996).

Natural dyes are replacing synthetic ones due to their safety and lack of serious side effects. Their disadvantage is that larger amounts of the active principle are needed for industrial use, unlike synthetics, which are produced on a large scale and at low cost (Vásquez, 2012).

Anthocyanins: general overview

Flavonoids are one of the most distinctive groups of secondary metabolites in higher plants (Winkel-Shirley, 2001); in turn, anthocyanins are the most important group of flavonoid pigments in plants. Anthocyanins are non-nitrogenous water-soluble plant compounds (Badui, 2006), considered flavonoids because they have the C6-C3-C6 carbon skeleton (Fennema, 2000; Garzón, 2008).

They are glycosides of anthocyanidins, which are aglycone bound to a sugar via a glycosidic bond and consist of two aromatic rings A and B connected by a three-carbon chain. The differences between anthocyanins are related to transformations in the chemical structure of the B ring, such as the number of hydroxyl groups, sugars, and aliphatic or aromatic acids attached to the molecule, as well as the position of the attachments (Kong et al., 2003).

Among the sugars that are part of the molecule, in order of abundance, are glucose, rhamnose, galactose, xylose, and arabinose, and occasionally, gentiobiose, rutinose, and sophorose (Badui, 2006). The basic skeleton of anthocyanins is the 2-phenylbenzopyrilium salt of flavilium with different substitutions (Sousa et al., 2005). Anthocyanic pigments (anthocyanins) are hydroxylated and methoxylated derivatives of the salt (Eder, 1996).

Approximately 20 anthocyanidins are known; the most important ones are pelargonidin, delphinidin, cyanidin, petunidin, peonidin, and malvidin, names that derive from the plant source from which they were first isolated. The combination of these aglycones with different sugars generates approximately 300 anthocyanins, which are responsible for a wide range of colors, from colorless to purple (Badui, 2006).

The color of anthocyanins depends on the number and orientation of hydroxyl and methoxy groups in the molecule. Increases in hydroxylation produce shifts towards blue hues, while increases in methoxylation produce red colors (Stintzing et al., 2002). On the other hand, glycosylation and acylation of the sugars increase the stability of the pigment (Giusti & Wrolstad, 2003).

Stability of anthocyanins

The stability of anthocyanins is related to the degree of oxidation, temperature, ionic strength, acidity, interaction with other complex molecules and free radicals (Garzón, 2008), chemical structure, concentration, light, oxygen, solvents, presence of enzymes, flavonoids, proteins, and metal ions (Castañeda et al., 2009; Olaya et al., 2009; Owusu, 2005).

pH affects the structure, color, and stability of anthocyanins due to the transition of different chemical species. This phenomenon is known as the bathochromic effect. As pH increases, it shifts from the orange-red of pelargonidin in acidic conditions to the intense violet-red of cyanidin in neutral conditions, and to the purple-blue of delphinidin in alkaline media (Garzón, 2008). At acidic pH, it exists in its most stable form as the red-flavilium cation; at pH values close to neutrality, it appears as chalcone or hemiacetal, which are unstable and colorless forms, and at higher pH, it becomes a highly oxidation-sensitive purple quinoid form (Brouillard, 1982).

Bordignon et al. (2009) studied the extraction of anthocyanins from strawberries (Fragaria vesca L.) in the pH range of 1 to 13 and found that the best extraction occurred at the lowest pH value. Zapata (2014) reported that at a pH of 2.1, optimal extraction of total anthocyanins in blueberries (Vaccinium corymbosum) was achieved. As pH increased, the anthocyanin content began to decrease due to the degradation of the flavilium cation, leading to the formation of hemiacetal and chalcone, both of which are unstable forms.

Moldovan et al. (2012) studied the degradation kinetics of anthocyanins present in extracts of sour blueberries (*Viburnum opulus* L.) during storage at pH 3 and 7, concluding that the lowest degradation occurred at the lowest pH value. Laleh et al. (2006) investigated the influence of pH on anthocyanin extracts from four species of the genus Berberis, observing that the lower the pH, the less degradation of anthocyanins occurred. For this reason, the practical use of these pigments as natural dyes is limited to acidic foods with pH below 3.5 (Francis, 1995; Hutchings, 1999).

High temperatures cause the degradation of these pigments by causing the loss of sugar from the molecule, resulting in the opening of the ring and the formation of chalcones (Falcão et al., 2008). High temperatures can lead to the loss of the glycosylating sugar at position 3 of the molecule and the opening of the pyran ring, resulting in the production of colorless chalcones (Falcão et al., 2008; Garzón, 2008; Falcão, 2003).

Kirca et al. (2006) studied the stability of anthocyanins from black carrots (Daucus carota L.) added to fruit juices (apple, grape, orange, grapefruit, tangerine, and lemon) and nectars (apricot, peach, and pineapple). The juices were subjected to thermal treatments in a range of 70 to 90 °C and then stored between 4 and 37 °C. The results showed that the degradation of anthocyanins was greater in products treated at 90 °C.

On the other hand, Pereira et al. (2010) studied the degradation kinetics of anthocyanins during the thermal treatment of blueberry juice between 40 and 80 °C, noting that this was first-order degradation and that degradation was greater at higher temperature values. Similar results were reported by Wang & Xu (2007) when studying the degradation kinetics of anthocyanins in blackberry juice during thermal treatment and storage. Likewise, Moldovan et al. (2012) reported that the degradation kinetics of anthocyanins in extracts of sour blueberries (*Viburnum opulus* L.) during storage between 2 and 75 °C resulted in first-order kinetics.

The rate of degradation of this factor is also influenced by the presence of oxygen, pH, and structural conformation. In general, the structural characteristics that lead to increased stability against pH changes also lead to thermal stability. Highly hydrolyzed anthocyanidins are less stable than methylated, glycosylated, or acetylated forms (Fennema, 2000).

Rebolledo (2007) reported similar results in a concentrate of cranberry juice (Vaccinium macrocarpon) obtained by nanofiltration; the concentration of anthocyanins present in the concentrated juice decreased with thermal treatments depending on the temperature, in an almost linear function. However, the color was not affected by either thermal treatments or storage time.

Oxygen affects anthocyanins directly by oxidizing them or indirectly by oxidizing constituents in the medium that then react with the anthocyanins (Falcão, 2003), resulting in the formation of brown or colorless products. Anthocyanins can react with oxygen radicals, acting as antioxidants. These oxidation mechanisms are favored when the temperature increases (Rein, 2005).

The effects of oxygen and ascorbic acid on the stability of anthocyanins are related. Ascorbic acid decolorizes anthocyanins in the presence of oxygen, copper, and iron ions by forming hydrogen peroxide, resulting in the degradation of both compounds when stored for extended periods (Badui, 2006). This reaction is inhibited in the presence of flavonols such as quercetin. Hydrogen peroxide acts by breaking the pyrilium ring of the anthocyanin through a nucleophilic attack at C-2, producing colorless esters and coumarin derivatives. These degradation products are destroyed and polymerized to form brown precipitates (Fennema, 2000).

The effect of ascorbic acid on the stability of anthocyanins has been explained as a possible condensation reaction between the acid and the pigments (Poei-Langston & Wrolstad, 1981). Ferreira et al. (2007), when studying the effect of light on the stability of anthocyanins in white spinach fruit extract, concluded that light had an adverse effect on their stability. Laleh et al. (2006) reached the same conclusion in their research regarding the stability of anthocyanins present in extracts of fruits from four species of the genus Berberis, as did Devi et al. (2012) when studying the stability of anthocyanins extracted from red sorghum bran. Cevallos-Casals & Cisneros (2004) found that during exposure to light, the purple-fleshed sweet potato dyes were degraded more slowly than the anthocyanins from purple corn, suggesting a protective effect of acylation in the anthocyanin molecule.

Anthocyanins change color when they form complexes, chelates, and salts with sodium, potassium, calcium, magnesium, tin, iron, or aluminum ions; for this reason, it is recommended that cans used for packaging foods containing anthocyanins be coated with a protective lacquer to minimize their interaction with undesirable metals (Badui, 2006).

The nature of the sugars influences the stability of anthocyanins. For example, anthocyanin containing galactose is more stable than that with arabinose (Lock, 1997). Sugars at high concentrations, as occurs in fruit preserves, stabilize anthocyanins. This effect is believed to be due to the reduction in water activity (a_w). The nucleophilic attack of water on the flavilium cation occurs at position C-2, forming a colorless carbinol base. When sugars are present in concentrations low enough to have little effect on a_w, they or their degradation products can sometimes accelerate the degradation of anthocyanins.

At low concentrations, fructose, arabinose, lactose, and sorbose have a greater degrading effect on anthocyanins than glucose, sucrose, and maltose. The degradation rate of anthocyanin follows the degradation rate of sugar to furfural. Furfural, which is derived from aldopentoses, and hydroxymethylfurfural, a derivative of ketohexoses, result from the Maillard reaction or from the oxidation of ascorbic acid. These compounds easily condense with anthocyanins, forming brown compounds. The mechanism of this reaction is unknown. It is highly temperature-dependent, accelerated by the presence of oxygen, and is very evident in fruit juices (Fennema, 1995).

On the other hand, the concentration of the pigment and a_w of the medium affect the stability of the color of anthocyanins (Garzón & Wrolstad, 2001; Garzón & Wrolstad, 2002). Olaya et al. (2009) observed that a_w of 0.35 caused the highest rate of degradation in anthocyanins from Castilla blackberries (*Rubus glaucus* Benth) and tamarillo (*Solanum betaceum* Cav.) at a storage temperature of 40 °C. The cause of the degradation of anthocyanins due to a_w is likely due to increased interaction between water and the flavilium cation, leading to the formation of an unstable pseudobase (Garzón & Wrolstad, 2001; Fleschhut et al., 2006).

Garzón & Wrolstad (2002) demonstrated that increasing the pigment concentration in concentrated strawberry juices improved the stability of anthocyanins, delaying color change compared to non-concentrated strawberry juice stored at 25 °C. The water molecule is involved in reactions that deteriorate anthocyanins, so its removal is advisable to reduce the chances of nucleophilic attack on the flavilium cation (Zapata, 2014).

Falcão et al. (2008) reported in their study evaluating the stability of anthocyanins from crude extracts of Cabernet Sauvignon grape skins (Vitis vinifera L.) that the half-life of anthocyanins and the percentage of color retention were higher at a temperature of 4 ± 1 °C, at pH = 3, and in the absence of light. However, anthocyanin degradation was greater when the storage temperature was 29 ± 2 °C under the same conditions. Ersus and Yurdagel (2007) observed a similar behavior in microencapsulated black carrot anthocyanins, where the half-life of the pigments was three times greater at 4 °C compared to storage at 25 °C. In general, anthocyanins are more stable in acidic media, free of oxygen under cold conditions, and in the dark (Eder, 1996).

Sources of anthocyanins

Anthocyanins are a group of water-soluble natural pigments that impart red, purple, and blue coloration to many fruits such as cherries, plums, strawberries, raspberries, and blackberries, among others (Fennema, 2000; Castañeda et al., 2009). Other sources of anthocyanins include cereals (purple corn) and some vegetables (Escribano-Bailón et al., 2004).

Anthocyanins are among the most well-known natural colorants. They are responsible for the red, orange, blue, and purple colors of cherries, plums, strawberries, raspberries, blackberries, grapes, red and black raisins (Lepidot et al., 1999), as well as apples, roses, and other plant-derived products like flowers (Badui, 2006). They significantly influence the sensory characteristics of foods due to their attractive colors and potential health benefits (Castañeda et al., 2009; Bridgers et al., 2010; Aguilera-Otíz et al., 2011).

In recent years, the study of anthocyanins in tropical fruits has gained momentum due to their coloring capacity (Garzón, 2008). Anthocyanins have been identified and quantified in some tropical fruits such as acerola (*Malphigia emarginata*), jussara (*Euterpe edulis*), guajiru (*Chrysobalanus icaco*), and jambolan or black cherry (*S. cumini*) (De Brito et al., 2007).

Drying processes

The food industry has a significant interest in powdered additives, particularly concerning their stability (physical, chemical, and microbiological), cost reduction in transportation and packaging, as well as for preparing dry products (Schmitz-Schug et al., 2013).

There are many drying techniques such as spray drying, freeze-drying, and tray drying that have been developed to increase productivity and achieve better process control to enhance product quality (Cano-Chauca et al., 2015). Both freeze-drying and spray-drying offer a clear advantage in obtaining products with low moisture content and high sensory, nutritional, and functional quality (Mosquera, 2010).

Freeze-drying is a unit operation by which frozen water in food passes directly from a solid state to a vapor state under high vacuum pressure (Rodríguez, 1986). According to Liapis & Litchefiel (1979), the most important characteristic to highlight about this operation is the excellent quality of its products, primarily due to the large amount of water removed, low thermal degradation, retention of volatile materials responsible for aroma and flavor, and the rigid structure of the dried material.

Another important feature of freeze-drying is the easy rehydration and original reconstruction of the dried products, due to the low degree of cellular and structural breakage (Boss, 2004). However, freeze-drying is a highly costly technique, in addition to the long periods required to obtain a product in optimal conditions. The energy expenditure involved in the process is high, considering that the raw material must undergo two processes, plus the energy necessary for handling the residual water (Barbosa-Cánovas et al., 2005). These factors have limited the expansion of its use not only in the food industry but also in the pharmaceutical sector, paving the way for other less costly and more efficient techniques, such as spray drying (Mosquera, 2010).

Spray drying

Natural colorants have gained significant importance in the global market, leading to the need to obtain them in powdered form to facilitate their transport and dosing, using a drying treatment under conditions that do not damage the product (Devia & Saldarriaga, 2005). Spray drying is a unit operation that transforms liquid substances into powder, facilitating their preservation, storage, transport, and handling, among others (Bhandari et al., 2008), and offers high efficiency and the ability to conserve the natural components present in these products (Bahnasawy et al., 2010).

The transformation from liquid to dry particles requires four basic stages: feeding atomization, air-liquid contact, water evaporation, and particle separation. It is the most common technique for microencapsulating components in the food industry; furthermore, it is the cheapest, with production costs lower than most other methods (Chhun, 2006).

Drying conditions determine efficient microencapsulation; the operational factors that influence it the most are feed flow rate, inlet and outlet air temperatures, and feed temperature (Liu et al., 2004), types of carriers and their concentration (Krishnaiah et al., 2014). The feed temperature relates to viscosity; as the temperature increases, the viscosity and droplet size increase. The inlet temperature determines the drying rate and final moisture content of the product (Dubernet & Benoit, 1986).

Air temperatures control the moisture content of the powdered product. As the inlet temperature increases and the temperature difference in the dryer decreases, the moisture in the product will decrease. Most products dried by spray drying contain 1 to 6% moisture (Reineccius, 2006). Although drying temperatures are high, process times are short compared to other drying processes, making this technique more cost-effective for heat-sensitive materials (Mosquera, 2010).

The drying of fruit juices, like that of other products with high sugar content, presents technical difficulties due to their high hygroscopicity and thermoplasticity under high temperature and humidity conditions (Adhikari et al., 2004). During the drying of these products, syrup can remain on the walls of the drying chamber. Additionally, there is the issue of unwanted agglomeration in the drying chamber and conduits, which can cause low product yields and operational problems. The problem of stickiness has been related to low glass transition temperature (Tg) values (Bhandari & Howes, 1999). Tg is the temperature at which products in an amorphous state transition from a glassy to a rubbery state, or vice versa (Roos, 1995).

For this reason, innovations have been made in the use of encapsulating materials as vehicles to facilitate drying during the production of fruit powders (Bhandari et al., 1993). Several authors have highlighted their use to reduce the adhesiveness of the material and, in some cases, the deposition problems on the equipment walls. The selection of the material to be used as a vehicle and its concentration will depend primarily on the product being developed and the anti-caking capacity of the vehicle (Kenyon, 1995).

Viscosity and soluble solids content are requirements in the preparation of the mixture to be dried, as these will affect the efficiency of the drying process and the characteristics of the final product. Proper viscosity of the solution and a high total solids content are critical factors for process yield. Low viscosity allows for better flow of the mixture in the spray system, while a high concentration of total solids increases yield (López et al., 2009). Total solids must be increased to achieve a good yield in the dry product, being careful not to excessively increase the viscosity of the mixture that will be subjected to spray drying (Reineccius, 2006).

Materials used in spray drying

Different materials can be used as encapsulants. The ideal encapsulant should form coatings, have emulsifying properties, be biodegradable, resistant to the gastrointestinal tract, present low viscosity with a high solids content, low hygroscopicity, and low cost (Barros & Stringheta, 2006). Furthermore, they should not impart aroma or flavor (Phisut, 2012), although they may enhance some sensory properties (Jittra et al., 2009) and should not react with or degrade the active ingredient during processing and storage (Barbosa-Cánovas et al., 2005; Ghosh, 2006). Among them are hydrocolloids such as starch and maltodextrin with various dextrose equivalence (DE) values, gum arabic, and some proteins (Shahidi & Han, 1993; Young et al., 1993) such as gelatin, casein, whey, soy, and wheat (Parra, 2011). Other possible encapsulating materials include inulin (Stevens et al., 2001) and chitosan (Ribeiro et al., 1999).

The use of high molecular weight compounds before spray drying is very common as an option to raise the glass transition temperature (Tg) of the dry product (Phisut, 2012). Maltodextrin is a good solution in terms of cost and effectiveness; it is a polysaccharide obtained by the partial acid hydrolysis of starch from corn, and potatoes, among others, and is classified according to its dextrose equivalence. It is soluble in water, has low viscosity, is tasteless, odorless, and forms colorless solutions (Bakowska-Barczak & Kolodziejczyk, 2011), allowing for the production of free-flowing powders without masking the original flavor, which makes them extensively used in the food industry (García et al., 2004). Moreover, they are especially useful due to their high solubility in aqueous solutions and high glass transition temperature values as a result of their high molecular weight (Kenyon, 1995). Maltodextrins with a dextrose equivalence of 10 to 20 are widely used in the microencapsulation of anthocyanins (Ersus & Yurdagel, 2007).

Similarly, maltodextrins help reduce problems of adhesion and agglomeration during storage, improving product stability (Silva et al., 2006). Several studies have demonstrated the influence of maltodextrin concentration on moisture content. Fazaeli et al. (2012) reported a decrease in moisture during the drying of black mulberry juice (Morus nigra) with increasing maltodextrin content (8, 12, and 16%); this could be due to additional concentrations of the encapsulant resulting in an increase in feed solids and a reduction in moisture. Other authors have reached similar conclusions (Mishra et al., 2014).

Modified starch by the addition of lipophilic compounds to increase emulsifying stability is another commonly used agent (Arburto et al., 1998). It can form small droplet-like particles (Shahidi & Han, 1993). Gum Arabic is one of the most important encapsulants used for colorants and flavorings (Beristain et al., 2001); its use is conditioned by emulsion stability and good retention. In the production of powders from pigment extracts, it can be used in combination with other encapsulants (Barros & Stringetha, 2006).

Arteaga & Arteaga (2016) evaluated the effect of a mixture of gum arabic, maltodextrin, and modified starch on the antioxidant activity, rehydration capacity, and anthocyanin content in microencapsulated blueberry powder. They observed that the combination of microencapsulants influenced the antioxidant capacity and anthocyanin content, although it did not affect the rehydration capacity of the powder.

Anthocyanins as natural colorants

Various studies have demonstrated the coloring ability of anthocyanins against several matrices. Ramírez et al. (2006) obtained a natural food colorant from Castilla blackberry (Rubus glaucus Benth) to evaluate its effectiveness in dairy products compared to the synthetic colorant Erythrosine (E-127). In another study, Ramírez et al. (2007) reported that this colorant was effective, relatively stable, and maintained the naturalness of the products to which it was applied.

On the other hand, Cevallos-Casals & Cisneros-Zeballos (2004) noted that despite the advantages that anthocyanins offer as potential substitutes for artificial colorants, their incorporation into food matrices or pharmaceutical and cosmetic products is limited due to their low stability during processing and storage.

Cano (2011) obtained three natural colorants from bilberry (*Vaccinium myrtillus* L.), Castilla blackberry (*Rubus glaucus*), and tree tomato (*S. betaceum* Cav.) for the partial or total replacement of curing salts in commercial sausages. Various authors have microencapsulated anthocyanins from different matrices using maltodextrin as the encapsulating agent: blackcurrant (Bakowska-Barczak & Kolodziejczyk, 2011); black carrot (Ersus & Yurdagel, 2007); myrtle (Fang & Bhandari, 2011); açaí (Tonon et al., 2008; Tonon et al., 2010); grapes (Vitis vinifera L.) (Burin et al., 2011), among others.

In the microencapsulation of anthocyanins extracted from eggplant (*Solanum melongena* L.), it was observed that the best spray drying conditions for anthocyanin retention were achieved using an inlet air temperature of 180 ºC and a solids concentration in the feed of 30%. Maltodextrin was used as the encapsulating agent (Arrazola et al., 2014). They also evaluated the stability of the powdered colorant in isotonic beverages and Aloe vera-based drinks, concluding that storage temperature influenced the stability of anthocyanins and parameters such as color. The isotonic beverages and Aloe vera drinks with maltodextrin, stored at 4 °C, showed the highest retention of anthocyanins (54% and 77.5%, respectively).

In another study, a natural powder colorant was obtained from fig peel (*Ficus carica* L.). The aqueous extracts of fig anthocyanins were spray dried, using maltodextrin as the encapsulating agent, at an inlet air temperature of 180 ± 2 ºC and three outlet air temperatures (80 ± 2 ºC; 90 ± 2 ºC; and 92 ± 4 ºC). For drying, the final mixture was standardized to 20% total solids, with the addition of maltodextrin at a rate of 16.25 g/100 mL of extract. The best conditions for obtaining the powdered colorant were at an inlet air temperature of 180 ºC and an outlet temperature of 92 ºC (Aguilera-Otíz et al., 2012).

Functional ingredients were obtained from blackberry (Rubus glaucus Benth) and bilberry (*Vaccinium floribundum* Kunth) pulp through microencapsulation. Several treatments were carried out with temperatures ranging from 130 to 150 ºC and combinations of gum arabic (GA) and maltodextrin (MD). The highest polyphenol and anthocyanin contents were achieved at 130 ºC with 10 g GA/90 g MD for the drying of blackberry pulp and 150 ºC with 10 g GA/90 g MD for bilberry pulp. The highest percentages of anthocyanins reported for blackberry and bilberry powders were 75.31% and 65.56%, respectively (Abadiano, 2015).

Herazo (2013) obtained a natural powder colorant from anthocyanins extracted from eggplant (*S. melongena*). Spray drying was carried out with maltodextrin as the encapsulating agent. It was observed that temperature and percentage of maltodextrin influenced most physical and chemical properties of the powder. The colorant with 30% maltodextrin dried at 180 °C, with an efficiency of 98%, showed lower moisture content (3.43%) and a_w (0.26), and higher solubility (93.61%).

Santhalakshmy et al. (2015) studied the effect of inlet air temperature on the physical and chemical properties of a powder obtained from *S. cumini* juice. The variations were within a range of 140 to 160 °C. The outlet temperature parameters (80 °C), as well as the concentration of maltodextrin (25%), remained constant in the study. The best inlet temperature for powder production was 150 °C, yielding optimal moisture content and a_w for the powder.

Natural colorants were prepared from blueberry, grape juice, and hibiscus (*Hibiscus sabdariffa* L.). The extraction of anthocyanins was performed in 95% ethanol and 0.01% citric acid, with the addition of Morrex 1918 (10-13 DE) until obtaining 30% total solids. The most appropriate outlet air temperature for obtaining the anthocyanin concentrate with minimal degradation was 90 ºC (Main et al., 1978).

From black carrots, Ersus & Yurdagel (2007) extracted anthocyanins in acidified ethanol. The extract was dried using maltodextrin Stardri 10 (10 DE), Glucodry 210 (20-23 DE), and MDX 29 (28-31 DE) as transport and encapsulating agents. Three combinations of inlet and outlet air temperatures were evaluated, maintaining a constant total solids percentage of 20%. The highest inlet and outlet air temperatures caused the greatest losses of anthocyanins during the drying process. The powder obtained at a drying temperature of 160 ºC using Glucodry 210 (20-23 DE) showed the highest anthocyanin content. This powder was characterized based on its anthocyanin content, antioxidant capacity, chromatic coordinates, hygroscopicity, and dry matter.

On the other hand, Tonon et al. (2009) reported that 10 DE maltodextrin was the encapsulant that showed the best protection and highest antioxidant activity of acai anthocyanins (*Euterpe oleracea* Mart.), compared to 20 DE maltodextrin, gum arabic, and cassava starch. The samples were stored at 25 and 35 ºC and a_w values of 0.328 and 0.529; it was observed that with the increase of temperature and a_w, their antioxidant activity decreased.

Silva et al. (2013) evaluated the simultaneous optimization of different encapsulating agents and temperatures to obtain a powdered colorant from jaboticaba (*Myrciaria jaboticaba*). They used as encapsulating agents 30% maltodextrin as control, 25% gum arabic + 5% maltodextrin, and 25% CapsulTM + 5% maltodextrin. The inlet air temperatures were 140, 160, and 180 ºC. The retention of anthocyanins, moisture content, total solids, hygroscopicity, total color difference, and antioxidant activity were the response variables. The variant that showed the highest statistical convenience corresponded to the mixture of 30% maltodextrin at 180 ºC; however, scanning electron microscopy showed that the combination of maltodextrin and gum arabic allowed the formation of more homogeneous particles.

A similar study was conducted by Arteaga & Arteaga (2016), who evaluated the effect of the mixture of gum arabic, maltodextrin, and modified starch on the antioxidant capacity, rehydration capacity, and anthocyanin content of a blueberry powder. The drying was carried out at an inlet air temperature of 120 ºC. The highest values of antioxidant capacity and anthocyanin content were obtained for the combination of 11.89% maltodextrin, 12.13% modified starch, and 75.98% gum arabic. However, they did not influence the rehydration capacity.

Conclusions

Anthocyanins are an attractive option as natural colorants in the food industry due to their ability to provide vibrant colors and their antioxidant properties, which respond to the growing demand for healthier and safer products. Nevertheless, their stability remains a challenge, as factors such as exposure to light, pH variations, and high temperatures can affect their effectiveness and durability in food products. Spray drying emerges as a promising technique to enhance the stability of anthocyanins, extending their shelf life and facilitating their integration into various food matrices. The reviewed studies confirm that this process not only preserves the bioactive properties of anthocyanins but also enables their application in the development of new products with natural colorants, contributing to innovation in this field. Despite these advances, further research is needed to optimize processing conditions to ensure greater stability and functionality of anthocyanins in industrial applications.

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Conflicts of interest

The authors declare that they have no conflicts of interest.

Author contributions

Daliannis Rodríguez: Conceptualization, data curation, formal analysis, investigation, methodology, supervision, validation, visualization, drafting the original manuscript and writing, review, and editing.

Data availability statement

Not applicable.

Statement on the use of AI

The authors acknowledge the use of generative AI and AI-assisted technologies to improve the readability and clarity of the article.