Quality of fruits of pitaya (*Hylocereus undatus* [Haworth] Britton & Rose) according to physiological maturity. A review

Calidad de los frutos de pitaya (*Hylocereus undatus* [Haworth] Britton & Rose) en función de la madurez fisiológica. Una revisión

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ABSTRACT

The fruit of pitaya has occupied a growing niche in the fruit market, since its organoleptic characteristics and rusticity have attracted the attention of consumers and producers, respectively. The organoleptic and nutritional quality of fruits are due to maturity stage. Therefore, determining the period in which the fruits reach the physiological maturity is important, since it aids the planning of the harvest and the quality control of fruits. In this sense, the aim of this review is to establish the ideal period for harvesting their fruits of pitaya (Hylocereus undatus), by determining the physiological maturity point. For this species, the number of days from anthesis to the full development of the fruit has shown to be the most reliable variable to determine the moment of harvest. From this designation, it is possible to indicate the stage (physiological maturity) in which the fruits present characteristics favorable to the species, for example, color, soluble solids content, ratio, and others. It is known that the place of production and the edaphoclimatic conditions are able to interfere and cause variation in the period in which the fruits reach the physiological maturity. Some studies in Mexico confirmed that the physiological maturation of pitaya fruits occurred between 25 and 31 days after anthesis (DAA). Other researches, including in Brazil, confirmed that this point occurred from 28 to 32 DAA. Thus, from the scientific studies carried out and published in the literature, to avoid losing their commercial value of fruits, it is recommended to harvest this fruits of pitaya between 25 and 32 DAA.

Additional key words: dragon fruits; maturity index; physiological quality; fruit quality.

RESUMEN

Los frutos de pitaya han ocupado un creciente nicho en el mercado de frutas ya que sus características organolépticas y rusticidad han atraído la atención de los consumidores y productores, respectivamente. La calidad organoléptica y nutricional de los frutos son consecuencia de la fase de maduración. Por lo tanto, determinar el periodo en que los frutos alcanzan la madurez fisiológica es importante, pues apoya la planificación de la cosecha y el control de calidad de los frutos. En este sentido, esta revisión tiene como objetivo establecer el periodo ideal para realizar la cosecha de los frutos de la pitaya (Hylocereus undatus), a través de la determinación del punto de madurez fisiológica. Para esta especie, el número de días de la antesis hasta el desarrollo pleno del fruto se ha mostrado como la variable con mayor confiabilidad para determinar el momento de la
cosecha. A partir de esta designación, es posible indicar la fase (madurez fisiológica) en que los frutos presentan características favorables a la especie, a ejemplo del color, contenido de sólidos solubles, ratio, entre otras. Se sabe que el lugar de producción y las condiciones edafoclimáticas son capaces de interferir y causar variación en cuanto al período en que los frutos alcanzan la madurez fisiológica. Algunos estudios en México confirmaron que la maduración fisiológica de los frutos de pitaya ocurrió entre los 25 y 31 días después de la antesis (DAA). Otras investigaciones, incluso en Brasil, confirmaron que este punto ocurrió en el período de 28 a 32 DAA. Por lo tanto, a partir de los estudios científicos llevados a cabo y publicados en la literatura, para evitar perder su valor comercial de los frutos de pitaya se recomienda cosecharlos entre 25 y 32 DAA.

**Palabras clave adicionales:** fruta de dragón; índice de madurez; calidad fisiológica; calidad de la fruta.

**INTRODUCTION**

The fruit growing is constantly evolving as regards the introduction of new varieties and species for commercialization, which has been boosted by the population's awareness of a healthier diet. In this sense, pitaya or dragon fruits (*Hylocereus undatus* [Haworth] Britton & Rose), fruit plant belonging to the Cactaceae family, has occupied a growing niche in the fruit market; with wide demand in the world market (Rodríguez, 2000; Le Bellec *et al*., 2006; Cordeiro *et al*., 2015).

Thus, with the increase in acceptance by exotic fruits worldwide, the pitaya’s market has favored and increased the economic and agronomic potential of its cultivation (Rodríguez, 2000). The organoleptic characteristics together with the nutraceutical properties make the pitaya a product of acceptance in the consumer markets (Silva *et al*., 2006; Andrade *et al*., 2007; Perween *et al*., 2018). In addition, the rusticity of the plant and the aggregate commercial value of the fruits have contributed to the expansion of the cultivation of this species, which makes it attractive to the fruit growers (Ortíz-Hernández *et al*., 1999; Bastos *et al*., 2006; Santos *et al*., 2010; Xu *et al*., 2019).

Fruits production is dependent on intrinsic, extrinsic and the combination of both factors, and their organoleptic and nutritional quality depends on its maturation stage (Centurión Yah *et al*., 2000). The maturation stage of fruits at the time of harvesting has an influence on their final quality, interfering in post-harvest. When the fruits are harvested immaturely, their maturing process is
impaired, with a reflection on its quality, since they become susceptible to physiological disorders, for example, result of cell disorganization and cell wall disruption. However, fruits harvested at super-mature stage will favor senescence, reducing shelf life, and hampering handling, storage and transport. This is due to their low physical resistance, besides being still sensitive to injuries and diseases, causing quantitative and qualitative losses (Kays, 1991; Chitarra and Chitarra, 2005).

Fruits maturation is one of the events less described in the models of plant phenology (Chuine et al., 2003). Thus, in order to obtain a product with commercial value, it is necessary to determine precisely when the fruit reaches the physiological maturity. It can be identified by physicals parameters (longitudinal length, equatorial diameter, thickness, weight, and color) and/or chemicals parameters (soluble solids content, titratable acidity, ratio, and pH).

Because the studies are still restricted with pitaya, little is known about harvest rates and post-harvest behavior of fruits of this species. In addition, the shortage related to the knowledge of pre- and post-harvest techniques for the management of the quality of the pitaya fruits has made it difficult to market them worldwide (Centurión Yah et al., 2008). Thus, this review aims to establish the ideal period for harvesting their fruits of pitaya (Hylocereus undatus), by determining of the physiological maturity point.

ORIGIN AND MORPHOLOGY OF PITAYA

Pitaya, belonging to the Cactaceae family, is originate from tropical and subtropical America, whose adaptability to different environmental conditions has favored your introduction in countries with edafoclimatic differences (Mizrahi et al., 2002; Tel-Zur et al., 2004). It is grouped into four genera: Stenocereus Briton & Rose and Cereus Mill. (which they are columnar cactaceae), and Selenicereus (A. Berger) Riccob and Hylocereus Britton & Rose (both are epiphyte cacti) (Zee et al., 2004; Le Bellec et al., 2006).

The Antilles words ‘Pitahaya’ or ‘Pitaya’, meaning fruit covered by scales, are the denomination used for both the plant and the fruit (Rodríguez, 1993; Zee et al., 2004). Among the multiple names for these species, it stands out ‘Moonflower’ and ‘Queen of the night” due to the characteristic of their flowers to open only at night and close in the early hours of the following day; besides the beauty of its flowers, being considered one of the most beautiful in the world (Mizrahi and Nerd, 1999).
In the eastern countries they are known as ‘Dragon fruit’, by the similarity of their external bracts with the characteristic scales of the dragon figure (Mizrahi and Nerd, 1999; Meráz et al., 2003). However, the use of the term ‘Pitahaya’ has become widespread, not only in Colombia and Nicaragua, where the word ‘Pitaya’ has been used repeatedly, but also in European and Asian countries whose markets are traded and where the main name ‘Pitahaya’ is often added to a local designation that allows better identification in the market (Rodríguez, 2000; Xu et al., 2019).

Pitaya is an epiphytic, rupiculate or terrestrial branched, perennial and succulent plant. The taxonomic group ‘Hylocereus’ is diploid, as in most cacti, characterized by plants with a scandal or climbing habit; grows in both trees and rocks (Ortíz-Hernández, 2000). In commercial scale is common to use the staking system in your production.

The stem is classified morphologically as cladodium, segmented with trigone or trialled branches, reaching up to 35 m in length and from 5 to 7 cm in diameter, with wings of approximately 2.3 cm in height (Rodríguez, 1993). The cladodium is succulent, with sharp, creased and horny edges; it is greenish with a photosynthesizing function, or greyish, with the aging, due to the wax that recovers it (Donadio, 2009). It is devoid of true leaves; however, there are modified leaves, the thorns (Paula and Ribeiro, 2004; Socha, 2007). In the stem there is areolas sub-winged with base dilated in a bulb; they are of 2 to 3 cm in diameter, distant of 3 to 5 cm between each, and have from 3 to 6 thorns each, of 1 to 4 mm (Donadio, 2009).

From the cladodes, in the intercostal spaces, numerous adventitious roots originate that contribute in the absorption of nutrients and in the fixation of the plant to the support, where it is conducted, without parasitic action (Rodríguez, 1993; Ortíz-Hernández, 2000). The root system is fasciculate and superficial, however, with the capacity of extracting nutrients from the soil, even when they are in low concentrations (Le Bellec et al., 2006).

The flower is complete, androgynous, solitary, lateral, of white or pink coloring and aromatic; measuring from 20 to 35 cm in diameter. It contains numerous stamens, having been counted above 800 in a single flower. They are arranged in two rows around the pistil, formed by 14 to 28 cream colored stilettos. The sepals are light green in color and the pollen is abundant and yellow in color (Crane and Balerdi, 2005; Le Bellec et al., 2006; Donadio, 2009).

In H. undatus, flower buds are formed shortly before the anthesis, exhibiting rapid development, about three weeks (Nerd et al., 2002b). The anthesis is nocturnal, lasting
approximately 15 h. The maximum flower opening occurs between 23h00 and 1h00. The emission of floral buds occur in the areolas, appearing a bud in each one of them and only once, not developing, in this region, any other reproductive or vegetative organ (Marques, 2010). The areolas are protruding or depressed points, where the axillary buds are located. In order to avoid self-pollination, H. undatus flowers have the highest stigma than anthers (Marques, 2008).

The fruit is of the berry type, of globose or subglobous format, and it measures from 10 to 20 cm of diameter and mass varying from 200 to 1.000 g; but the average mass of the fruit varies from 350 to 450 g (Nerd and Mizrahi, 1997). Its formation takes place from the development of the ovary (Mizrahi and Nerd, 1999).

According to the species, the fruits may present diversified characteristics, such as shape, presence of thorns and pericarp and pulp color, reflecting high genetic variability (Junqueira et al., 2010). The pericarp may have pink, red or yellow tonality, with foliar scales (bracts) varying in number and length, which is formed from the receptacle surrounding the ovary (Mizrahi and Nerd, 1999). The pulp is juicy, white, red or magenta color; according to the species, with approximately 18 °Brix (Le Bellec et al., 2006; Lorenzi et al., 2006; Livera-Muñoz et al., 2010).

The fruits follow a breathing pattern that divides them into climacteric and non-climacteric. In this respect, some studies performed with pitaya concluded that this is within the group of climacterics (Chávez and Stevenson, 1992; Garnica and Quintero, 1994; Camargo and Moya, 1995; Rudas, 1995). However, other authors, based on the low ethylene concentration obtained in their experiments, classified as non-climacteric (Nerd and Mizrahi, 1997, 1999; Zee et al., 2004; Arévalo-Galarza and Ortíz-Hernández, 2004).

The seeds are distributed numerically throughout the pulp, approximately 3 mm in diameter, dark in color, obovate in shape, smooth, shiny and with high germination capacity (Crane and Balerdi, 2005; Le Bellec et al., 2006). Weiss et al. (1994); Nerd and Mizrahi (1997) observed a positive correlation between the fruit mass and the number of seeds.

PRODUCTION AND ECONOMIC IMPORTANCE OF PITAYA

The most widespread pitaya species are the red pericarp (Hylocereus spp.), whose fruits may have white pulp (Hylocereus undatus [Haworth] Britton & Rose) or red pulp (H. polyrhizus
Among them, the species *Hylocereus undatus*, red pitaya with white pulp is the world's most widely cultivated (Nerd *et al.* 2002a) in countries of Oceania (Australia and New Zealand), of Asia (Malaysia, Indonesia, Philippines, Vietnam, Cambodia, Thailand, China, Korea, Taiwan, Japan and Israel), of Europe (Spain), of North America (United States and Mexico), of Central America (Guatemala, El Salvador, Nicaragua, Costa Rica and Panama), and of South America (Colombia, Venezuela, Ecuador, Peru, Uruguay and Brazil) (Rodríguez, 1993; Mizrahi and Nerd, 1999; Xu *et al.*, 2019).

A few decades ago the pitaya was little known and from the 90's received more attention, occupying a growing niche in the exotic fruit market. The number of producing countries of this species has grown, being widely consumed in Asia (Le Bellec *et al.*, 2006; Fernandes *et al.*, 2018; Xu *et al.*, 2019). Significant production is occurring and expanding in many countries including: Colombia, Mexico, Nicaragua, Ecuador, United States, Thailand, Malaysia, Indonesia, Vietnam, China and Australia (Junqueira *et al.*, 2010; Cavalcante *et al.* 2011; Paull and Chen, 2019). Vietnam, the leading exporter of fruits of pitaya in the world, has almost 40,000 ha devoted to cultivation of this species with a volume of production reaching about 1 million metric tons (ADAWR, 2017).

The interest for this fruit increases, on the part of the consumers, by reason of its organoleptic characteristics and nutraceutical properties (Silva *et al.*, 2006; Andrade *et al.*, 2007). It is considered a nutritious fruit and can be consumed both in natura or as raw material of a range of industrialized products, as beverages, cosmetics and medical (Esquivel, 2004). Some species are rich in flavonoids, vitamins and fibers, besides being source of vitamin A and B (B1, B2 and B3), phosphorus, calcium, potassium and sodium, with caloric value of 38 kcal 100 g⁻¹ pulp (Crane and Balerdi, 2005; Wu *et al.*, 2006; Esquivel *et al.*, 2007a; Gunasena *et al.*, 2007; Perween *et al.*, 2018).

On the other hand, the attention of the fruit growers is aroused by the aggregate commercial value of the pitaya, being an alternative for the cultivation. In addition, due to its rusticity, it has become an option with agronomic, economic and nutritional potential in shallow, sandy and stony soils (Ortíz-Hernández *et al.*, 1999; Bastos *et al.*, 2006; Santos *et al.* 2010; Xu *et al.*, 2019).
The propagation of the pitaya can be done by means of seeds or vegetative structures, highlighting the cutting, grafting and micropropagation. As for the average productivity of this species, it is variable according to the soil and climatic conditions, cultivation techniques and orchard age, ranging from 10 to 30 t ha\(^{-1}\) (Le Bellec \textit{et al.}, 2006). Vaillant \textit{et al.} (2005) affirmed that in Nicaragua, well-managed crops can produce up to 26 t ha\(^{-1}\), Bastos \textit{et al.} (2006) has reported, in Brazil, an average yield of 14 t ha\(^{-1}\) and according to Nguyen \textit{et al.} (2015) the yield of fruit of pitaya averages 22-35 t ha\(^{-1}\), in Vietnam.

**PHYSIOLOGICAL MATURITY OF FRUITS OF PITAYA**

The fruits go through a series of transformations during their development process. Fruit ripening is a complex and genetically programmed process, resulting in changes in its color, aroma, texture and taste, which are important in its acceptance for consumption. However, it is necessary to determine the point of harvest, considering that its lack of characterization constitutes an important cause of post-harvest loss in fruits and vegetables crops. Reduction of post-harvest losses and quality deterioration are essential in increasing food availability from the existing production. Minimizing this loss has a great significance for food security, economic growth and welfare of the society (Ayub \textit{et al.}, 1996; Kasso and Bekele, 2018).

In the pitaya crop, the annual flowering period is related to the cultivation region, because it is a species dependent on photoperiod, characterized as long days (Nerd \textit{et al.}, 2002b; Luders and McMahon, 2006). However, it is important to determine the period in which the fruits reach the physiological maturity, aiming to optimize the harvest and obtain quality product; considering that the edaphoclimatic conditions may have influence during the development of the fruits.

Due to the importance of determining the appropriate phase for fruit harvest, it is necessary to evaluate its pattern of growth and development from flowering. This procedure assists in the establishment of maturation indices, based on both environmental and varietal variations, as well as being practical, so that it can be used efficiently by producers (Cavalini, 2004).

In order to obtain the harvest at the correct moment, it is essential to determine the physiological maturity stage of the fruit, and it can be identified by physical parameters such as longitudinal length, equatorial diameter, mass, shape, color and firmness; and/or chemicals, from the soluble solids content, titratable acidity, pH, among others. However, one of the criteria most used in
determining the harvest point is the number of days of the anthesis until the full development of the fruit (Warrington et al., 1999; Lemos et al., 2018).

The determination of the physiological maturity phase based solely on fruit appearance is empirical, as it is a subjective measure, subject to variations and errors. In this sense, the maturation stages of some species are defined by the pericarp color, being used by the consumer to judge the maturity (Kays, 1991; Cavalini, 2004).

According to Thé et al. (2001), the pericarp color is closely related to fruit maturation and climatic conditions during the growing period. Color is considered an important parameter for producers and consumers, as it indicates whether or not the fruit has the ideal conditions for commercialization and consumption. However, color in most cases does not contribute to an effective increase in the nutritional value or quality of the product (Chitarra and Chitarra, 2005), but, in general, consumers prefer fruit of bright and strong color.

The occurrence of the first change in the pericarp color of *H. undatus* has been mentioned in the literature between 24-29 days after anthesis (DAA); becoming completely red between 2 and 5 d after the first color change (Castillo-Martínez and Ortíz-Hernández, 1994; Nerd et al., 1999; Centurión Yah et al., 2008; Ortiz and Takahashi, 2015). Centurión Yah et al. (2008); Ortiz and Takahashi (2015) obtained completely red fruits at 31 and 30 DAA, respectively.

Previously unpublished images obtained from studies by Ortiz and Takahashi (2015) are present in this literature review to make this study even more instructive and illustrative (Fig. 1).

Figure 1. Transition externally in the coloring of the pericarp of pitaya fruits.
According to the progress of the maturation of pitaya fruits, studies have observed a reduction of the hue color angle ($h^\circ$), that is, the fruits passed from green to red coloration when they reach the physiological maturity (Centurión Yah et al., 2008; Ortiz and Takahashi, 2015). Conforme Van To et al. (2002), the range of $h^\circ$ in pitaya fruit suitable for marketing must be equal to or less than 30°. Osuna Enciso et al. (2011) obtained completely mature fruits with values below 30°.

According to Wybraniec and Mizrahi (2002); Le Bellec et al. (2006), the red coloration of the fruit pericarp of *Hylocereus* spp. is due to the pigments of the group of betacyanins, whose synthesis is activated by high availability of sugars and light, among other factors (Castellar et al., 2003). Phebe et al. (2009) found a significant negative correlation between hue color angle values and the total content of the betacyanins of the *H. polyrhizus* pericarp, with a drastic increase of 90% in betacyanins between 25 and 30 DAA.

Another important characteristic to take into consideration in pitaya fruits is the luminosity, since the contrasts in luminosity allow to dispose the fruits in a more attractive presentation. Thus, the lightness index ($L^*$) has been evaluated in studies carried out in order to determine the time at which the pitaya fruits reach the physiological maturity (Ortiz and Takahashi, 2015).

Centurión Yah et al. (2008) did not obtain significant differences when analyzing the lightness index during the development of *H. undatus* fruits. However, Ortiz and Takahashi (2015) observed that the $L^*$ decreased in fruits of this same species, which is not to say that the fruits became less attractive, however, they verified that the chroma ($C^*$) increased with the progress of maturation, indicating that the pericarp color became more intense, which would possibly increase its acceptance by consumers.

According to Tucker (1993), Chitarra and Chitarra (2005) and Silva et al. (2019), the reduction of the green of the fruit pericarp is a process of color change, which, in addition to allowing the appearance of the typical color of the analyzed species, is indicative of the maturation stage of fruits and the harvest point. Therefore, the evolution of coloring of pitaya fruits from 21° to 32° DAA, through the external and internal fruit pericarp (Fig. 1 and 2); being possible to observe the reduction of the green of the pericarp and the beginning of the appearance of the typical coloration of this species from the 28th DAA, becoming completely red at 30 DAA.
In addition to color, the fruit size variable is also used to define fruit maturation stages (Ortiz and Takahashi, 2015; Almanza-Merchan et al., 2016; Chacón-Padilla and Monge-Pérez, 2016). Ortiz and Takahashi (2015) did not find a significant difference in the longitudinal length during the evolution of the maturation of pitaya fruits from 21st to 32nd DAA, which ranged from 10.6 to 11.7 cm. However, Centurión Yah et al. (2008) obtained an increase of this with the proximity to the physiological maturity, obtaining fruits with longitudinal length of 8.9 cm, at 31 DAA; Osuna Enciso et al. (2007) reported fruits of this same species with a mean longitudinal length of 14.3 cm.

The equatorial diameter of fruits has also been reported in the literature in pitaya, with continuous increase as the physiological maturity advances; obtaining mature fruits between 7.9 and 8.2 cm (Osuna Enciso et al., 2007; Ortiz and Takahashi, 2015; Centurión Yah et al., 2008). Martínez (2011) observed Hylocereus spp. fruits with an equatorial diameter varying from 5.2 to 7.8 cm.

Other characteristics were studied and reported in the literature during the evolution of the maturation of pitaya fruits, among them the pericarp and pulp thickness. According to Ortiz and Takahashi (2015), the pericarp and pulp thickness presented decreasing and increasing tendency, respectively, from the 21st to the 32nd DAA. They observed, during this period, that the pericarp thickness reduced from 1.06 to 0.17 cm and the pulp thickness increased from 4.60 to 7.17 cm (Fig. 2). Martínez (2011), when evaluating six genotypes of pitaya, obtained materials with a pericarp
thickness from 0.22 to 0.42 cm and Castillo-Martínez et al. (2005), thicknesses from 0.26 to 0.37 cm, when studying five genotypes of *H. undatus*.

Fruit, pulp and pericarp mass have been considered when determining the physiological maturity point of pitaya fruits. In this sense, Ortiz and Takahashi (2015) observed that the fruit and pulp mass showed a tendency increasing from 21º to 32º DAA, varying from 293.1 to 416.2 g and from 87.6 to 253.3 g, respectively. Centurión Yah et al. (2008) observed the same trend, stating fruit and pulp mass of 469.2 g and 368.9 g at 31 DAA, respectively.

Osuna Enciso et al. (2007) reported average fruit mass of 442.0 g and Nerd et al. (1999) of 437.5 g. Castillo-Martínez et al. (2003); Osuna Enciso et al. (2007) and Castillo-Martínez et al. (2005) observed pitaya fruits with pulp mass of 188.4 g, 297.8 g and from 139.6 to 320.1 g, when working with five *H. undatus* genotypes, respectively. In relation to the pericarp mass, Centurión Yah et al. (2008); Ortiz and Takahashi (2015) reported decreasing trends during the days after anthesis. The authors conclude that with the advance of the maturation of pitaya fruits, the pericarp mass tends to decrease and the pulp mass to increase, what is desired by the consumers. Castillo-Martínez et al. (2005) and Martínez (2011), working with different *H. undatus* genotypes, obtained fruits with a pericarp mass from 72.4 to 120.5 g and from 57.9 to 140.6 g, respectively, being possible to observe that there is variability within the species.

The progression of pericarp and pulp percentage of pitaya fruits during their maturation has also been studied and Ortiz and Takahashi (2015) noted that from the 21st to the 32nd DAA the pericarp percentage of the fruits decreased from 71.3 to 34.0%, and in reverse order, there was an increase in the pulp percentage from 28.7 to 66.0%. It is favorable and expected, considering that the pulp is the edible portion of the fruit.

Castillo-Martínez et al. (2005) reported fruits of *H. undatus* with 73.0% of pulp and Osuna Enciso et al. (2007), at 31 DAA, with 79.0%. Martínez (2011), working with six genotypes of pitaya, evaluated materials from 40.5 to 80.6%, and it is possible to observe that there is intraspecific variation regarding this variable. As for the pericarp, Centurión Yah et al. (2008) reached ripe pitaya fruits with 20.4% of pericarp, and Nerd et al. (1999), with 32.5%.

Thus, Ortiz and Takahashi (2015) observed that the pulp/pericarp ratio showed a tendency to increase throughout the harvest from 0.40 at 21 DAA to 1.98 at 32 DAA, due to the increase in
pulp mass and the decline of pericarp mass. Centurión Yah et al. (2008) observed increased in the pulp/pericarp ratio from 1.5 to 3.9 from 25th to 31st DAA.

In addition to the physical transformations during fruit maturation, several biochemical transformations also occur, among them the increase of soluble solids and the reduction of the titratable acidity. According to Gross et al. (2016), there is a relation between both variables and the maturation stage of the fruit.

It is known that the soluble solids content is dependent on the maturation stage, and generally increases during maturation evolution by biosynthesis or degradation of polysaccharides (Chitarra and Chitarra, 2005). In this sense, some authors evaluated the soluble solids content in pitaya fruits and observed an increase of this variable with the advancement of maturation, obtaining ripe fruits with 12.2 °Brix (Ortiz and Takahashi, 2015) and 13.6 °Brix (Osuna Enciso et al., 2011). Other authors when evaluating different genetic materials of pitaya, reported values from 10.9 to 14.1 °Brix (Castillo-Martínez et al., 2005), 14.5 to 17.6 °Brix (Martínez, 2011), 12.0 to 16.0 °Brix (Livera-Muñoz et al., 2010) and 16.0 to 17.0 °Brix (Nerd et al., 1999). Centurión Yah et al. (2008), working with H. undatus, observed a close relationship between color development and soluble solids increment, where fruits with 20 d of development recorded 4.6 °Brix, while at 31 d they reached 12.6 °Brix.

An important aspect that has an effect on the concentration of soluble solids in the pulp is the exposure of the fruit to light during growth, as it activates the formation of pigments responsible for the coloring of the red pericarp, compounds of the group of the betacyanins and the sugars present in the pulp (Castellar et al., 2003; Esquivel et al., 2007b).

For Centurión Yah et al. (2008), the taste of the pitaya fruit ranged from bittersweet to sweet between 27 and 31 DAA and the highest fruit acceptance was between 29 and 31 DAA. According to Nerd et al. (1999), the accumulation of sugars during the maturation of the pitaya fruits is related to a decrease in the content of starch and mucilages of the pulp; there is no contribution of metabolism of the pericarp, as occurs in fruits of Opuntia ficus-indica (L.) Miller (De La Barrera and Nobel, 2004).

The titratable acidity is another chemical variable used in the evaluation of the physiological maturity of pitaya fruits, as well as Osuna Enciso et al. (2011); Ortiz and Takahashi (2015), which
reported ripe fruits with acidity of 0.63 and 0.27%, respectively. According to Centurión Yah et al. (1999), fruits with titratable acidity of 0.24% present acceptable flavor by consumers.

Several other authors, evaluating the fruit acidity of *Hylocereus* spp., reported different values, such as 0.24% (Centurión Yah et al., 1999), 0.30% (Sornyatha and Anprung, 2009), 0.36% Arévalo-Galarza and Ortíz-Hernández, 2004), 0.40% (Centurión Yah et al., 2008) and between 0.30 and 0.60%, studying six genotypes (Martínez, 2011).

In fruits of *H. undatus* and *H. polyrhizus*, Nerd et al. (1999) found that the acidity was higher in color-changing fruits than in fruits with advanced coloring, such as Ortiz and Takahashi (2015) in *H. undatus*. According to Arévalo-Galarza and Ortíz-Hernández (2004), the increase of acidity before the change of color shows the beginning of the maturation processes. In addition, the reduction of acidity is a problem in the pitaya pulp, since this indicator does not detect the sweetness of the fruit.

Conforming to Thé et al. (2001) and Cavalini (2004), the ratio provides an indicative of the fruit flavor, as it relates the amount of sugars and acids present. This relationship tends to increase during maturation, due to the increase of sugars and the decrease of acids, evidencing the conditions of harvest, storage and immediate consumption.

However, Chitarra and Chitarra (2005) recommend caution in establishing this relationship, because insipid fruits, containing low levels of soluble solids and acids, present high ratio, which can lead to erroneous interpretations of quality. As reported by Osuna Enciso et al. (2011), the increase in the ratio of pitaya fruits is due to the drastic reduction of the titratable acidity, not being an indicator of quality, since the soluble solids do not increase. Martínez (2011) and Centurión Yah et al. (2008) also observed that the increase in the ratio was due to the decrease in acidity. However, Ortiz and Takahashi (2015) found that in addition to the titratable acidity reduction, the increase in soluble solids content also contributed to the increase in the ratio of *H. undatus* fruits.

For Van To et al. (2002), the best indicator of flavor in pitaya is the ratio, whose ideal value is around 40. Ratio higher than recommended by these authors were reported by Ortiz and Takahashi (2015), who obtained ripe fruits with a ratio of 55.5 at 32 DAA. However, Centurión Yah et al. (2008) obtained fruits with a ratio of 35.5 at 31 DAA. Martínez (2011), when evaluating six genotypes of pitaya, obtaining materials with a ratio ranging from 33.1 to 48.6.
In relation to pH, Esquivel et al. (2007b) reported pitaya fruits (*Hylocereus* spp.) with pH between 4.2 and 4.9 and Stintzing and Carle (2006) between 4.3 and 4.7. Similar value was cited by Ortiz and Takahashi (2015) in fruits considered mature (32 DAA), with average pH of 4.6. However, Cálix de Dios and Castillo-Martínez (2008) reported a pH of 1.7 in *H. undatus* subspecies *luteocarpus*.

It is known that some aspects are important at the time of harvesting of pitaya fruits, such as the pericarp color, which is considered determinant, in addition to soluble solids content and ratio. However, the number of days of the anthesis to full fruit development has been considered one of the criteria most used in determining the harvest point (Nerd et al., 1999; Warrington et al., 1999).

Centurión Yah et al. (2008) observed that the physiological maturity of pitaya fruits (*H. undatus*) in Yucatán-Mexico occurred between 25th and 31st DAA, because in this period the color of the pericarp varied from light green mixed with incipient red tones, until purple red, on all its surface. These authors also observed that at 31 DAA, growth was still active, although this age was considered harvest limit, in order to avoid cracking of the pericarp. During the evolution of the maturation, there was accumulation of the edible portion of the fruit and increases in the content of reducing sugars, soluble solids and ratio, however, firmness and acidity reduced. However, the authors concluded that there was a perception of the variation of flavor from bittersweet to sweet, with the fruits harvested between the 29th and 31st DAA the most accepted by the consumers.

Castillo-Martínez and Ortíz-Hernández (1994) observed that the development period of the *H. undatus* fruits, in Oaxaca-Mexico, occurs from May to September, with physiological maturity from 31st to 41st DAA. For these, the onset of the maturation of pitaya fruits is characterized by the color change of the pericarp, between 24th and 25th DAA; being that the maturation comprises from the first manifestation of red coloration in the pericarp until the appearance of a brindle color brown. However, as the latter state leads to the loss of the commercial value of the fruit, the authors considered that the useful harvest stage occurs from the 25th to the 31st DAA. Similar periods in relation to the stage in which the fruits of this species reach the physiological maturity were obtained by other authors, such as from 28th to 30th DAA (Van To et al., 2002) and from 25th to 31st DAA (Martínez, 2011).

Nerd et al. (1999) reported that, in *H. undatus* fruits, the onset of color change also occurs from 24th to 25th DAA, and after 4 to 5 d, they become completely red, confirming that the development
of the pericarp color is related with the soluble solids content. Van To et al. (2002) state that the fruit of *H. undatus* must be harvested when they acquire the red color, in addition to suggesting that the best indicator of the pitaya flavor is the ratio, whose ideal value is close to 40.

Ortiz and Takahashi (2015) verified that the physical and chemical characteristics evaluated were influenced by the maturation of pitaya fruits, with the exception of the longitudinal length. Thus, they concluded that the *H. undatus* fruits, in Paraná-Brazil, reached the physiological maturity between the 30th and 32nd DAA, proving that this is the ideal period for harvesting the fruits; since in this period the fruits have become completely red, in addition to having reached fruits with soluble solids content, titratable acidity, pH and ratio recommended and characteristic for the species under study.

As can be seen, many characteristics are important and essential in the designation of the ideal period for harvesting the pitaya fruits. Therefore, determining the physiological maturity of the fruits is necessary in order to optimize the harvest and quality of the final product. According to Cavalini (2004), using more than one variable to characterize a maturity stage allows greater precision when classifying fruits in their stages.

**CONCLUSIONS**

For the pitaya, the number of days of the anthesis until the full development of the fruit has shown to be the most reliable variable to determine the time of harvest. From this designation, it is possible to indicate the phase (physiological maturity) in which the fruits present characteristics favorable to the species under study, such as color, soluble solids content, ratio, among others; making it possible to obtain a product with quality and acceptability by consumers.

It is known that the place of production and the edaphoclimatic conditions are able to interfere and cause variation in the period in which the fruits reach the physiological maturity. In this way, from the studies carried out in this area, the majority have recommended to harvest the fruits between the 25th and 32nd days after the anthesis; with the purpose of avoiding the loss of its commercial value.

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