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Review Article

Pitahaya (*Hylocereus* spp.): a short review

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Abstract

Hylocereus is a native American cactus of varied habits and widely distributed from the Florida coast to Brazil. The fruit is known under several commercial and native names, but "pitahaya" or "pitaya" prevails all around. The genus contains 14 species and it is part of the subtropical and tropical American rainforests. It is common to find *Hylocereus* in family gardens in Central America, where it is traditionally used as food and medicine. Commercial plantations are distributed around the world due to its agronomic, industrial and economic importance. *Hylocereus* species cultivated around the world are mainly *H. undatus*, *H. monacanthus* and *H. megalanthus*. Research related to *Hylocereus* has increased significantly in the fields of taxonomy, anatomy, physiology, genetics, biochemistry, medicine, agronomy and industry, but there is still too much to do. This document describes part of *Hylocereus* history, technological advances and it provides perspectives of research and usage of this emerging crop.

Keywords: Cactaceae, epiphytic cacti, climbing cacti, pitaya, pitahaya

Pitaya (*Hylocereus* spp.): uma revisão

Resumo

Hylocereus é um cacto nativo americano de hábitos variados e amplamente distribuído da costa da Flórida ao Brasil. O fruto é conhecido sob diversos nomes comerciais e nativos, mas "pitahaia" ou "pitaya" prevalecem mundialmente. O gênero contém 14 espécies e é parte das florestas subtropicais e tropicais americanas. É comum encontrar Hylocereus em jardins familiares na América Central, onde é tradicionalmente utilizado como alimento e remédio. Plantações comerciais estão distribuídas ao redor do mundo devido à sua importância agronômica, industrial e econômica. As espécies de Hylocereus cultivadas em todo o mundo são principalmente *H. undatus*, *H. monacanthus* e *H. megalanthus*. Pesquisas relacionadas à Hylocereus têm aumentado significativamente nas áreas de anatomia, taxonomia, fisiologia, genética, bioquímica, medicina, agronomia e indústria, mas ainda há muito a fazer. Este documento descreve parte da história do Hylocereus, os avanços tecnológicos e oferece perspectivas de pesquisa e utilização da cultura emergente.

Palavras-chave: Cactaceae, cactos epífitos, cactos trepador, pitaya, pitahaya

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Introduction

Hylocereus shows high potential as an ornamental and fruit crop, as well as industrial source of compounds; its demand is high in the national and international markets. Its production could potentially create jobs and promote income for the nation that produces it. Most *Hylocereus* species are found in Mesoamerica in varied landscapes ranging from a few meters to 1840 m above sea level and with rainfall from 350 to more than 2000 mm (Ortiz-Hernández, 1999). The species in this genus show high flower, stem and fruit polymorphisms, and sometimes those characteristics are so contrasting, that makes taxonomic identification difficult.

Hunt (2006), based on Britton & Rose´s (1963) descriptions, inferred that it is possible to consider that there are 14 *Hylocereus* species. In Mexico, nine species have been registered, but only four are widely found: *H. undatus* (Berger) Britton & Rose, *H. purpussi* (Weing.) Britton & Rose, *H. triangularis* (L.) Britton & Rose and *H. ocamponis* (Salm-Dyck) Britton & Rose (Cálix de Dios, 2004; Cálix de Dios & Castillo, 2005, 2008). *H. costaricensis* Britton & Rose is found in Nicaragua, while *H. megalanthus* Bauer (K Schumann ex Vaupel) is found in Colombia and Peru. The species most cultivated around the world are *H. undatus*, *H. monacanthus* (Lem.) Britton & Rose (previously known as *H. polhyrizus*), *H. costaricencis* and *H. megalanthus* (previously known as *Selenicereus megalanthus)*.

In Mexico and Central America, several *Hylocereus* species are grown in family orchards using basic technology. Meanwhile, Israel, Malaysia, Thailand and the United States use advanced technology resulting in high yields, particularly in Israel, where yields up to 40 t ha^{-1} of fruit are harvested (Mizrahi & Nerd, 1999).

In spite of the significant scientific research in pitahaya in the last ten years, there is still much to know. This document summarizes pitahaya knowledge through time, but it also provides perspectives of research and usage of this emerging crop.

Development

Origin, History and Distribution

Cactaceae family members were known in Europe after the discovery of America. The first literary record of pitahaya is in "Historia General y Natural de las Indias" (General and Natural History of the Indies), published in 1535 and written by Fernández de Oviedo y Valdés, the first New World relator. In chapter XXVI, the following phrase, "De los cardones en que nasce la fructa que llaman pitahaya" (Cactus from which the fruit known as pitahaya is born), could refer to the column-like cactus called pitaya in Mexico (Bravo-Hollis, 1978); but Olaya (1991) shows a fruit illustration from General and Natural History of the Indies, which highly resembles a *Hylocereus* fruit.

Some Mexican species of the genus *Hylocereus* are known as "Cuauhnochtli" in Nahuatl (Bravo-Hollis, 1978). Fernández de Oviedo says this term is used to identify the *Hylocereus* genus. CUAUH, derived from CUAHUITL, meaning the tree in which pitahaya plant lives. Another possible name could be COANOCHTLI (COATL means snake) to name tall, skinny and climbing species like the genus *Selenicereus, Nyctocereus* and *Aporocactus* (Bravo-Hollis, 1978). Patiño and Martínez (Echeverri, 1990) say that "pitaya" is a Haitian word meaning "scaly fruit." Bravo-Hollis (1991) believes the word "pitaya" is a Quechua word (Antillean) introduced by the Spanish conquerors and refers to any fleshy, juicy and edible fruit from a cactus. In Central and South America, "pitaya" and "pitahaya" have the same meaning; however, in Mexico, "pitahaya" is used for fruits from epiphytic cactus like *Hylocereus*, while "pitaya" is used for fruits from column-like cactus (Ortiz-Hernández, 1999).

Hylocereus species are endemic to America (Britton & Rose, 1963). *H. undatus* origin is uncertain and it may be native of Mexico or Colombia (Fouqué, 1972), but Jorge & Ferro (1989) consider South America as origin of this species because the most primitive genus have been found there. Bravo-Hollis (1978) cites different authors that consider *H. undatus* comes from Martinica or Colombia. In Mexico, *H. undatus* (Figures 1 and 2) is found in almost all tropical and subtropical forests; birds propagate seeds from this species and there is a large morphological variation in phenotypes (Bravo-Hollis, 1978). *H. megalanthus* is native of the Andean region (Colombia, Peru, Bolivia, Ecuador and Venezuela). Germans consider *H. triangularis* or *H. trigonus* of Brazilian or Uruguayan origin (Pérez-Arbelaez, 1990), while Fouqué (1972) places *H. triangularis* and *H. ocamponis* as native of Uruguay, Brazil and Colombia.

Figure 1. Pitahaya fruits from Mexico.

Figure 2. Fruits of *H. undatus*, with different colored pulp.

In Central and South America, *Hylocereus* is cultivated in Guatemala, Nicaragua, Mexico, Colombia, Costa Rica, Venezuela and Peru. *Hylocereus* has been introduced for production to Bahamas, Bermuda, the United States (Florida and California), Australia, Thailand, India, China, Taiwan, Philippines, Malaysia, Vietnam, Indonesia, Cambodia, Israel and others (Nerd et al., 2002; Lim, 2012). *H. undatus* has become an important crop in Southeast Asia, ever since it was introduced via the Philippines, in the XVI Century (Casas & Barbera, 2002), or Indochina, in 1860, where it is considered a native species (Nerd et al., 1999).

In 1984, Israel introduced *Hylocereus* accessions from America, and ever since it has carried out several agronomical, physiological and genetic studies to increase yield and fruit quality (Mizrahi et al., 1997, 2002; Raveh et al., 1995, 1998; Metz et al., 2000; Ben-Asher et al., 2006; Weiss et al., 1994, 2010; Cisneros & Tel-Zur, 2010, 2011, 2012; Cohen & Tel-Zur, 2012).

Reproductive biology and Genetics

Several pitahaya bloom flows occur in the Northern Hemisphere from May to October (Barbeau, 1990; Nerd & Mizrahi, 1997; Ortiz-Hernández, 1999). In the Far East, *Hylocereus* flowering is artificially stimulated with light, since it requires long photoperiod for flowering (Jiang et al., 2012). However, researchers in Israel did not observe this effect when artificial lighting was used on *H. undatus* or *H. megalanthus*, but the removal of young flowering buds delayed flowering in *H. undatus* without affecting total flower yield (Khaimov & Mizrahi, 2006). Likewise applying CPPU [N-(2-chloro-4-pyridinyl)-N-phenylurea] promotes early flowering in *H. undatus* and *S. megalanthus* and increases total flower number, while gibberellic acid (GA_3) application delays flowering and lowers flower number in these species (Khaimov & Mizrahi, 2006).

Benerji & Sen (1955) performed the first embryological and cytological studies in *H. undatus*. The ovule of this species has fusioned funiculus that gives rise to the edible part of the fruit (Flores & Engleman, 1976). When anthesis occurs, the campylotropous ovule is completely formed (Castillo et al., 2000). Cisneros et al. (2011) consider *Hylocereus* ovules as amphitropous, bitegmic and crassinucellate, which during mega-gametogenesis and embryogenesis show abnormalities, suggesting apomixes.

There are auto-fertile and auto-infertile *Hylocereus* species (Weiss et al., 1994, Ramírez, 1999; Castillo et al., 2005). Yet, fertility between species is evident, since cross pollination among several species promotes 100 % fruit set. When cross pollination is performed by bees, fruit weight is greater than with artificial pollination; fruits also tend to have a longer form with cross pollination within the same species (Lichtenzveig et al., 2000). Seed viability varies among *Hylocereus* species and within the same species (Cisneros & Tel-Zur, 2012).

In Israel, pollination is performed manually to guarantee fruit set because of the absence of natural pollinators and *Hylocereus* auto-infertility (Wiess et al., 1994; Mizrahi et al., 1997; Nerd & Mizrahi, 1997). For cross-pollination, identified-compatible pollen is used, since pollen source affects fruit development time (metaxenia). This phenomenon can be used to control ripening period of *H. monacanthus* fruit before its commercialization (Mizrahi et al., 2004). Fruit ripening of *H. monacanthus* can be delayed 1 to 3 weeks when *S. grandiflorus* or *H. megalanthus* pollen is used, but not when *H. undatus* pollen is used. Pollen source has a significant effect in fruit size, dry pulp biomass, and number of seeds per fruit, while sugar content decreases in *H. monacanthus* fruits when its flowers are pollinated with *S. grandiflorus* (Mizrahi et al., 2004).

Tel-Zur et al. (2011a) found high genetic variability when characterized 44 *Hylocereus* accessions from different parts of the world. Most *Hylocereus* species are diploid; only *H. megalanthus* is tetraploid. There were not significant correlations between stomata length, stomata density and nuclear DNA content, or between fruit weight and seed number. However, high variation was observed between accessions in stomata length (39.9 ± 0.9 to 86.6 ± 1.8 μm), stomata density (5.7 ± 0.3 to 20.3 ± 0.4 mm2), flower number per plant (5 ± 0 to 55.3 ± 7.8), fruit weight (77 ± 16 to 474 ± 19 g), potential yield (0.8 to 21.8 Kg planta^{-1}), number of viable seeds per fruit (270 ± 118 to 7417 ± 1478) and fruit ripening period (28 ± to 160 ± days). Ramírez (1999) evaluated 40 descriptors in four Mexican *Hylocereus* accessions and found high phenotypic variation in shoot, flower and fruit. Fruit weight varies from 100 to 1200 g and ripening period from 27 to 120 days (Ramírez, 1999; Ortiz-Hernández, 2000).

Tel-Zur et al. (1999) have proposed a protocol for DNA isolation, and ever since, studies at cytological and chromosomal level have been published. Also, there are results about cross breeding diverse *Hylocereus* species for high fruit quality hybrids (Lichtenzveig et al., 2000; Tel-Zur et al., 2003, 2004a,b; 2005, 2011a,b; Cisneros & Telzur, 2011, 2012; Cohen & Tel-Zur, 2012). Plants resulted from cross breeding *H. megalanthus*, *H. undatus* and *H. monacanthus* have high ploidy levels (Tel-Zur et al., 2003). Triploid and aneuploid clones from crossbreeding *H. monacanthus* and *H. megalanthus* produce viable seeds and the number of seeds per fruit depends on the pollen donor. Tel-Zur et al. (2005), using RAPD analysis, have proved that the origin of these species is allopolyploid instead of autopolyploid.

As there is no synchronization in flower aperture of *Hylocereus*, Metz et al. (2000) have developed a below 0 °C, long-term storage protocol for *H. monacanthus* and *H. undatus* pollen to have it ready when it is needed. Auto infertility, asynchronicity in the flower aperture, and the cost of manual pollination made Cohen & Tel-Zur (2012) investigate how to ensure fruit set using auto polyploidyzation. The resulted hybrids show morphological changes and are auto fertile, thus avoiding artificial pollination.

Cisneros & Tel-Zur (2012) mention that the following techniques: fluorescence activated cell sorting (FACS), molecular markers, marker assisted selection (MAS) and quantitative trait loci (QTL) used with phenotypic, genomic and cytological evaluations of *Hylocereus* allowed them to obtain a model that associates agronomical characteristics with the gene that controls their expression and influence inheritance. This model outlines the pathways for polyploidy seed formation and development after interspecific-interploid hybridization.

Nutritional, Medicinal and Industrial Properties

Nutritional

In Mexico since prehispanic times, *H. undatus* is used as food and for its curative properties (Clerck & Negreros-Castillos, 2000). The fruit is consumed raw or transformed into wine, juice, jelly, yogurt, jam, preserves, and other desserts (Herbach et al., 2006; Shetty et al., 2012). Each 100 g of *H. undatus* pulp contains 1.4 ± 1.4 µg beta-carotene, 3.4 ± 1.4 µg lycopene and 0.26 ± 0.06 mg vitamin E (Charoensiri et al., 2009), and up to 24 mg vitamin C (Arévalo-Galarza & Ortiz-Hernández, 2004). Addition of *H. monacanthus* or *H. undatus* pulp in yogurt improves milk fermentation rates, lactic acid content, syneresis percentage, antioxidant activity and total phenolic content (Zainoldin & Baba, 2012).

H. undatus and *H. monacanthus* pulp contain glucose, fructose and oligosaccharides of various molecular weights, contributing to total concentrations of 86.2 and 89.6 g Kg^{-1}, respectively (Wichienchot et al., 2010). *H. monacanthus* has nutritional properties; fruit pulp is rich in fiber, vitamin C, minerals and phytoalbumin contents, which confer high antioxidant values (Jafaar et al., 2009). Dried juice contains high protein, fat, fiber, ash and antioxidants (Rebecca et al., 2010; Tze et al., 2012), and the peel has 150 ± 2.19 mg of beta-cyanine per 100 g, 10.8 % pectin, dietary insoluble and soluble fiber (3:8:1), glucose, maltose and fructose (Jamilah et al., 2011).

Young stems *H. undatus* are edible (Castillo, et al., 2005; Juárez-Cruz et al., 2012), as well as fresh flower buds that are eaten as vegetables, while dried ones are used for homemade medicine (Ortiz-Hernández, 1999). In Taiwan, dry flowers are consumed as vegetable (Mizrahi & Nerd, 1999). Juárez-Cruz et al. (2012) consider young stems to have high nutritional value; their composition (in g per 100 g) is total humidity (90.5 to 91.3), ashes (10.8 to 12.3), raw protein (11 to 12.1), raw fiber (7.8 to 8.1), ethereal extract (0.9 to 1.5), nitrogen-free extract (67.5). The mineral content, expressed as percentage of dry mass, is: P K Ca Mg Na (0.2, 2.3 – 4.8, 0.4 – 0.5, 0.6 – 0.7, 0.07 to 0.1), and as mg Kg^{-1} of dry mass: Cu Fe Mn Zn (9 – 16, 7.5 – 28.8, 30.5 – 40, 9.1 - 34).

Industrial

Hylocereus fruits can be processed by freezing, concentration, dehydration, fermentation, thermal processing and chemical conservation. From the pulp and peel natural colorants and pectin can be extracted using home, artisanal or industrial technologies (Esquivel, 2007). Red or purple pitahaya (*H. monacanthus* and *H. costaricencis*) pigments are potential colorant sources for the food industry (Wybraniec & Mizrahi, 2002; Esquivel & Araya, 2012). These colorants are very stable during processing and storage (Herback et al., 2006, 2007). Betacyanin contents, in the pulp and peel of *Hylocereus* fruits, are 10.3 to 13.8 mg 100 g^{-1} (Wu et al., 2006) and have been identified using several techniques (Wybraniec et al., 2007). Several betacyanines have been separated from *H. monacanthus*, such as betanin, isobetanin, phyllocactin, isophyllocactin, betanidin, isobetanidin, bougainvillein-R-I, hylocerenin and isohylocerenine (Wybraniec & Mizrahi, 2002; Wu et al., 2006; Stintzing & Carle, 2007). Pigments identified either in *H. costaricensis* and *H. monacanthus* are similar (Esquivel et al., 2007); however, some *H. costaricensis* clones have greater betanin and isobetanin content, while others have higher phyllocactin and hylocerenin contents. In addition to that, new betalain types were found in some clones: neobetanin (14, 15-dehydrobetanin) and gromphrenin (Betanidin-6-O-glucoside).

Pitahaya peel could potentially be used as thickening agent and natural colorant (Harivaindaram et al., 2008), in cosmetic hydrating creams (Stintzing et al., 2002) or diet beverages ingredient. The mucilage extracted from fruit peel is highly perishable and requires preservatives or dehydration (Tze et al., 2012), but due to its rheological qualities, its use as encapsulating agent for active principles under optimized spray drying could be possible (García-Cruz, 2011).

Medicinal

Mayas used *H. undatus* fruits as hypoglycemic, diuretic, against heart disease (Argueta, 1994; Ankli et al., 1999), wound disinfectant, tumor dissolution with stem sap (Mendieta & Del Amo, 1981), and dysentery cure (Hopkins & Stepp, 2012).

In the last decade, it has been shown that *H. moncanthus* fruits have antioxidant and anti-proliferation properties (Wu et al., 2006; Esquivel et al., 2007; Nurliyana et al., 2010; Kim et al., 2011). Wu et al. (2006) have verified that *H. monancanthus* peel and pulp are rich in polyphenols, and peel could inhibit cancer cell growth (melanoma B16F10 and other types) (Kim et al., 2011). Tenore et al. (2012) have shown that polyphenol extracts from the fruit have antioxidant properties and nutracetic potential, and that the pulp is source for phytochemically bioactive compounds (antioxidants). Oligosaccharides from *H. undatus* and *H. monacanthus* have pre-biotic characteristics, resistance to acid conditions in the stomach, and partial resistance to human a-amylase, and they also promote lactobacillus and bifidobacterias (Wichienchot et al., 2010).

Pitahaya seed oil is a potential source of natural antioxidants and contains phenolics, tocopherols, and sterols (Lim et al., 2010). Current studies in the subject have focused on stabilizing the compounds (Lim et al., 2012; Ayala-Aponte et al., 2010). *H. undatus* and *H. monacanthus* contain 50 % of essential fatty acids; linoleic acid is in greater proportion than linoleic (C18:2, 48% and C18:3, 1.5%). In *Hylocereus* seeds, the linoleic acid concentration is greater than in flax seed, canola, sesame or grapevine. However, seed mass relative to the fruit is very low (1:99) (Ariffin et al., 2009). Nonetheless, Chemah et al. (2010) mention that pitahaya seeds have high potential as source of antioxidant and essential fatty acids, with an exceptional level of linoleic acid: 660 g Kg^{-1} in *H. megalantus*, 540 g Kg^{-1} in *H. undatus* and 480 g Kg^{-1} in *H. monacanthus*.

Acetone extracts (70 % concentration) of *Hylocereus* peel have high antimicrobial activity, particularly against *Salmonella typhi* (Escobar et al., 2010). Likewise, the phenolic fractions of *H. monacanthus* fruit have great antimicrobial spectrum than non-fractionated extracts (Tenore et al., 2012). Chloroform extracts of *H. polyrhizus* and *H. undatus* have antimicrobial activity against gram-positive and gram-negative bacteria, but *H. polyrhizus* extracts have greater effect (Nurmahani et al., 2012).

In rats, an antihepatotoxic effect has been shown after paracetamol induced hepatoxicity (Latif et al., 2012). A pitahaya based diet decreases, in rats, dyslipidemia (increased and modifiable risk factor for cardiovascular disease, particularly coronary disease due to lipid alteration in the blood) (Mohd et al., 2009). Betanidine extracted from *H. ocamponis* and administered to atherogenic BALB mice in 9.6 mg dosages for 40 days reduced, through an unidentified mechanism, glucose levels by 50.9 % (Lugo-Radilla et al., 2012).

In terms of fertility, Ankli et al. (1999) consider *H. undatus* is used for abortion prevention. Aziz & Noor (2010) have shown that *H. costaricensis* fruit promotes rat fertility; 500 mg Kg^{-1} of ethanol extracts from pitahaya fruits increased sperm count, and 1000 mg Kg^{-1} incremented sperm viability and production rate; additionally, under histological observations high sperm density in the seminal tubes was found. Methanol extracts from *H. polyrhizus* in 5000 mg Kg^{-1} day^{-1} for 28 days showed no signs of acute or subchronic toxicity or mortality (Hor et al., 2012).

Ecology and Physiology

Hylocereus is considered an epiphyte or hemi-epiphyte, which could turn into a parasite of the host plants by aerial invasion or root introduction into the cambium or root pith, thus causing the dead of the host. According to Barbeau (1990), pitahaya (*H. undatus*) is a tropical climate cacti, resistant to water stress, and adapted to mean temperatures of 21 to 29 °C. Best results for *H. megalanthus* cultivation are obtained between 1000 to 1750 m above sea level and 18 to 25 °C (Becerra, 1986, 1994), 1500 to 2000 mm $year^{-1}$ rainfall, good drainage soils, 5.5 to 6.5 pH, 30 % or lower soil slopes (Becerra, 1986). It can survive from -2 to 15 °C during the month of November (Cacioppo, 1991). *Hylocereus* is found in regions with greater than 2000 mm per year of rainfall, extreme temperature range of 11 to 40 °C and up to 1840 m above sea level, particularly in Mexico and Central America. Excessive rain causes flower rotting and fall.

Interest around the World to introduce *Hylocereus* species as a crop has promoted physiology research, as net photosynthetic rate is related to species productivity. One particular production environment is under arid and semiarid conditions, which are different from the tropical or subtropical environments that this species is used to live and where water is not a yield restriction (Nobel & de la Barrera, 2002a). Under desert conditions, in Israel and United States, besides the role of water in the plant, the effects of light intensity, temperature and nutrition, are under study.

The highest maximal net instantaneous CO_2 rate uptake in field conditions in Israel reached 12 µm m^{-2} s^{-1} and 378 mmol m^{-2} d^{-1}. This is the highest recorded daily net uptake for *H. undatus* at 38/29 °C and 39/61 % RH day/night under optimal conditions (Ben-Asher et al., 2006). The first studies on water stress on *H. undatus* were in a growth chamber. The results indicated that two weeks without irrigation had little effect on net CO_2 uptake, but 17 days decreased growth by 78 % (Raveh et al., 1995; Nobel & de la Barrera, 2002a, 2004). In another study, when watering was withheld under growth chamber environmental conditions, net daily CO_2 uptake decreased 33 % in 7 d and 63 % after 12 d (Nobel & de la Barrera, 2002a); however, under field conditions in a desert in Israel, net daily CO_2 decreased 53 % after 4 days and 89 % after 8 days of water stress. Difference in results between field conditions and growth chamber are explained by the vapor pressure deficit that is three times greater under field conditions (Ben-Asher et al., 2006).

The effect of high temperature on net CO_2 uptake was transcendental for *H. undatus* introduction as a crop in regions of Israel, like the Arava and Jordan River valleys, where the daily mean temperature exceeds 37 to 38 °C and causes tissue damage in stems and death (Mizrahi & Nerd, 1999; Ben-Asher et al., 2006). Some other zones where it has been introduced, like Northern Africa or the Southeast of United States, can also experience high temperatures (Nobel & de la Barrera, 2002b). On the other hand, temperatures lower than -1.3 °C killed half the chlorenchyma cells in *H. undatus* (Nobel & de la Barrera, 2004). The maximal net CO_2 uptake is at 30/20 °C while the lowest occurs at 40/30 °C (Nobel & de la Barrera, 2002a and 2002b).

H. undatus under natural conditions is exposed to drastic changes in photosynthetic photon flux (PPF). Some epiphytes, including *H. undatus*, in the canopy of a deciduous forest receive 3 to 8 times more PPF during the dry season than during the rainy season (Andrade et al., 2006). This changes decrease CO_2 uptake (Raveh et al., 1995; Ortiz-Hernández et al., 1999). In this type of vegetation, PPF can be 40.86 mol m^{-2} d^{-1} in the dry season and 49.7 mol m^{-2} d^{-1} in a clear day of the rainy season (Andrade et al., 2006). *H. undatus* has a considerable net CO_2 uptake with 2 mol m^{-2} d^{-1} of PPF (Nobel & de la Barrera, 2004). Daily net CO_2 uptake reaches 90 % of its maximal value with only 10 mol m^{-2} d^{-1} PPF, increases up to 20 mol m^{-2} d^{-1}, and declines after this level because of photoinhibition (Rave et al., 1995), thus light intensity must be reduced by 40 %; in Israel, shade netting is used to reduce PPF by 30 to 60 % (Nobel & de la Barrera, 2004; Raveh et al., 1998; Mizrahi & Nerd, 1999).

The effect of nutrition on net CO_2 uptake in *H. undatus* has involved mainly nitrogen doses variations. After 22 weeks, the maximal CO_2 uptake of *H. undatus* plants growing in sand / vermiculate were 2.5 μmol m^{-2} s^{-1} with 0.16 mM N, 5.6 μmol m^{-2} s^{-1} with 1.6 mM N and 9.8 μmol m^{-2} s^{-1} with 16 mM N; the latest doses is the full strength Hoagland's solution; the highest net CO_2 uptake in *H. undatus* is reached with the highest nitrogen concentration (Nobel & de la Barrera, 2004). When half strength Hoagland's solution was applied, only 76 % of the net CO_2 uptake occurred at night. Low nitrogen doses (0.8 mM or less for 22 weeks) caused stem bleaching and decreased chlorophyll content (0.3 g m^{-2}) compared to 16 mM (0.63 g m^{-2}) (Nobel & de la Barrera, 2002c). However, *H. undatus* has a lower nutrition response, 2 weeks or longer, than most C_3 and C_4 plants, which implies lack of genetic plasticity and low nutrient absorption capacity through root (Nobel & de la Barrera, 2002c and 2004).

Raveh et al. (1995) indicate that doubling environmental CO_2 concentration, from 370 to 740 μmol mol^{-1}, causes half of the net CO_2 uptake to occur 3 h earlier and decrease 0.5 h faster under different PPF, air temperature and drought conditions. These changes increase 34 % daily net CO_2 uptake (from 214 mmol m^{-2} d^{-1} at 370 μmol mol^{-1} and 286.7 μmol m^{-2} s^{-1} at 740 μmol mol^{-1}); this increment occurs at phases II and IV. Doubling CO_2 concentration causes net CO_2 uptake under more favorable environmental conditions to increase by 250 % in the afternoon, decrease 150 % after 2 h and 20 % after 7 h, and completely disappear at dawn. Malic acid that accumulates during the night, and eventually inhibits PEPCase activity (Ting, 1985), explains the night decrease of net CO_2 uptake at double the CO_2 environmental concentration since it was synthetized at a greater rate (Raveh et al., 1995). Weiss et al. (2010) have found that, in a greater than 1000 μmol mol^{-1} CO_2 concentration, pitahaya plants increased 52 % daily CO_2 uptake, 80 % maximum CO_2 rate uptake, 30 % nightly acid accumulation, total stem growth and growth rate, if compared to a crop under 380 μmol mol^{-1}. *H. undatus* has the characteristic potential of CAM plants to respond positively to CO_2 increments.

Propagation and Husbandry

Hylocereus propagation can be through seed or vegetative, but the latter is used more often. Vegetative propagation is done by cuttings or stem fractions, grafts and *in vitro* (meristems or ovules). *Hylocereus* propagation by stem fractions has been employed with ornamental purposes as rootstock to help other cactus grow when they have difficulties to survive directly on the ground, lack chlorophyll, are slow growers, have poor root systems, to speed flowering, shorten the seedling stage or for massive multiplication (Jeong, 2007). *H. undatus* cuttings do not form callus; adventitious roots differentiate in the peryclicle (Cavalcante, 2008). Roots from the cuttings are very sensitive to water salinity, 50 % of cuttings die when the electrical conductivity of water is 4.0 dS m^{-1}, and organs of the survival cuttings show growth problems (Cavalcante et al., 2007).

The husbandry techniques used in Mexico for growing pitahaya are based on traditional production practices and adaptations to systems employed in Colombia and Nicaragua (Figures 3 and 4)(Becerra, 1994; Ortiz-Hernández, 1999). However, high technology techniques from Israel have not been incorporated in Latin America

(Figures 5 and 6) (Raveh et al., 1998; Mizrahi & Nerd, 1999; Mizrahi et al., 1999). In Israel, yields from 32 to 40 t ha^{-1} are reached 3 years after planting, against 2 to 3 t ha^{-1} in drier, warmer and saltier places, aside from reaching productive age much later (Mizrahi & Nerd, 1999).

Figure 3. *H. undatus* climbed on trees of *Gliricidia sepium* (cocoite) in Yucatan, Mexico, in a very poor soil.

Figure 4. *H. costaricensis* cultivation in Masaya, Nicaragua, in a terrace system.

Figure 5. Planting pitahaya in Israel, after pruning to induce flowering.

Figure 6. Planting pitahaya intensive production in Israel.

The *Hylocereus* genus can be planted in the open in tropical regions (Barbeau, 1990), but in drier and warmer climates, 30 to 60 % artificial shade netting is necessary to protect the plants from high solar radiation (Raveh et al., 1998; Mizrahi & Nerd, 1999; Cavalcante et al., 2011). *H. monacanthus* and *H. costaricensis* are more tolerant to high solar radiation than other species because of a waxy coating that covers their stems (Raveh et al., 1998).

Postharvest

Fruits from *Hylocereus* species are identified as not climacteric (Nerd & Mizrahi, 1998; Nerd et al., 1999; Arévalo-Galarza & Ortiz-Hernández, 2004). Starch degradation increases in the pulp after fruit maturation, and it is shown partially by soluble sugar accumulation. In *H. undatus*, amylase and invertase activity correlate with increments of fructose and glucose, which concentrate around the center of the pulp (Wu & Chen, 1997).

H. megalanthus fruits should be stored at 10 °C to reduce weight, acidity and sugar losses (Nerd & Mizrahi, 1998; Nerd et al., 1999). *H. undatus* and *H. monacanthus* fruits stored at 20 to 26 °C only have a 6 to 10 d shelf life (Nerd et al., 1999; Arévalo-Galarza y Ortiz-Hernández, 2004). Application of 1-MCP (1-methylcyclopropene) increases shelf life on *H. monacanthus* fruits harvested 30 to 35 days after anthesis and stored for 28 days at 10 °C; under this treatment phenolic, ascorbic acid, and betacyanine contents are unaffected (Novita, 2008). Fruit immersion in a 500 µg L^{-1} of 1-MCP for 4 h at room temperature, delays ethylene production for 14 days of storage because respiration rate is reduced and fruit senescence slowed. 1-MCP application provides greater firmness to the *H. megalanthus* fruit and represents an alternative to reduce undesirable texture changes during storage (Ayala-Aponte & Serna-Cock, 2011).

Shelf life in *H. monacanthus* fruits increases applying calcium chloride by reducing anthracnose (*Colletotrichum gloesosporioides*) lesion size, and increasing calcium content in the rind and firmness without changing pH, soluble solids or fruit tritratable acidity (Awang et al., 2011). Lum & Norazira (2011) consider that useful life and fruit quality in *H. monacanthus* could increase by fruit immersion in 35 °C water for 60 minutes.

Disinfected *H. undatus* fruits with 1000 ppm $NaCl_2$ stored under controlled atmosphere with 1 % oxygen and 12 °C have prolonged shelf life of up to 35 d, without affecting quality (Vargas et al., 2007). Fruits harvested 28 to 30 days after anthesis can be stored up to 35 d in modified atmosphere chambers (O_2 transmission at 400 mL m-2 día-1) at 10 °C (Gross et al., 2002).

Storing fruits of *H. undatus* under low temperature is a common practice to maintain quality and increase shelf life. However, fruits could show frost damage and this reduces their commercial value. Low temperature inhibits phenol – polyphenol oxidase (PPO) and peroxidase (POD), and temperatures below 11 °C partially degrade fruit cells. Damage is reversible if the cold period is shorter than 7 d (Balois-Morales et al., 2007).

Pests and Diseases

Holes and damages left by insects are fungi and bacteria entrance sites that can eventually kill plants. INRA-CEE (1994) and Badillo (1995) have observed different pest in pitahaya crops in Nicaragua: stem weevil *Maracayia chlorisalis* Walker (might be controlled with *Trichogramma*), *Cotinis mutibales* Gory and Percheron and *Euphoria limatula* Janson beetles, *Metamasiu fareih striatofo* Galli, laminated legs bugs *Leptoglossus phyllosus* y *Leptoglossus zonatus* Dallas, ants from genus *Atta* (*Atta caphalote*, *Atta colombica* and *Acromymex* sp) and *Solenopsis* sp. In Colombia, *Dasiops saltans* (spear fly) in *H. megalanthus* causes loses from 40 to 80 % on flowering, and thus on production. This fly deposits its eggs on the flower buds, and the larvae drill anthers. The buds turn red and fall easily (Delgado et al., 2010). Ho et al. (2006) propose thermal treatment with warm air 46.5 °C for 20 minutes against fruit fly (*Bactrocera* spp) to disinfect *H. undatus* fruits, followed by 2 to 4 weeks storage at 5 °C. Fruits treated as described deteriorate externally, but flavor stays acceptable after some time.

Diseases registered in *Hylocereus* are caused by *Erwinia carotovora* y *Xanthomonas campestris*, *Dothiorela* sp., *Colletotrichum gloesporoides* Penz, *Alternaria* sp, *Curvularia* sp., *Phoma* sp., *Cladosporium* sp., *Vollutella* sp., *Helminthosporium* sp., *Corynespora* sp. (INRA-CEE, 1994; Badillo, 1995), *Bipolaris cactivora*, *Colletotrichum gloeosporioides*, *Fusarium oxysporum*, *Xanthomonas campestris*, *Ascochyta* sp., *Aspergillus* sp., *Botryosphaeria dothidea*, *Capnodium* sp., *C. gloeosporioides*, *Dothiorella* sp., *Fusarium* sp., (Taba et al., 2006; Wang & Lin, 2005; Masyahit et al., 2009a,b), *Bipolaris* sp., *Botryosphaeria* sp., *C. gloeosporoides* and *Monilinia* (Masyahit et al., 2009a). Nematodes (*Meloidogyne* spp) also attack this plant. *H. undatus* is host to *Botrysphaeria dothidea*, in addition to *B. dorsalis*, *B. correcta* and *B. cucurbitae* (Ho et al., 2006). Phoulivong et al. (2010) consider that anthracnose caused by *C. gloesporioides* (Penz) Penz & Sacc is not common in tropical fruits, yet this disease has been identified in *Hylocereus* sp. fruits in Malaysia (Masyahit et al., 2009a).

Using *Hylocereus* rootstock, there are important fungi-induced diseases, such as *F. oxysporum* and *B. cactivora* (previously known as *Helminthosporium cactovorum* and *Drechslera cactivora*), *Glomerella cingulata* and *Pectobacterium carotovorum* subsp. Carotovorum (Hyun et al., 1988; Kim *et al*., 2000, 2007). A specific type of cancer in *H. undatus* and *H. monacanthus* rootstock was caused by *Neoscytalidium dimidiatum* (Penz.) Crous & Slippers (Chuang et al., 2012).

Postharvest Pathology

Postharvest diseases have been associated with *Fusarium lateritium*, *Aspergillus niger* and *Aspergillus flavus* (Le et al., 2000), *Bipolaris cactivora* (Petrak) Alcorn (Taba et al., 2007; Masyahit et al., 2009b), *Aspergillus* spp., *Xanthomonas campestris* and *Dothiorella* spp. (Barbeau, 1990). Masyahit et al. (2009c) observed *in vitro* factors that affect development of associated pathogens with *H. monacanthus* fruit after harvest. Theese authors have found three antagonic bacteria: *Bukholderia cepacia*, *B. multivorans* and *Pseudomonas aeruginosa* against *Bipolaris* sp., *Colletotrichum gloeosporioides*, *Botryosphaeria* sp. and *Monilinia* sp. Field collected fruits showed *Alternaria* sp., *Ascochyta* sp., *Aspergillus* sp., *Bipolaris cactivora*, *Botryosphaeria dothidea*, *Capnodium* sp., *Colletotrichum gloeosporioides*, *Dothiorella* sp., *Fusarium* sp., *Gloeosporium agaves*, *Macssonina agaves*, *Phytopthora* sp. and *Sphaceloma* sp. The same authors observed that mycelia growth was inhibited at 35 °C and pH 4 and 10. A 30 °C temperature was favorable for *C. gloeosporioides* growth.

Conclusions

Hylocereus is a potential food source for the present and future, besides having great potential for medicine and industrial production. Genetic diversity of pitahaya in its natural habitat, in particular under ecological niches, needs evaluation. Collection, selection and evaluation of genotypes from contrasting environments could be an ample topic of research.

The level of research in the physiology of pitahaya is remarkable, particularly in *H. undatus* under dry and high temperate conditions. Yet, there is a need for research on *Hylocereus* behavior in its natural habitat, in dry and cold places, in temperature high valleys, or warm high solar radiation and high relative humidity conditions, like the ones in tropical regions.

In spite of advances in research on the effect of increased tropospheric CO_2 concentration on net CO_2 uptake in *H. undatus*, climate change also implies increase in mean air temperature as results of increasing greenhouse gases. Thus, effect of both CO_2 and temperature on pitahaya physiology needs to be studied. The effect of nitrogen and other nutrients on net photosynthesis and growth of pitahaya needs to be assessed.

The increasing planting area of *Hylocereus* around the world under diverse production environments demands more research concerning disease and pest control, particularly during plant propagation, fruit production and postharvest fruit life.

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