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Red betalains from *Opuntia* spp.: Natural colorants with potential applications in foods

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ABSTRACT

Natural red colorants are highly appreciated by the food industry, and betalains are one such category. There are few sources in nature of betalains, which are commonly obtained from red beet as a colorant additive and acceptable for addition to foods according the regulations of several countries. Red and purple *Opuntia* fruits could be a new source of these pigments for commercial purposes. The content of the pigment varies according the species and the extraction procedures. The stability of the pigments is another aspect to be considered. Betalains are also suggested as antioxidants and the final colorant could be considered as a functional additive. Additionally, the inhabitants of many arid zones of the world could benefit from an increase in the demand of *Opuntia* fruits, a plant with low growing requirements.

Keywords: *Opuntia* spp., cactus pear, betalains, natural pigments, colorants

INTRODUCTION

There are few sources of betalains in nature. It has only been reported in beetroot (*Beta vulgaris*), amaranth (*Amaranthus*), djulis (*Chenopodium formosanum*), and some cactaceas such as cactus pear (*Opuntia* spp.), pitayas (*Stenocereus* sp.), pitahayas (*Hylocereus undatus*), and garambullo (*Myrtillocactus geomerizans*) (Sapers and Hornstein, 1979; Reynoso et al., 1997; Cai and Corke, 2000; Wybraniec and Mizrahi, 2002; Yañez-Lopez et al., 2005; Castellanos-Santiago and Yahia, 2008; Tsai et al., 2010). Beetroot is the main source for commercial betalains, used as natural red colorants in the food industry for many years (Serris and Biliaderis, 2001), primarily to color foods with no requirement for thermal treatments, such as yogurt, ice cream, syrups, and sausages (Forni et al., 1992; Diaz et al., 2006; Lozano, 2009). The developing of new sources for natural pigments has been increased because the official EU and USA regulations have restricted the use of synthetic red colorants as additives in food, due to toxicity related to their carcinogenic effects (Tsuda et al., 2001). In this context, the red-purple fruits of *Opuntia* could be a potential source for betalains as natural colorants, with the added advantage of antioxidant properties (Kanner et al., 2001; Kuti, 2004; Azeredo, 2009).

Betalains in *Opuntia* spp.

The two principal groups of betalains, the betacyanins (red) and the betaxanthins (yellow), show absorption at different wave lengths (540 and 480 mm, respectively).

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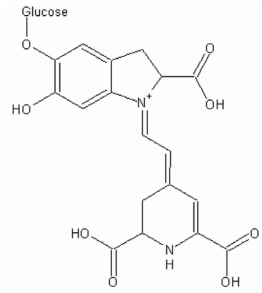

Fig. 1. Betanin or isobetanin.

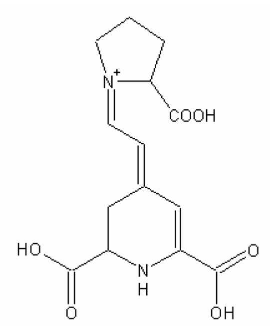

Fig. 2. Indicaxanthin.

Betanin and indicaxanthin are the main colorant components in *Opuntia ficus-indica* fruits, while isobetanin was detected in a low level (Morales et al., 2008) (Figs. 1 and 2). While the main cactus pear identified as a source of betalains is *Opuntia ficus-indica*, other authors have identified these pigments in *Opuntia stricta*, *Opuntia streptacantha, Opuntia robusta, Opuntia undulate, Opuntia lasiacantha, Opuntia decumbens, Opuntia boldinghii, Opuntia matudae, Opuntia xoconostle*, and *Opuntia macrorhiza* (Martínez et al., 2000; Moreno et al., 2003; Díaz et al., 2006; Castellanos-Santiago and Yahia, 2008; Castellar et al., 2008; Guzmán-Maldonado et al., 2010; Moussa-Ayoub et al., 2011; Osorio-Esquivel et al., 2011). Both kind of betalain pigments are of interest for industrial purposes, but in this article we focus on the red betalains because we think that, in the food industry, natural red colorants are scarce compared with the yellow ones. Cactus pear shows a wide range of betalains concentration according the species. Sepúlveda et al. (2003) studied the betanin content of 14 different types of *Opuntia*. The results showed a great variability in the betanin content among the fruits (48.3–138.1 mg 100 g^{-1}). Viloria-Matos et al. (2001, 2002) studied the betalains in *O. boldinghii* fruits. Their results showed a major red fraction with a maximum absorbance at 537 nm and a betacyanin content close to 80 mg L^{-1}. Moreno et al. (2003) reported a betalain concentration of 0.59 mg 100 mL^{-1} in fresh juice of *O. boldinghii*. Castellar et al. (2003) studied the pigment content in three species of *Opuntia: O. stricta*, *O. undulata*, and *O. ficus-indica*. The authors show that *O. stricta* is the richest in pigments (80 mg 100g^{-1}) of similar content compared with the red beet, that is, only betacyanins were detected (betanin and isobetanin), while in the other two species both betacyanins and betaxanthins were identified. Recently, Moussa-Ayoub et al. (2011) reported in *O. macrorhiza* fruit's pulp a total betacyanins content of 0.45 mg/100 mg d.w.

Forni et al. (1992) were among the first authors to study and identify the betalains in red cactus pear (*O. ficus-indica*) from Italy, reporting 14 mg 100g^{-1} in a betacyanin water extract.

Compared with beetroot, cactus betalains show fresh odor and flavor, free of the earth-like flavor of geosmin and 2-Methoxy-3-sec-butyl pyrazine of beetroot. In addition, as a fruit, cactus pear does not accumulate nitrates, thus representing lower risk for microbiological contamination (Stintzing et al., 2001; Moßhammer et al., 2006). For this reason, cactus fruits colorants may be used in food without the negative flavor impact of colorants derived from beetroot extracts (Stintzing et al., 2001, 2005; Butera et al., 2002; Piga, 2004; Azeredo, 2009). As an alternative for the production of this dyestuff, the purple cactus pear, an ancient crop in arid zones, is an alternative to increase the low agricultural potential of this type of land, with significant benefit for its inhabitants.

Betanin, also called "beetroot red", is among the natural pigments accepted for foods and is classified as additive E-162 (EU) and 73.40 (FDA, USA). Thus, the betanin extracted from *Opuntia* fruits does not need new color certification, since is the same pigment (Castellar et al., 2006). Cactus pear betalains can cover the color range in which anthocyanins are traditionally used, but in addition, betalains can be applied in foods of low acidity without affecting the color_(Azeredo et al., 2007).

Factors influencing betalain content in cactus fruits

The betalain content in the fruit is affected by factors such as cultivar or variety, distribution in the fruit (peel or pulp), stage of maturity (García-Gutierrez et al., 2006), and climate or geographic site of production (Stintzing and Carle, 2004). Díaz et al. (2006) observed that the betanin of a water extract of *O. lasiacantha* from different locations from Mexico ranged from 19.33 to 27.7 mg 100 g^{-1} but without significant differences, due to the high variation coefficient observed.

Betalains are not homogeneously distributed in the cactus pear fruit. In some varieties the betalains are more concentrated in the peel than in the pulp, with the reverse in others, as reported by Odoux and Dominguez-López (1996), who determined the betalain content in pulp and peel of different *Opuntia* species from the Botanical Garden of Blañes, Spain (Table 1).

Cultivar differences were reported also by Castellanos-Santiago and Yahia (2008). Table 1 shows betalain content in different Mexican cultivars, with the highest values in the fruit of *O. robusta* (8.1 mg g^{-1}) comparable to that found in some red beets (8.6 mg g^{-1}). This study included yellow/orange cultivars, such as *O. megacantha*, showing higher levels of betaxanthins than betacyanins, and yellow cactus pear fruit (*O. albicarpa*) practically devoid of betalains.

The results of Castellanos-Santiago and Yahia's study (2008) are very important to evaluate the value of the cactus pear fruits as a source of colorants, because the yield of pigment could significantly increase when the whole fruit is processed.

Recently, Gandía-Herrero et al. (2010) studied the betalain content of yellow and violet *Opuntia* fruits from Murcia (south-eastern Spain). The authors didn't differentiate the species of *Opuntia* and reported a betanin content in the violet *Opuntia* of 34.1, 88.4, and 35.1 µg g^{-1} fresh weight in the flesh, peel, and epidermis, respectively. These results suggest that the use of the whole fruit will increase the pigment yield.

The geographic effect was reported by Sepúlveda et al. (2003). The authors studied the betanin content of 14 different types of *Opuntia* from different sites in Chile (Table 2). The betalain content in the peel and pulp is highly variable among the fruit of different localities as well as in samples from the same locality. *Opuntia stricta*, one of the species with the highest content of betalains reported in the literature, has not been identified in Chile, but this study shows that some Chilean ecotypes show even higher values than those of *O. stricta*. The most common *Opuntia* in the world is *O. ficus-indica* and the pulp from Chilean fruits of this species showed high level of betalains (40 mg 100 g^{-1}), similar to those of some commercial red beet (40–60 mg 100 g^{-1} fresh fruit) (Castellar et al., 2003). The geographic effect is a variable that needs to be studied for more than one harvest time because several factors affect the plant from one year to another.

The highest values were reached in the pulp of *O. ficus-indica* from Antumapu and *Opuntia* sp. from Melipilla, with 60.10 and 58.57 mg 100 g^{-1}, respectively. These sites are located further south than Las Cardas and Til-Til.

In order to use cactus pear to obtain red-purple colorant at an industrial scale, is important to select the best cultivar with the highest betalain content for reproduction.

Biological effects of betalains

Tesoriere et al. (2004a) suggested some biological effects of betalains, reporting that betanin and indicaxanthin may be involved in improvement of the oxidative status of LDL in vivo. Moreover, other studies showed that consumption of cactus pear fruit positively affected the body's redox balance and decreased the oxidative damage of lipids, and that the intake of red beet juice also delayed the LDL oxidation. These effects were linked to betalains (Tesoriere et al., 2004a; Sembries et al., 2006). Betalains has been mentioned as a new class of dietary cationized antioxidant because it would in-

Table 1
Betalains content in pulp and peel of different *Opuntia* species

Species	Fruit color	Peel	Pulp	Total	Reference
Opuntia sp_1*	Purple	118.3	126.8	113.9	Odoux and Domínguez-López, 1996
Opuntia sp_2*	Purple	44.8	27.6	42.0	Odoux and Domínguez-López, 1996
Opuntia sp_3*	Purple	72.0	49.3	56.8	Odoux and Domínguez-López, 1996
O. robusta *	Purple	19.0	58.2	30.4	Odoux and Domínguez-López, 1996
*O. robusta-robusta**	Purple	40.5	86.1	51.6	Odoux and Domínguez-López, 1996
*O. sherri**	Purple	8.4	6.0	7.9	Odoux and Domínguez-López, 1996
*O. robusta*Wendl**	Reddish-purple	5.29	2.86	8.15	Castellanos-Santiago and Yahia, 2008
*O. robusta***	Reddish-purple	2.06	0.99	3.0	Castellanos-Santiago and Yahia, 2008
*O. streptacantha***	Reddish-purple	2.04	1.04	3.08	Castellanos-Santiago and Yahia, 2008
*O. macrorhiza***	Deep red-purple	0.52	0.45	0.97	Moussa-Ayoub et al., 2011

*weight as mg 100 g^{-1} fresh weight. **weight as mg g^{-1} dry matter.

Table 2
Betanin content in different Chilean red and purple cactus pear fruits (mg 100 g^{-1} fresh weight)

Site	Species	Peel	Pulp	Total
Las Cardas (30°13′S, 71°13′W)	*Opuntia* sp.	19.91	17.52	16.6
	O. streptacantha	24.72	19.21	20.4
	Opuntia sp.	42.44	18.98	25.3
	Opuntia sp.	29.92	20.03	23.0
	O. pumila	35.04	21.45	26.5
Til-Til (33°4′S, 70°55′W)	*O. ficus-indica*	38.49	36.50	34.0
	O. ficus-indica	41.99	40.90	37.1
	O. ficus-indica	39.00	48.26	39.1
Antumapu (33°34′S, 70°38′W)	*O. ficus-indica*	42.96	38.77	37.0
	O. ficus-indica	37.78	41.23	35.8
	O. ficus-indica	44.98	37.84	36.2
	O. ficus-indica	39.47	17.64	24.6
	O. ficus-indica	69.18	60.10	62.4
Melipilla (33°40′S, 71°11′W)	*Opuntia* sp.	46.03	58.57	45.9

Data source: Sepúlveda et al. (2003).

crease the affinity for membranes, preventing oxidative stress in model systems (Kanner et al., 2001). Several studies have demonstrated that betalains provide protection against oxidative stress-related disorders (Tesoriere et al., 2004a, b, 2005; Livrea and Tesoriere, 2007), in addition to their high availability in humans (Kanner et al., 2001). This point is especially important because many authors have determined the antioxidant activity of many plants, included *Opuntia*, but without taking into account their bioavailability to humans.

In some studies of colored cactus pear, vitamin C, carotenoids, flavonoids, and also the betalains appear as components with interesting antioxidant activity (Sáenz and Sepulveda, 2001; Galati et al., 2003; Kuti, 2004; Morales et al., 2008). As mentioned above, their vitamin C, carotenoid, and flavonoid antioxidant activity are well known, but betalains' antioxidant activity has only come to light in recent years (Kanner et al., 2001; Butera et al., 2002). A study done on colored cactus pear fruits from Sicily show that the yellow cultivars exhibit the highest amount of betalains, followed by the red and white cultivars. The fruit extract shows an antioxidant activity between 4.20 and 5.31 µmol TROLOX g^{-1} edible pulp, in the red and the yellow cultivars respectively. Purified betanin and indicaxanthin_exhibit TROLOX molar equivalents of 20.0 and 1.76, respectively. The cactus pear total antioxidant activity is 2-fold higher compared with that of pear, apple, tomato, and grape, and similar to that of red grape, orange, and grapefruit (Butera et al., 2002).

Thus betalains could also be used as a functional ingredient in the food industry in addition to having application potential as a healthy natural colorant.

The literature reports the presence in cactus pear of polyphenols, which have a well-known antioxidant role in combatting the oxidative stress diseases (Manach et al., 2005). The intake of polyphenols has been inversely correlated to the incidence of several chronic diseases, such as several types of cancer and cardiovascular disease (Mertens-Talcott et al., 2006).

The purple ecotype of *O. ficus-indica* has the highest concentration of total phenolics, close to 660 mg L^{-1} juice (Stinzing et al., 2005) and 900 mg L^{-1} pulp (Sáenz et al., 2009). Other studies have identified the presence of flavonoids as flavonol glycosides, among which significant amounts of isorhamnetin-3-rutinoside, rutin, and kaempferol-3-rutinoside, quercetin were found in a blend of yellow and red cultivars (Galati et al., 2003). Kuti (2004) isolated conjugated flavonoids (quercetin, kaempferol, and isorhamnetin) from different varieties of *Opuntia*, with the antioxidant activity stronger in the purple-skinned variety.

Since it is difficult to separate betalains from phenolics compounds, both are extracted together, which means an advantage from the point of view of the antioxidant capacity of the colorant.

Betalains stability

Temperature, water activity, pH, metals, light, oxygen, and enzymes have been identified as the main factors that affect the degradation of betalains. Temperature can be considered the most important factor affecting the betalains stability, both in its processing and in its storage (Herbach et al., 2006; Azeredo, 2009). Betalains are labile compounds, and can be lost when high temperatures are used. These results guide the need to design extraction procedures that avoid high temperatures, but preserve the microbiological quality of the product.

Betalain stability studies have mainly involved pigment extracted from beetroot (von Elbe et al., 1974; Sapers and Hornstein, 1979; Delgado-Vargas et al., 2000; Herbach et al., 2006; Azeredo, 2009). One of the first studies on thermal degradation of betalain from *Opuntia* was done by Merin et al. (1987), who determined the color stability of betacyanin in cactus pear fruit juices at temperature up to 90 ºC. The authors report that degradation rates were dependent on pigment concentration, being lower for higher concentrations. The presence of oxygen has only a marginal effect on the thermo-stability of the pigment, suggesting that oxidation was not the major chemical mechanism responsible for degradation; the dye was more stable in solution at pH 4. In the last decade some studies examined betalains from purple cactus pear (Butera et al., 2002; Castellar et al., 2003, Stinzing et al., 2005; Moßhammer et al., 2005; Herbach et al., 2006) and some from amaranth (Cai et al., 1998; Cai and Corke, 2000). In those studies it was observed that the betalain stability is affected by processing, sometimes reaching a total loss of its color.

Farías (2003) followed the stability of betacyanin in aqueous solutions at different pH levels, and observed that after a heating treatment of 5 min the higher stability was at pH 3–4, while the higher loss was at pH 6–7.

During processing many foods, for example beverages, are subjected to high temperatures to extend their shelf-life and preserve microbiological quality. Their pH is thus another parameter to be considered in order to maintain the color of the product.

Encapsulation technology makes it possible to protect betalains with an encapsulating agent, thus improving their stability and increasing their shelf life. Encapsulation of betalains as active agents has been studied by few authors (Azeredo et al., 2007; Sáenz et al., 2009 and Pitalua et al., 2010). In the last years Sáenz et al. (2009) studied the encapsulation of betalains from cactus pear natural juice. Juice concentration before encapsulation could strengthen its colorant power due to higher pigment content, and enhance its role as a functional additive by also concentrating the phenolic compounds present in cactus pear fruits.

Cactus pear juices as a source of betalains

Seeking an easy way to use the cactus pear as a natural colorant in foods, Sáenz et al. (2002a) obtained a concentrated juice from purple cactus pear applying similar technologies to that used for other fruit juices. Table 3 shows the characteristics of fresh cactus pear juice of concentrated juice obtained from purple cactus pear. The process shown in Fig. 3 was followed to obtain the concentrate juice (color “extract”).

Different steps have been reported for obtaining fresh cactus pear juice or concentrated juice (Rojas, 2000; Sáenz et al., 2002a). Variables such as raw material (peel, pulp, or both), clarification (enzyme or membrane), and washing after pressing could affect the final betalain content. The steps must be designed to obtain the highest pigment concentration in the final product.

In order to increase the yield of betalains in the concentrate, a coloring extract was prepared according to Rojas (2000) using the whole purple cactus pear (*O. fi-*

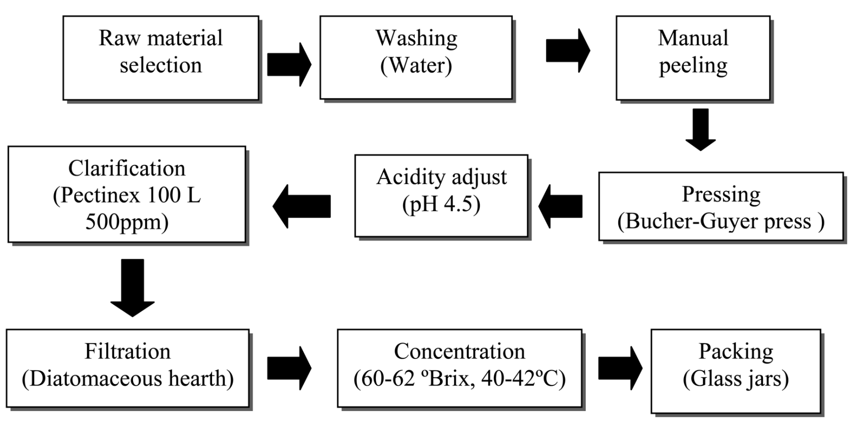

Fig. 3. Flow-chart to obtain a color “extract” (Sáenz et al., 2002a)

Table 3
Purple cactus juice and color extract: physical and chemical characteristics

Parameter	Fresh cactus pear juice	Concentrated cactus pear juice
Soluble solids (ºBrix)	15.8 ± 0.28	61.6 ± 0.32
pH	5.6 ± 0.0	4.3 ± 0.05
Acidity (% citric acid)	0.062 ± 0.005	0.81 ± 0.06
Betanin (mg/100g)	26 ± 0.001	100 ± 0.005
Color		
L	20.6 ± 0.0	22.8 ± 0.05
a*	3.67 ± 0.12	3.79 ± 0.005
b*	0.8 ± 0.05	0.34 ± 0.01
C*	3.7 ± 0.1	3.8 ± 0.006
H_{ab}	8.81 ± 1.13	5.12 ± 0.15

L—lightness, a*—redness, b*—yellowness, C*—chroma, H_{ab}—hue angle. Data source: Sáenz et al. (2002a).

cus-indica) to take advantage of the fact that betalains are in both the peel and the pulp of the fruit, avoiding the clarification process because a portion of the pigment was lost during this step, and washing the press residues twice with water to extract the remaining pigment of the pressed pulp, resulting in an increase of 23% in the betalain concentrate. The concentrated juice showed characteristics that would allow its direct use in foods and shows a betanin content of 123 mg $100g^{-1}$ (Sáenz et al., 2002b), this results, are attractive for its industrial potential, but the sugar content could limit the application only to sweet foods.

Moszhammer et al. (2005) developed a process to produce clarified juice from *O. ficus-indica* cv. 'Rossa', separating the peel and the pulp by carborundum, peeling of the frozen fruits, and passing it through a finisher. To improve the filtration process different enzyme preparations were tested, and the juice was pasteurized at 92 ºC and rapidly cooled. The resulting juice showed a betacyanin loss of 27% compared to the finished pulp.

Castellar et al. (2008) reported another process to prepare a betalain extract, in which the juice was fermented to obtain the betanin at high concentration, low viscosity, and sugar-free. *Saccharomyces cerevisiae*, var. *bayanus* has been the optimum for this process. After fermentation and centrifugation, the supernatant, containing the pigment, was concentrated under vacuum. The final product showed a pH of 3.41, 5.2 ºBrix, 9.65 g L^{-1} betanin, and viscosity 52.5 mPas.

Other technologies, such as membrane technologies, could be used to obtain betalain juice or concentrate. Compared with the traditional separation and concentration methods, this technique has a reasonable cost, is a non-thermal process, and does not employ the use of chemical agents (Cassano et al., 2010), maintaining, therefore, the pigment's stability and avoiding its degradation by factors such as temperature. Cassano et al. (2007) clarified *O. ficus-indica* cv. 'Gialla' (orange-yellow) to produce a juice concentrate by osmotic distillation and, more recently, Cassano et al. (2010) studied the effect of microfiltration and ultrafiltration to concentrate betalains. They observed that both methods are useful for this purpose, with betacyanins concentration of 40.12 mg L^{-1} and 34.93 mg L^{-1} in themicrofiltrated and ultrafiltrated retentate, respectively.

Potential applications of cactus pear betalains in foods

The attraction of consumer, especially children consumers, to red-colored foods such as as dairy products, juices, ice-creams, marmalades, confectionery, etc., presents an opportunity not only to use a natural and bioactive colorant to replace synthetic dyes, but also to increase the use of arid and semiarid zones for *Opuntia* crops and consequently improve the quality of life for low-income inhabitants of these areas.

Betalains could be used as functional ingredients in the food industry, especially for the milky and soft drinks industry (Moszhammer et al., 2005, 2006). Cactus pear colorant powders from different red-purple *Opuntia* (*O. stricta, O. streptacantha*) have also been obtained by spray drying, using glucose syrup (DE29) and maltodextrin (10 and 20 DE) as carrier agents. The powder stability and reconstituted products were studied (Rodríguez-Hernández et al., 2005; Obón et al., 2009). Potential colorants from *O. ficus-indica* have been obtained by freeze-drying using maltodextrin (18–20 DE) by Moszhammer et al. (2006).

There is little research on the behavior of cactus betalains as additives in foods. One study by Moreno et al. (2003) focused on a species without commercial use from Venezuela (*O. boldinghii* Br et R). The authors prepared different citric beverages by blending cactus pear juice with orange and grapefruit juices and added ascorbic acid. The products were pasteurized (60 ºC for 30 min) and stored at 7 ºC for 21 days in amber bottles. All the formulations retained a higher percentage of betalains when a higher dose of ascorbic acid was added, suggesting protection from oxidative reactions; however, the sensory panel preferred the beverage without added ascorbic acid, probably due to changes in pH of the beverages that it caused.

Sáenz et al. (2002a) tested the application in yogurt of concentrated cactus pear juice containing 100 mg 100 g^{-1} of betanin. The concentrated juice was added in two doses, 0.2% and 0.3%, and was compared with a commercial product. The color of the product was followed during 30 days and the sensory panel didn't observe color differences between the samples.

Farías (2003) prepared a sample beverage blending concentrated cactus pear juice (2%) as source of betalains, sugar (12%), citric acid, aroma, and water. This beverage was pasteurized in the bottle (80 ºC, 5 min) and stored under two temperatures conditions: 20–22 ºC for 30 days, and 5–6 ºC for 50 days. The color degradation was followed by mean of a* parameter. The color remained constant during 50 days at 5–6 ºC while decreased markedly at 20–22 ºC at 10 days storage.

Rodríguez-Hernández et al. (2005) spray-dried *O. streptacantha* juice using maltodextrins and compared the natural juice color with the reconstituted powder until it reach 14.5 ºBrix. They found that the reconstituted product showed a slight change in color, attributed significantly to the maltodextrin concentration. The authors didn't follow the effect of storage on the reconstituted juices.

Obon et al. (2009) tested a powder obtained by spray drying from *O. stricta* fruits, in two food model systems: a sweetened yogurt and a soft drink (*O. stricta* powder, sucrose, ascorbic acid, citric acid, sodium benzoate, and potassium sorbate) which was filtered aseptically through 0.2 µm sterile filters, and both foods were aseptically packed. In the yogurt the colorant was added until the color was similar to berry fruits, and in the soft-drink up to reach a determined absorbance at 535 nm. Both foods were refrigerated at 4 ºC for 1 month and maintained a vivid red-purple color. In this study the soft-drink was not thermally treated to protect the colorant, but the industry probably will try to avoid chemical preservatives and use thermal treatments. Therefore the behavior of the cactus colorant in the face of heat treatments needs to be studied.

Our group is currently developing a project to clarify and concentrate betalains by membrane technologies (studying the best temperature of water extraction of the betalains) and, after the pigment is stabilized, using encapsulation techniques. This combination of technologies appears to be an alternative strategy for providing a new highly pure, stable, and functional colorant for the food industry.

In conclusion, new doorways are opening to study the best variety and climatic conditions to obtain cactus pear fruits rich in red betalains, and to determine the optimal conditions for extraction procedures and for pigment stability in different kind of foods. The resolution of all those aspects could be certainly a contribution to the food industry with a natural and functional colorant and also for the inhabitants of the arid zones who can look at this crop with new appreciation.

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