# Pitaya (*Stenocereus* spp.): an under-utilized fruit

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## ABSTRACT

Pitaya (*Stenocereus* spp.) is an exotic fruit, which has been consumed since ancient times by pre-Hispanic cultures. Recently in Mexico, this cactus has been the target of commercial attention due to the pleasant taste of their succulent fruits with juicy and sweet pulp, and a great variety of colors (white, yellow, purple and red fruits). This fruit has excellent sensory, nutritional, nutraceutical, agroindustrial and medicinal attributes; however, it has been under-utilized. The high content of betalains in this fruit allows us to consider these varieties as a source of natural pigments to be used in the food industry. The aim of this study is to show "the state of the art" of the properties of *Stenocereus*, to promote its study, dissemination, production, consumption and agroindustrial use. The present study shows a description of its botany, distribution, cultivation, physiology, pre and postharvest aspects, nutritional and nutraceutical composition, as well as agroindustrial and medicinal uses. The production of this fruit represents an opportunity for the economic development of some arid and semi-arid zones of Mexico due to the agronomic, nutraceutical and agroindustrial advantages. Therefore, more studies are required, mainly on physiological, nutraceutical, medicinal and agroindustrial aspects, more specifically on the non-studied species of *Stenocereus,* and future researches should deal with development of agro-technologies to guarantee high yields and good quality products to enable growers to make a living from it.

***Keywords*:** *Stenocereus*, *cactus, antioxidants, exotic, agroindustrial uses.*

## INTRODUCTION

The pitayo tree is a columnar cactus belonging to the genus *Stenocereus* (Bravo and Sánchez-Mejorada, 1991). The name derives from the Greek words: "στενός" (*stenos*) meaning "tight or narrow", referring to the narrow ribs of plants, and *cereus* meaning "candle". 22 to 24 edible species of this genus have been reported in America (Terrazas *et al*., 2005; Rosales-Bustamante *et al*., 2009); 20 of these species are endemic to Mexico (Arreola-Nava, 1999; Bárcenas and Jiménez, 2010). Therefore, Mexico could be considered the center of origin, being the country with the largest and most important cactus diversity (Esquivel, 2004; Reyes-Agüero, 2006; Novoa *et al*., 2015).

Recently, this cactus has been the target of commercial attention due to the pleasant taste of their succulent fruits with juicy and sweet pulp, and a great variety of colors (white, yellow, purple and red) (Campos-Rojas *et al*., 2011; García-Cruz *et al*., 2012), but this fruit has been under-utilized. However, its commercial use has not yet been studied, probably because it is a local and perishable crop, and due to the lack of knowledge of the nutritional and nutraceutical properties of most species (Pimienta-Barrios and Nobel, 1998; Treviño *et al*., 2012). Therefore, this fruit shows a commercial potential at the national and international level (García-Suárez *et al*., 2007; Campos-Rojas *et al*., 2011) mainly due to its antioxidants properties (Campos-Rojas *et al*., 2011; García-Cruz *et al*., 2013; Pérez-Loredo *et al*., 2016). Furthermore, there are few studies on the pitayo; consequently, the identification of the state of the art from the horticultural point of view, is difficult. Due to the above, this study is a compilation of the available information related to this exotic fruit.

### *Botanic description*

There are few taxonomic and phylogenetic studies on *Stenocereus.* According to Mercado and Granados (2002) the pitaya tree belongs to the order: *Caryophyllales*; family: *Cactaceae* and tribe: *Pachycereae*. In Latin America, fruits belonging to the genus *Stenocereus*, *Cereus*, *Selenicereus* and *Hylocereus* are called "pitahaya", a generic and vernacular name (Hunt *et al*., 2006; Le Bellec *et al*., 2006). However, "pitaya" and "pitahaya" have been used incorrectly as synonyms (Hunt *et al*., 2006; Le Bellec *et al*., 2006); "pitaya" corresponds to the genus *Stenocereus* (Ortiz, 1999; García-Suárez *et al*., 2007), while "pitahaya" corresponds to the genus *Hylocereus* (Ortiz, 1999); pitaya is described and discussed in this study.

This cactus is characterized by being an arborescent plant with a defined trunk and ramifications from the base, young stems, and branches with 4 to 20 or more shoots; the flowers are located between the areoles and the thorns (Buxbaum, 1961; Pimienta-Barrios and Nobel, 1994). Pitaya fruits are polyspermatic pigmented berries with a rounded or ovoid shape and an exocarp (peel) possessing areoles with thorns (Buxbaum, 1961; Pimienta-Barrios and Nobel, 1994; Arnaud *et al*., 1997), which are similar to small needles (Figure 1), and provide natural protection. The juicy pulp has a sweet, delicate flavor; it has black, soft, small (1 mm), and triangular seeds, which are easy to digest (Pimienta-Barrios and Nobel, 1994; Arnaud *et al*., 1997; Luna-Morales and Aguirre, 2001), in comparison to the fruits of other cactus, such as the cactus pear fruit (*Opuntia* spp.) (Pimienta-Barrios and Nobel, 1994).

There is a diversity of *Stenocereus* species (Table 1), with characteristic morphological variation. The fruit weight varies among species and even among variants (Table 2). Some species have reported fruits weighing more than 400 g (Corrales, 2002). In addition, pulp and peel weights show variation among species; the skin of *S. griseus* is thinner compared to the one of *S. pruinosus*. It has been noted that domesticated species of *S. stellatus* weigh more (30%) than wild species (Rodríguez-Morales *et al.,* 2013). Consequently, the latter, not yet used, has a commercial potential. The thickness of the skin and the size of the thorns provide resistance to physical damages; and those features determine pitaya's resistance to postharvest handling (Campos-Rojas *et al*., 2011).


**Figure 1. A**) tree and **B**) flowers from pitayo, **C**) thorns and **D**) pulp of pitaya fruit (*Stenocereus pruinosus*).

### *Distribution*

The pitayo tree grows in tropical deciduous forests (Pimienta-Barrios and Nobel, 1994), mainly in arid and semiarid zones in an area encompassing from Southern Arizona, USA (Parker, 1989) to some regions in Latin America (Granados *et al*. 1999; García-Cruz *et al*., 2012) such as Honduras, El Salvador (Arias and Terrazas, 2006), Colombia and Venezuela (Anderson, 2001; Terrazas *et al*., 2005). Mexico is the biggest producer. Fruit production is developed mainly in four regions of the country, in the states of Mixteca Oaxaca-Puebla, Michoacán, Sinaloa-Sonora and Jalisco-Zacatecas (Castro-Álvarez *et al*., 2015).

**Table 1.** *Stenocereus* ("*pitayos*") species endemic to Mexico.

| Species | Distribution | Endemic | Cultivation | References |
|---|---|---|---|---|
| *S. alamosensis* | Mexico | + | -- | (Terrazas *et al*., 2005; Arreola-Nava, 1999) |
| *S. beneckei* | Mexico | + | -- | (Arreola-Nava, 1999) |
| *S. chacalapensis* | Mexico | + | -- | (Terrazas *et al*., 2005; Arreola-Nava, 1999) |
| *S. chrysocarpus* | Mexico | + | -- | (Arreola-Nava, 1999; Arias and Terrazas, 2006; Yetman, 2007) |
| *S. dumortieri* | Mexico | + | R | (Luna-Morales and Aguirre, 2001; Luna-Morales, 2004; Arias *et al*., 2013; Martínez-Falcón *et al*., 2012) |
| *S. eruca* | Mexico | + | -- | (Arreola-Nava, 1999; Hernández, and Godínez, 1994) |
| *S. fricci* | Mexico | + | R | (Arreola-Nava, 1999; Arias and Terrazas, 2006) |
| *S. griseus* | Mexico, Colombia, Venezuela and South America | -- | C/R | (Arreola-Nava, 1999; Corrales, 2002; SIB, 2015; Padrón, 2012; Fuentes *et al*., 2011) |
| *S. gummosus* | Mexico | + | - | (Arreola-Nava, 1999; Esquivel, 2004) |
| *S. montanus* | Mexico | + | W | (Arreola-Nava, 1999) |
| *S. pruinosus* | Mexico | + | C/ W | (Arreola-Nava, 1999; Flores *et al*. 2011; Arellanes *et al*., 2013) |
| *S. queretaroensis* | Mexico | + | C/ W | (Arreola-Nava, 1999; Gallardo-Vásquez and De la Barrera, 2007; Gudiño and De la Barrera, 2014) |
| *S. stellatus* | Mexico | + | C | (Arreola-Nava, 1999; Luna-Morales and Aguirre, 2001; Flores *et al*., 2011; Arellanes *et al*., 2013) |
| *S. thurberi* | Mexico, Arizona | - | W | (Arreola-Nava, 1999; Esquivel, 2004; Parker, 1989) |
| *S. treleasei* | Mexico | + | W | (Arreola-Nava, 1999; Granados *et al*., 1999) |
| *S. eichlamii* | Mexico, Guatemala and El Salvador | -- | -- | (Arias and Terrazas, 2006; Arias *et al*., 2003) |
| *S. martinezii* | Mexico | + | -- | (Vega-Aviña *et al*., 2000) |
| *S. quevedonis* | Mexico | -- | W | (Gudiño and De la Barrera, 2014; Granados *et al*., 1999) |
| *S. zopilotensis* | Mexico | -- | -- | (Arreola-Nava and Terrazas, 2004) |
| *S. standleyi* | Mexico | -- | -- | (Segura *et al*., 2009) |

C= cultivated specie; W= wild species; R= recollected species.

**Table 2.** Fruit weights of some most commonly traded pitaya (*Stenocereus* spp.) species.

| Species | Weight (g) | | | References |
|---|---|---|---|---|
| | Pulp | Skin | Total | |
| *S. pruinosus* (red and orange) | 129 -131 | 48 - 50 | 177.0 - 180.9 | (García-Cruz *et al*., 2013) |
| *S. pruinosus* (31 variants) | 79 - 333 | 15 - 69 | 86 – 399 | (Luna-Morales, 2006) |
| *S. stellatus* (white, red, yellow, and purple) | - | - | 76 - 101 | (Pérez-Loredo *et al*., 2016) |
| *S. griseus* (17 variants) | - | - | 100 - 290 | (Martínez-González and Cruz-Hernández, 1995) |
| *S. griseus* (white and red) | 44 | 18 - 22 | 63 - 69 | (Emaldi *et al*., 2006) |

### *Cultivation*

From the physiological point of view, the cultivation of this fruit during its development demands little irrigation, and a modest use of fertilizers and pesticides (Pimienta-Barrios and Nobel, 1994). It is tolerant to high temperatures (Drennan, 2009; Gudiño and De la Barrera, 2014) of which the species *S. queretaroensis* is a remarkable example (Gudiño and De la Barrera, 2014). Pitaya harvest starts in April and lasts until October; although in other regions it has been reported to end in November or December (Flores, 2003).

### *Economic importance*

In the last decade, pitaya production in Mexico has increased more than 10 times, reaching a production of 4 500 t. It should be noted that this production is 160 times lower than the production of cactus pear fruit (*Opuntia* spp.), but more profitable, since the value of pitaya production is 32 times less (SIAP, 2017) than the value of cactus pear fruit production. Despite it being a fruit of limited seasonality (Ochoa-Velasco and Guerrero-Beltrán, 2012), this crop could provide significant benefits to farmers, due to the low water demand required by this crop (Barrios, 2013). Moreover, the cultivation of these fruits could be considered as an alternative use of plant genetic resources. An agronomic study could improve its management and marketing with the intention of granting added value.

Of the species located in Mexico, *S. queretaroensis* (Pimienta-Barrios and Nobel, 1995; Granados *et al*., 1999; García-Suárez *et al*., 2007), *S. stellatus, S. griseus, S. pruinosus* (Granados *et al*., 1999; García-Suárez *et al*., 2007), *S. treleasei, S. fricci,* and *S. quevedonis* are the ones with the greatest commercial use (Granados *et al*., 1999). *S. queretaroensis* (Gudiño and De la Barrera, 2014) is the most consumed one in Mexico. *S. griseus* ("pitaya de mayo") and *S. stellatus* ("pitaya agria") are mainly cultivated in the Mixteca region of Oaxaca, which are the most important for the economy of many communities of some semi-arid zones in Mexico (López Gómez *et al*., 2000). Other species are cultivated in backyard gardens (Arreola-Nava, 1999; Granados *et al*., 1999; Luna-Morales, 2004) for self-consumption and/or to be sold in local markets (García-Suárez *et al*., 2007).

### *Physiology of pitaya*

Being plants with Crassulacean Acid Metabolism (CAM), cacti absorb $CO_2$ mainly at night. This behavior favors their development in arid environments (Pimienta-Barrios *et al*., 1997; Hernández-López *et al*., 2008) because they lose less water (Pimienta-Barrios *et al*., 1997) compared to species with stomatal opening during daytime (plants with $C_3$ and $C_4$ metabolism). CAM plants will have a special importance when global warming causes drought and water-use-efficiency. During storage, the respiration pattern corresponds to non-climacteric fruits (Rodríguez-Irepan *et al*., 2011; García-Cruz *et al*., 2016) with a decrease of the respiration rate (10 to 4 mg $CO_2$ kg·h$^{-1}$) with asymptotic behavior (Kays, 1991; Armella *et al*., 2003). Ethylene is a hormone that plays a central role in the ripening of climacteric fruits; however, an ACC oxidase (an enzyme that participates in the synthesis of ethylene) enzyme gene has been identified in *S. stellatus* pitaya during ripening (Rodríguez-Irepan *et al*., 2011). The role of ethylene or ACC oxidase enzyme in non-climacteric fruits is still unknown (Barry and Giovannoni, 2007), although these could participate in the ripening process or in response to the senescence process of the pitaya fruit (Barry and Giovannoni, 2007; Rodríguez-Irepan *et al*., 2011).

Another relevant aspect on pitaya physiology is the tolerance to salt; because, in the environment where pitayas thrive, salinity is a common condition. Orozco *et al*. (2017) pointed out that pitaya seeds are more tolerant to salt concentration than seeds from other columnar cacti. Also the increasing saline stress cause an increase in photosynthetic pigments (chlorophyll and carotenoid), suggesting the formation of osmolyte compounds that help protect plant cells subjected to the low water potentials caused by saline stress (Orozco *et al*., 2017).

***Pre and postharvest aspects***

Depending on the pitaya variety, the ripening period is characterized by the change of the epidermis color, e.g. from a bright green to a yellowish green. The epidermis color and the hardness of the thorns are used as harvesting indicators, even though the determination of the adequate time depends on the subjectivity of the harvester or the requirements of the buyer (Armella *et al*., 2003). Other quality parameters used as harvesting indicators are the total soluble solids-when the fruit shows 13°Bx it is ready to be harvested (Arnaud *et al*., 1997; Armella *et al*., 2003). Likewise, it has been proposed that acidity is related to fruit maturity; therefore, acidity is also used as a quality or harvesting indicator (Pérez-Loredo *et al*., 2016). Stintzing *et al*. (2003) suggested that a sugar:acid ratio between 10:1 and 18:1 is indicative of a good taste and acceptability of a fruit.

The short life of the fruit is the main limitation for it to be marketeted (Esquivel, 2004; Rodríguez-Irepan *et al*., 2011), since in an advanced stage of maturity the fruit tend to show longitudinal dehiscence (Pimienta-Barrios and Nobel, 1994; Rodríguez-Irepan *et al*., 2011). Another aspect that limits pitaya marketing is the presence of long thorns, which provide natural protection to the fruit during transportation, are undesirable to consumers (Armella *et al*., 2003). After removing the thorns, the postharvest life of the fruit shortens, because the thin and delicate epidermis is sensitive to abrasion damage, and fruits are more sensitive to cracking and post-harvest damage (Nerd and Mizrahi, 1999; Campos-Rojas *et al*., 2011). These characteristics should be the aim of breeding efforts to ease difficulties.

Shelf life at room temperature is 3 to 6 d (Ochoa-Velasco and Guerrero, 2013; García-Cruz *et al*., 2016), although the presence of thorns in the fruit prolongs shelf life at cold storage (Arnaud *et al*., 1997; Armella *et al*., 2003). To handle the post-harvest problems in pitaya, refrigeration has extended the shelf life of the fruit up to 20 days (Arnaud *et al*., 1997; Armella *et al*., 2003). After a 20 days storage period refrigerated fruits do not have an attractive appearance but still have a good taste, sweet pulp, therefore it is suggested to prepare jams, juices, nectars, dehydrated pulp and frozen pulp with them (Arnaud *et al*., 1997; Armella *et al*., 2003). There is no information about post-harvest losses caused by physiological disorders, decay, and cold damage, so it is recommended to propose emerging technologies for the agroindustrial use of the pitaya fruit. Some emerging technologies such as UV radiation exposure, high hydrostatic pressures (Ochoa-Velasco and Guerrero-Beltrán, 2012; Ochoa-Velasco and Guerrero, 2013; Sandate-Flores *et al*., 2017), and ozonization have been applied for the conservation of pitaya juice providing important results for agro-industrial management.

***Nutritional quality***

Fiber content, which has beneficial effects against diabetes, obesity, and colon cancer (Yangilar, 2013), varies according to the species. *S. pruinosus* has a fiber content similar to the one reported in xoconostle (sour prickly pear) (0.3-1.04%) (Guzmán-Maldonado *et al*., 2010; López *et al*. 2015); but a higher one compared to the fiber contained in white pitahaya (*Hylocereus undatus*) (0.45%) (Liaotrakoon *et al*., 2013). The pulp of the pitaya fruit is characterized by a low protein content (1.08-1.51%) (Table 3); however, protein concentration in seeds is higher (8.1-9.2%) (Pimienta-Barrios and Nobel, 1994). Thus, the consumption of the whole fruit represents an alternative for low-cost protein intake in comparison to other fruits due to the digestible seeds.

The protein concentration in pulp (approximately 1%) is similar to the one found in cactus pear fruit (1.03%) (Chiteva and Wairagu, 2013), but higher to the one reported in xoconostle (0.60-0.87%) (Hernández-Fuentes *et al*., 2015) and pitahaya (*Hylocereus polyhizus*) (0.27%) (Jaafar *et al*., 2009). The lipid content is similar to the one reported for xoconostle (0.10-0.50 %) (Contreras *et al*., 2011; Hernández-Fuentes *et al*., 2015) and cactus pear fruit (0.40%) (Moreno *et al*., 2008; Chiteva and Wairagu, 2013). Pitaya fruit is characterized by a high content of vitamins B, C and E (Beltrán-Orozco *et al*., 2009) particularly, vitamin C (0.85-1.7%) is present in concentrations similar to those reported in xoconostle "Cuaresmeño" (0.76-1%), but higher than to those reported in cactus pear fruit (0-0.52%) (Chiteva and Wairagu, 2013) and pitahaya (0.26-0.58%) (Esquivel *et al*., 2007).

Pitaya fruit has high sugar content (Bravo and Scheinvar, 1998; Luna-Morales, 2006) and total soluble solids (TSS) content; both characteristics are affected by various factors such as species, variety, geographic distribution, and pigmentation (Table 3). The varieties of *S. pruinosus* have shown higher values of TSS (García-Cruz *et al*., 2013) compared to those in *S. stellatus* fruits, regardless of color (Pérez-Loredo *et al*., 2016). Pitaya fruit is sweeter (9.3-17.5 °Bx) compared to the fruit of other cacti, such as xoconostle of the species *Opuntia matudae, O. duranguensis, O. joconostle, O. ezontepecana, O. oligacantha* and *O. scheinveriana* (4.28-6.12 °Bx) (Hernández-Fuentes *et al*., 2015), but it is similar (7.5-12.92 °Bx) to the sweetness of pitahaya fruit (*Hylocereus* sp.) (Esquivel *et al*., 2007) and cactus pear fruits of *O. ficus-indica* 13.9 °Bx (Fernández-López *et al*., 2018).

Another component derived from CAM metabolism (Lüttge, 2004) is the presence of malic acid, which is responsible for acidity in cactus fruits. Pitaya fruit has a lower concentration of malic acid (0.13-0.81%) compared to pitahaya (1.044%) (Obenland *et al*., 2016) and xoconostle (6%) (Morales *et al*., 2012; Morales *et al*., 2015), but similar or greater compared to cactus pear fruit (0.18%) (Palma *et al*., 2015). It should be noted that the red pitaya belonging to *S. pruinosus* has higher values of malic acid than the orange variety (García-

Cruz *et al*., 2013). In contrast, white fruits belonging to *S. stellatus* have higher values of malic acid than *S. pruinosus* fruits (Pérez-Loredo *et al*., 2016). Therefore, the malic acid content varies according to the species and not in accordance with the pigmentation of the fruit (Table 3). In this respect, fruits with greater sensory acceptance have a sugar:acidity ratio of 10:1 and 18:1 (Stintzing *et al.,* 2003). The pH in pitaya (3.37-5.8) is greater than the pH reported in xoconostle (2.8-3.2) (Guzmán-Maldonado *et al*., 2010; Contreras *et al*., 2011) which is very acidic, but similar to the pH (4.26-4.98) found in pitahaya (*Hylocereus* sp.) (Esquivel *et al*., 2007; Liaotrakoon *et al*., 2013), which is also favored by consumer preferences.

**Table 3.** Chemical composition of fruit pulp of some pitaya species (*Stenocereus* spp.).

| Species | *S. pruinosus* (red and orange) | *S. stellatus* (white, yellow, purple and red) | *S. stellatus* (red, cherry, yellow and white) | *S. queretaroensis* | *S. griseus* |
|---|---|---|---|---|---|
| Crude fiber | 0.53-0.67 | 1.39-1.63 | -- | -- | 3.29 |
| Protein (%) | 1.20-1.30 | 1.08-1.30 | 1.00* | 1.51 | 1.29 |
| Lipids (%) | 0.10-0.12 | 0.39-0.49 | 3.0* | -- | 0.12 |
| Carbohydrates or total sugars (%) | 8.50-10.20 | 9.65-10.85 | 11.7* | 5.6±0.8 | -- |
| Reducing sugars (%) | -- | 4.33-6.46 | 8.86-9.91 | 3.4±0.4 | 8.60 |
| Total soluble solids (°Bx) | 9.30-10.30 | 9.53-9.63 | 9.33-9.67 | 10.7±0.8 | -- |
| Malic acid (%) | 0.13-0.17 | 0.48-0.81 | -- | 0.15-0.50* | -- |
| pH | 5.7-5.8* | 3.37-3.64 | 4.09-4.3 | 4.5±0.3 | 4.96-5.20 |
| Ash (%) | 0.61-0.63 | 0.48-0.58 | 0.48* | -- | 0.46 |
| Water (%) | 87.1-89.00 | 85.39-86.50 | 86.3* | -- | -- |
| Reference | (García-Cruz *et al*., 2013; García-Cruz *et al*., 2016*) | (Pérez-Loredo *et al*., 2016) | (Mercado and Granados, 2002*; Beltrán-Orozco *et al*., 2009; Caballero *et al*., 2016*) | (Pimienta-Barrios and Nobel, 1994*; 1995) | (Mercado and Granados, 2002) |

*Reference

Iron is the main mineral (40%) in pitaya, followed by copper and zinc (19.4 and 12.7%, respectively), the iron content for the species *S. pruinosus* (Table 4) is greater in orange fruits than in red fruits (García-Cruz *et al*., 2013). The concentration of calcium is low; although, it plays an important role in water retention by succulent tissues (Stintzing and Carle, 2005).

### *Nutraceutical quality*

The nutraceutical ingredients, which are products of secondary metabolism and are present in vegetables, provide health benefits, including prevention and treatment of illnesses (Wildman and Kelley, 2007). These ingredients help to prevent some health problems of the century such as obesity, cardiovascular disorders (Badimon *et al.,* 2010; Das *et al.,* 2012), cancer, osteoporosis, arthritis, diabetes, cholesterol and others (Das *et al.,* 2012).

**Table 4.** Concentration of minerals (mg kg$^{-1}$ dry sample) in red and orange pitaya fruits (*Stenocereus pruinosus*).

| Variants | P | K | Ca | Mg | Fe | Cu | Zn | Mn |
|---|---|---|---|---|---|---|---|---|
| Red | 3.6 | 1.1 | 0.90 | 2.35 | 22.8 | 9.67 | 7.04 | 4.61 |
| Orange | 3.4 | 1.2 | 0.95 | 2.15 | 27.9 | 14.31 | 8.77 | 4.34 |

Source: García-Cruz *et al.* (2013).

Betalains are found among the restricted nutraceutics, mainly in families of the order Caryophyllales (Esquivel and Araya-Quesada, 2012; Khan and Giridhar, 2015; Brockington *et al.,* 2015). These are red and yellow pigments responsible for the color of the pulp and skin of pitaya, cactus pear, xoconostle and pitahaya fruit (Grimaldo-Juárez *et al.,* 2007; Yahia and Mondragon-Jacobo, 2011; García-Cruz *et al*., 2013; Liaotrakoon *et al*., 2013; López *et al*., 2015). These metabolites are bio-synthetically derivates of betalamic acid, and they are grouped in betacyanins and betaxanthins; the former are responsible for the red-purple colorations and betaxanthins are responsible for the yellow-orange color (Zrÿd and Christinet, 2004; Stintzing and Carle, 2007). These compounds assist in the prevention of cancer; avoid oxidation of membrane lipids due to antioxidant properties (Livrea and Tesoriere, 2006); they do not present toxic effects in humans as some synthetic pigments (Sumaya-Martínez *et al*., 2010); and are also used in the food (Bárcenas and Jiménez, 2010; Rivera *et al*., 2010) and cosmetic industry (Bárcenas and Jiménez, 2010).

The variation in the intensity of the red color, in pitaya pulp, is due to the high proportion of betacyanins (Yáñez-López *et al*., 2005), as has been reported for red fruits of *S. stellatus* and yellow fruits of *S. pruinosus* (Table 5) (Pérez-Loredo *et al*., 2016). In general, pitaya pulp has higher concentrations of betalains (up to 6 mg g$^{-1}$ dw according to García-Cruz *et al*., 2016) than other cacti fruits such as cactus pear (3.28 mg g$^{-1}$ dw) (Ramírez-Ramos *et al.,* 2015), xoconostle (0.2-3.15 mg$^{-1}$ g dw) (Guzmán-Maldonado *et al*., 2010; López *et al*., 2015) and pitahaya, with only 0.17 mg g$^{-1}$ (dw) of betacyanins (Liaotrakoon *et al*., 2013).

Phenolic compounds, due to their diversity and wide distribution, are the most important group of natural antioxidant metabolites. There are epidemiological evidences that show the health benefits and the contribution of these compounds in the prevention of some degenerative diseases (Soto-Hernández *et al*., 2017a; Soto-Hernández *et al*., 2017b). These metabolites are compounds with the ability to chelate heavy metals, modulate some enzymes and neutralize free radicals (reactive oxygen species produced by oxidative stress in the organism, affecting lipoproteins, lipids of blood plasma and other biomolecules) (Delgado-Vargas and Paredes-López, 2002; Georgé *et al*., 2005).

Phenolic compounds are mainly accumulated in the skin more than in the pulp of the pitaya (Kanellis *et al*., 2014). This was also observed in cactus pear and xoconostle fruit (López *et al*., 2015; Ramírez-Ramos *et al.,* 2015). The greatest concentration of phenolic compounds has been found in red pitayas of *S. stellatus* compared to the orange and white pulp pitaya (García-Cruz *et al*. 2012; García-Cruz *et al*. 2013; Pérez-Loredo *et al*. 2016), even though the antioxidant activity is greater in white varieties (Pérez-Loredo *et al*., 2016) due to a synergistic effect of these metabolites and betalains, as reported for cactus pear (Ramírez-Ramos *et al.,* 2015; Albano *et al*., 2015) and xoconostle fruit (López *et al*., 2015). Azeredo (2009) noted that betacyanins are more powerful antioxidants than betaxanthins, which explains the greater antioxidant activity in red pitayas of *S. pruinosus* (García-Cruz *et al*., 2013).

**Table 5.** Nutraceutical concentration and antioxidant activity in the pulp of some species of pitaya (*Stenocereus* spp.) fruit.

| Properties | Red | Orange | Red | Orange | White | Red |
|---|---|---|---|---|---|---|
| | (*S. pruinosus*) | | (*S. griseus*) | | (*S. stellatus*) | |
| Betaxanthins (mg·g$^{-1}$ dw) | 2.6 | 2.3 | 1.48 | 1.77 | Nd | 1.5 |
| Betacyanins (mg·g$^{-1}$ dw) | 2.5 | 0.3 | 2.00 | 0.37 | Nd | 1.5 |
| Total phenols (mg GAE g$^{-1}$ dw) | 13.6 | 10.56 | 1.67 | 0.53 | 4.47 | 5.79 |
| Antioxidant activity (ABTS) (µmol TE g$^{-1}$ fw) | 1100 | 750 | -- | -- | 790.5 | 673.7 |
| References | (García-Cruz *et al*., 2013) | | (García-Cruz *et al*., 2012) | | (Pérez-Loredo *et al*., 2016) | |

Dry weight: dw; fresh weight: fw. Nd: Non detectable.

Phenolic compounds are mainly accumulated in the skin more than in the pulp of the pitaya (Kanellis *et al*., 2014). This was also observed in cactus pear and xoconostle fruit (López *et al*., 2015; Ramírez-Ramos *et al.,* 2015). The greatest concentration of phenolic compounds has been found in red pitayas of *S. stellatus* compared to the orange and white pulp pitaya (García-Cruz *et al*. 2012; García-Cruz *et al*. 2013; Pérez-Loredo *et al*. 2016), even though the antioxidant activity is greater in white varieties (Pérez-Loredo *et al*., 2016) due to a synergistic effect of these metabolites and betalains, as reported for cactus pear (Ramírez-Ramos *et al.,* 2015; Albano *et al*., 2015) and xoconostle fruit (López *et al*., 2015). Azeredo (2009) noted that betacyanins are more powerful antioxidants than betaxanthins, which explains the greater antioxidant activity in red pitayas of *S. pruinosus* (García-Cruz *et al*., 2013).

Some authors reported that ascorbic acid is also an important source of antioxidants in some fruits, mainly in pitaya (Beltrán-Orozco *et al*., 2009), cactus pear (Kuti, 2004; Ramírez-Ramos *et al.,* 2015) and xoconostle fruit (López *et al*., 2015). In accordance with the above, the yellow and white varieties of pitaya have higher contents of ascorbic acid, and thus, higher antioxidant activity compared to the red varieties (Beltrán-Orozco *et al*., 2009). In this respect, has been reported that the consumption of 100 g of pitaya pulp covers 21% of the daily-recommended intake (60 mg per day) of ascorbic acid for adults (Beltrán-Orozco *et al.,* 2005).

It has been documented that the consumption of pitaya fruit, mainly yellow and white varieties, provides protection against free radicals (17 µmol g$^{-1}$ equivalents to Trolox g$^{-1}$), with a concentration similar to the lowest value reported in *Vaccinium* blue berries (16.8-17.3 µmol·g$^{-1}$ equivalent to Trolox g$^{-1}$) (Kähkönen *et al*., 2001; Beltrán-Orozco *et al*., 2009).

Another type of metabolites present in pitaya fruits are the volatile compounds. Aldehydes and alcohols have been found in some pitaya fruits (*S. griseus*) of the varieties "Yellow", "Jarra", "Melón", "Solferino", "Olla" and "Smooth red", which produce herbaceous aromas, and esters, which produce fruity aromas. Among the identified esters, methyl hexanoate, ethyl hexanoate, ethyl acetate, and ethyl butyrate were found, while pentanal, pentanol, hexanal, 2-nonenal, and trans-2-hexenal were detected among the aldehydes and alcohols. The pleasant, fresh, and herbaceous aroma is due to the presence of 1-hexanol and hexanal, while the fruity *flavor* (taste and smell) in the pitaya fruits is due to the presence of ethyl acetate and ethyl butyrate. Differences in the concentrations of volatile compounds have been found among varieties of *S. griseus*, which were higher in "Jarra" compared to the variety "Olla"; however, these varieties have a commercial potential (Yáñez-López *et al*., 2005) since these attributes are favored by the consumer preferences.

***Agro-industrial uses***

Due to its organoleptic properties (color, taste and smell), the pitaya fruit is consumed as table fruit and used for the preparation of fresh water, ice creams, jams (Luna-Morales and Aguirre, 2001; Campos-Rojas *et al*., 2011; Martínez *et al.,* 2011), jellies (Martínez *et al.,* 2011), ice lollipops, and liquors (Luna-Morales and Aguirre, 2001; Martínez *et al.* 2011). Jams are made using the white and red variety of *S. griseus*, but the jam with the greatest sensory acceptance and stability is the one made with the red variety, because its attributes of color, taste, and consistency are not altered after three months of storage (Emaldi *et al*., 2006). Sodas, syrups, jams and salads of frozen pulp (Vázquez *et al.,* 2009) have been proposed for crafting. Traditionally, seeds of *S. pruinosus* mixed with corn seeds are used to make "tortillas" (Luna-Morales and Aguirre, 2001). Polysaccharides (pectins) from pulp and skin of the fruit are used in industrialization processes (Vázquez *et al.,* 2009; Bárcenas and Jiménez, 2010).

Other preservation alternatives for juices made from the species *S. griseus*, are those treated with UV light and stored up to 25 d without affecting pH, TSS and phenolic compounds, but with a slight total change of color due to the significant reduction in betalains and antioxidant activity, in addition to the reduction of aerobic mesophiles and yeasts (Ochoa-Velasco and Guerrero-Beltrán, 2012; Ochoa-Velasco and Guerrero, 2013). Therefore, the use of UV light for the treatment of pitaya juice could be a feasible alternative to produce microbiologically safe juices for the consumer (Ochoa-Velasco and Guerrero-Beltrán, 2012).

The pitaya juice also has been mixed with pineapple juice and then treated with high hydrostatic pressures (400-600 MPa at 25 °C for 2-10 min). High pressures seem to be a good option to retain most of the antioxidant compounds in the pitaya-pineapple beverage (Sandate-Flores *et al*., 2017). The characteristics of the pitaya fruit makes it a promising option for agro-industrial use, particularly *S. pruinosus,* which has been declared as potentially industrial and nutraceutical, due to its weight, diameter (polar and equatorial), edible fraction, and high content of carbohydrates, iron, phenols, betalains and antioxidant activity (García-Cruz *et al*., 2013).

***Medicinal uses***

Information on medicinal properties of pitaya fruit is limited in comparison to other parts of the pitayo tree. The whole plant of *S. pruinosus* is an alternative for the formulation of antifungal drugs (Treviño *et al*., 2012). The aerial part of *S. marginatus* (potentially ornamental) has been used in infusions to treat diarrhea (Hernández *et al.,* 2003) and the raw plant is used for the treatment of *Diabetes mellitus* type 2 (Romero-Cerecero *et al.,* 2009). The aerial part and flower of *S. thurberi* species are used to treat bites by bees, ray, snake, and *Scorpaena* sp., uterine cancer, blood pressure, cardiac problems (Dimayuga *et al*., 1998a) as well as wounds and ulcers (Dimayuga *et al*., 1998b). The steamed stem is used in the treatment of diabetes *mellitus* (Andrade-Cetto and Heinrich, 2005). Likewise, the medicinal potential of the pitaya stem extract has been mentioned as having flavones, sesquiterpene, lactones and alkaloids, which have activity against *Helicobacter pylori* (Moreno *et al*., 2015). The stem and leaves of *S. gummusus* are used to treat blood pressure, venomous snake and ray bites, and to control cholesterol and parasites (Dimayuga *et al*., 1998a; Dimayuga *et al*., 1998b). Its antimicrobial activity against *Bacillus subtilis* and *Streptococcus faecalis* (Dimayuga *et al*., 1998b) has also been reported. The root of *S. stellatus* is used in infusions for the treatment of gastrointestinal disorders (Hernández *et al.,* 2003; Hernández *et al.,* 2005).

## CONCLUSIONS

Pitaya fruit is part of Mexico's cultural identity but it suffers from a little recognized potential and a commercial underutilization. However, due to its nutritional content and nutraceutical properties, it represents a great opportunity to develop new agro-industrial products.

The presence of betalains in pitaya fruit places this fruit as feasible raw material for the production of nutraceuticals due to antioxidant properties. Due to the limited information on pitaya fruit, we propose more research oriented to agronomic management, physiological in nature during pre-harvest, as well as the study of nutritional and nutraceutical quality.

Also, the identification of better pitaya phenotypes with commercial importance to increase the demand and create new opportunities to market this fruit. These fruits have big potential as fruit of the future due to their high water-use-efficiency stemming for their CAM photosynthetic pathway.

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