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ORIGINAL RESEARCH ARTICLE

Physiological changes of pitayo fruit (*Stenocereus thurberi*) before and after harvest in Sonoran Desert

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ABSTRACT

Open pitaya (*Stenocereus thurberi*) flowers were marked at 10, 20, 30 and 40 days after floration (DAF). When fruit were formed, they were collected from each of the dates with the objective of evaluating physical, physiological and quality changes before and after harvest. In fruits with different DAF, the analyses of fruit size (diameter and length), weight, density, firmness, color in pulp and peel (L*, a* and b*), respiration rate (CO_2) and ethylene production were carried out. In the case of ripe and overripe fruit, in addition to the variables mentioned above, pH, percentage of total soluble solids TSS and total acidity (% citric acid equivalents) were evaluated. Fruit with 40 DAF were stored for up to 14 days at 25 °C and 80% RH to evaluate daily changes in respiration rate and ethylene production. It was found that during development the fruit tended to grow more in length than in diameter. In color, the best indicators of changes during fruit development were the parameters L* and b* for peel and for flesh L* and a*. For firmness in pitaya fruits, no significant differences were found with the methodology used. Changes in ethylene production and respiration rate during storage and development showed the usual behavior of climacteric fruits. Pitaya fruits with 40 FDD presented quality characteristics similar to those accepted by the consumer for this type of fruit. It is concluded that it is possible to evaluate the different stages of development in DDF of pitaya fruit based on the changes of the color space variables L*, a* and b*, in addition to the fact that the fruit follows the classical climacteric behavior.

Keywords: Pitaya; Fruit; Physiology; Quality; Climacteric

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1. Introduction

In Mexico, the export of exotic fruits, including pitaya, is becoming increasingly important due to its high cost in European and Asian markets[1]. No studies were found that estimate the productive potential of this species in the Sonoran Desert. However, in the state of Oaxaca, where there are up to 11 different varieties of pitaya *(Stenocereus griseus* (Haw.) Buxb), a productivity of 13.8 t per hectare has been reported[2]. In addition, it has been estimated that an adult plant of certain *Stenocereus* species can maintain commercial production for more than 100 years[3]. If to the above mentioned, we add that pitaya is distributed in most of the state of Sonora[4], we can conclude that there is an important unexploited commercial potential in Sonoran pitaya. Ojeda and Barrera[5] subjectively defined four stages of pitaya fruit development according to the approximate flowering time from four zones of the Sonoran Desert. During fruit development, they found an increase in size, weight, pH, TSS and a decrease in titratable acidity. Analysis of CO_2 and ethylene production did not confirm a climacteric fruit pattern. In addition, the results of ash, moisture, protein and crude fiber analysis in seeds did not show changes for the four stages of development in the four sampling zones. Muy[6] also studied pitaya from a region located northeast of Hermosillo, Sonora. In his experiment, he marked open flowers (**Figure 1**) taking into account the period of fruit development in days after flowering (DAF). Based on the parameters evaluated, the fruit showed a double sigmoid growth and a climacteric respiration pattern. The main pigments identified were betalains and betaxanthins, initially observed in fruits at 40 DAF, which increased in concentration as pitaya development progressed. While β-carotene was only identified in fruits with 40 DAF. In contrast to what was obtained by Ojeda and Barrera[5], Muy found a decrease in pH and an increase in titratable acidity. Cruz[7] concluded that the fruit of *Stenocereus stellatus*, a species related to *S. thurberi*, showed a non-climacteric respiration pattern, in opposition to that reported by Muy[6]. Due to the contradictions in the literature on the physiology of fruit development and its potential commercial importance, the general objective of the present work is to study the physiology of *Stenocereus thurberi* fruit development in the Sonoran Desert area where this fruit continues to be harvested.

Figure 1. Pitaya with fruit and flower. Photo 2: Ad Konings Available from: https://www.naturalista.mx/photos/85349568.

2. Materials and methods

2.1 Raw materials

Open flowers of *Stenocereus thurberi* that showed no signs of senescence were labeled in an area of approximately 3 km^2 located 40 km north of the city of Hermosillo, Sonora, Mexico.

2.2 Sampling

At least 10 fruits were harvested at random from different individuals of *S. thurberi* after 10, 20, 30 and 40 days after flowering (DAF). In addition, ripe fruit (abscission of spines, turgor in the peel, rounded shape (diameter/length >1), showing no breaks in the peel, according to Muy[6], and overripe (with clear signs of maturity and exposed areas of the flesh) were harvested (**Figure 2**). The fruits were immediately transferred to the laboratory for analysis in a container containing ice, in order to reduce the effect of field heat on respiration and for transport time.

Figure 2. Pitaya overripe, open and ripe closed fruit. Photo 1: Southwest wanderer. Available from: https://www.naturalista.mx/photos/6161091. Photo 2. https://sonorasilvestre.com/pages/pitaya.

2.3 Evaluation of quality parameters

The variables analyzed in this study were firmness, which was determined at two opposite points in the middle part of the fruit in areas where the peel and thorns had been previously removed. For this purpose, a blunt-tipped punch was used in a Chatillon (kgf) machine. Weight (g), density (g·mL^{-1}), equatorial diameter and polar diameter were also recorded. For skin color, thorns were removed and measured three times in two different areas of the fruit. For flesh color, the fruit was cut into two parts for duplicate measurements (parameters L*, a* and b*; MINOLTA Chroma Meter CR-300). The variables pH, TSS and total titratable acidity, especially in the early stages of pitaya development, required adaptation for sampling. The pulp was placed on a porous cloth inside a 50 mL centrifuge tube, fixing the cloth with the stopper so that there was a space between the cloth and the bottom of the tube. The tube with the pulp was centrifuged at low speed for 10 min to obtain the juice without the interference of seeds or parts of the pulp itself. TSS were measured in an Abbe refractometer (%) using a few drops of the juice, while pH and total titratable acidity (% citric acid) were measured with an automatic titrator (Mettler DL21).

2.4 Respiration and production of ethylene (C_2H_4)

Six fruits from each sampling were used for the evaluation of these metabolic gases. Each fruit was placed in a closed system for 15 min to 1 h depending on its stage of development. Subsequently, 1 mL of the headspace of the container was injected into a VARIAN gas chromatograph (Star 3400) fitted with a Hayesep N 80/100 Mesh column and equipped with flame ionization and thermal conductivity detectors. Results were expressed as mL CO2 kg·h^{-1} and μL C_2H_4 kg·h^{-1}. For the observation of the climacteric peak, ten fruits of 40 DAF were stored for 14 days in a chamber at 25 °C and 80% RH, evaluating these gases daily.

2.5 Analysis of results

A completely randomized sampling design was used where the experimental units were randomly marked and harvested fruits from different individuals. The data were analyzed considering the DAF variable as treatment, using analysis of variance with an error level of 5%. Tukey's multiple range test was used to find differences between means using the SAS statistical package (Statistical Analysis System. SAS Institute Inc., Cary, N.C.).

3. Results

3.1 Quality parameters

Variations in firmness, weight, fruit size (equatorial and polar diameters), as well as skin and flesh color at different DDF are shown in **Table 1**. The firmness parameter is directly related to fruit maturity, especially the pulp which becomes softer as the sugars are split[8]. However, this was not reflected by the instrument used. Judging from the standard deviation of the data, good results were obtained, but the method was not sensitive to changes related to fruit physiology. Compression could be useful for this type of fruit, although thinner punches could also be used. Perhaps an aspect to be rescued would be the variation of the results, which was greater in those of 40 DAF. As for weight, the polar and equatorial diameter of pitaya showed an increase as the DAF increased. Weight increased slightly more than 2 times from day 10 to 20 DAF, but only increased 1.13 times for the following dates, which did not represent a statistical difference. The weight found in this study for all stages of fruit development is lower than that reported by Ojeda and Barrera[5] and Muy[6]. The latter study reports weight variations from 13.7 g for fruit at 10 DAF to 36.82 g for fruit at 40 DAF. There are many reasons that could have influenced the weights found in this experiment, from the amount of rainfall received during fruit formation to the fact that the *S. thurberi* population studied is completely wild. For example, Cruz[9] reported weight values from 178 to 419 g for different cultivars of *Stenocereusspp,* although in already improved populations. On the other hand, equatorial diameter increased equally at 20 DAF, but significantly more at 40 DAF. While polar diameter, despite having resulted greater ($p \leq 0.05$) than at 10 DDF, its trend was not clear. The size changes evaluated in this study imply a faster increase in length than in diameter. The same behavior was found by Muy[6], where the diameter/length ratio ranged from 0.92 to 0.95 cm for fruits at 10 and 40 DAF. Fruit density decreased as pitaya ripening progressed. Thus, for 10 DAF the density was 1.33 g·mL^{-1} ± 0.019; for 20 DAF 1.04 g·mL^{-1} ± 0.165; for 30 DAF 1.007 g·mL^{-1} ± 0.026 and for 40 DAF it was 0.94 g·mL^{-1} ± 0.056. This is to be expected as parenchymatous tissue increases. In some *Stenocereus* species, as the fruit grows, the percentage of thick peel decreases, while the percentage of pulp increases[6,7]. It was also observed that fruits with 10 and 20 DAF sank in water, those with 30 DAF remained fluidized and those with 40 DAF floated in water. This implies that this behavior of the fruits in water could be used to determine their stage of development.

Regarding color, it was expected that lightness would decrease in the peel, as the fruit became darker due to maturity, which indeed happened. At 40 DAF there was a 1.2-fold reduction in L*, while in pulp it was 2.2-fold, since there was an important change from green to red. In other fruits, the increase in L* is associated with turgor, since the greater the lushness, the higher the brightness value. Likewise, the parameters a* and b* decreased in peel from 10 DAF to 40 DAF by 3.2 times for a* and 1.7 times for b* with significant differences. The colorimetric method perceived more loss of green color of peel in the value of a*, with slight changes to yellow in b*. In pulp the relevant change was in the a* parameter by increasing 6.3 times ($p \leq 0.05$) at 40 DAF, although in the b* value there were also significant differences, it was not entirely clear the behavior (1.5 times less at 40 DAF). The fruit flesh changes from white to pink at the beginning of development and with absence of black seeds. Subsequently, the flesh reaches dark red colors and black seeds towards the end of development. At intermediate ripening stages, brown seeds and pink to red flesh were observed. Thus, the parameter a* tends to positive values for fruits close to senescence, so this could be a valuable indicator of ripening progress.

Table 1. Quality variables and physical characteristics of pitaya fruit peel and pulp harvested at different days after flowering (DAF)

DDF	Firmness (kgf)	Weight (g)	Diameter(cm)		In-shell color			Pulp color		
			Equator	Polar	L*	a*	b*	L*	a*	b*
10	6.66[as] ± 1.75	8.096[a] ± 1.74	2.86[a] ± 0.34	2.75[a] ± 0.19	45.171[a] ± 1.95	-8.88[a] ±1.98	24.59[a] ± 2.94	74.62[a] ± 1.72	2.01[a] ± 0.25	17.33[a] ± 1.16
20	6.27[a] ± 0.92	16.60[b] ± 5.67	3.47[a] ± 0.45	3.73b ± 0.45	51.84[b] ± 3.54	-6.14[a] ± 3.62	20.58b ± 4.54	81.19[b] ± 2.78	1.96[a] ± 1.06	21.51[b] ± 2.57
30	631[a] ± 1.35	18.87[b] ± 8.70	3.41[a] ± 0.63	3.70b ± 0.71	43.34[a] ± 2.93	-5.41[a] ± 2.87	17.31[c] ± 3.57	42.69[c] ± 1044	2.96[a] ± 4.57	6.49[c] ± 4.07
40	7.44[a] ± 2.29	18.08[b] ± 6.95	5.86[b] ± 7.72	3.25[c] ± 0.44	37.41c ± 11.75	-2.75[b] ± 13.7	14.67[d] ± 6.70	33.81[d] ± 11.22	12.58[b] ± 10.15	11.78[d] ± 7.19

*: means with different superscript in each column are different ($p \leq 0.5$). Standard deviation (±).

As for the samples at 10, 20 and 30 DAF, it was not possible to obtain enough juice to perform the analyses shown in **Table 2**. In mature pitaya without knowing the DAF the pH was higher (6.9) than that reported by Muy Rangel[6] and Cruz[7] of 4.3 and 4.6 respectively (**Table 2**). In pitaya S. pruinosus the pH was 5.8[10] and in S. griseus 5.2[1]. less acidic pH favor consumer preference[11].

Table 2. Comparison of pH, TSS and total acidity between pitaya fruit with 40 overripe DDF and fruit harvested unmarked at ripe and overripe stages

Pitaya	40 FDD			Unmarked Fruit		
	pH*	% SST	%Ac. Citric	PH	% SST	%Ac. Citric
Mature	-	-	-	6.94 ± 0.5	13.77 ± 1.31[a]	0.14 + 0.1[a]
Overripe	7.57 ± 0.78[b]	16.03 ± 1.3[b]	0.097 ± 0.1[b]	7.34 ± 0.69[b]	16.56 ± 4.21[b]	0.11 ± 0.16[b]

*: values with different superscript are statistically different. Mean and standard deviation (±).

This is in addition to the fact that 13.77% TSS was found in ripe fruits, similar to that reported by Ojeda and Barrera[5] with 14.4%. Arnaud *et al.*[12] and Armella *et al.*[13], mention that when the fruit reaches 13.0%, it is ready to be harvested. It has been proposed that acidity is related to fruit maturity; therefore, acidity is also used as a quality or harvest indicator[14]. Stintzing *et al.*[15], suggest that a sugar: acid ratio between 10:1 and 18:1 is indicative of good flavor and acceptability of a fruit. In this experiment, the 0.14% citric acid in ripe pitaya was similar to that found by Ojeda and Barrera[5] with 0.19%. However, other researchers reported values between 0.61 and 0.64%[6,16]. Acids generally decreased towards the end of storage, possibly due to their use as respiratory substrates during ripening[18]. The results show similarity between overripe fruit at 40 DAF and fruit with no record of DAF, which were different ($p \leq 0.05$) with respect to ripe fruit with no record of DAF.

3.2 Respiration and production of ethylene (C_2H_4)

In the rate of respiration and ethylene production of pitaya, a direct relationship was observed with the developmental stages monitored (**Table 3**). At 10 DAF, within the early developmental stage, CO_2 levels were low (0.036 kg·h^{-1}), increased about 10-fold (0.371 kg·h^{-1}) at 30 DAF to slightly decrease again by 2.2-fold (0.164 kg·h^{-1}). The general pattern of a non-climacteric fruit, especially at the ripening stage close to senescence (“ripening”, does not show significant changes in both respiration and ethylene, being generally low values[18]. On the one hand, although CO_2 levels during sampling did not reach even mL·kg·h^{-1}, changes were manifest. But, on the other hand, this difference could also be explained by the coincidence, at a given time, of several developmental stages in the same plant: mature fruits, fruits with 12 to 20 days of development, flowers about to open, flowers with two days after fluoridation and newly initiated flower buds[19]. Also, the variation of ethylene in pitaya indicates a pattern different from the non-climacteric pattern. There was a decrease of almost half at 20 DAF compared to 10 DAF, ending with almost 10 times more ethylene at 40 DAF. However, at this last date there was a high variation in the results. For his part, Rodríguez-Irepan *et al.*[20], identified a gene for the ACC oxidase enzyme (an enzyme involved in ethylene synthesis) in pitaya *S. stellatus* during the ripening stage.

Table 3. Respiration values and ethylene production in pitaya fruits harvested at different days after flowering (DAF)

DAF	Respiration rate (mL CO_2 kg·h^{-1})	Ethylene production (µL C_2H_4 kg·h^{-1})
10	0.036 ± 0.007^{a}*	0.826 ± 2.190^{a}
20	0.229 ± 0.080^{c}	$0.446 + 0.210^{a}$
30	0.371 ± 0.079^{d}	-
40	$0.164 + 0.024^{b}$	$7.908 + 17.55^{a}$

*: means with different superscript in each column are different ($p \leq 0.5$). Standard deviation (±). Not detected (-).

The postharvest evaluation of pitaya at 40 DAF showed a possible behavior of a climacteric fruit (**Figure 3**). Respiration rate increased from 0.15 mL CO_2 kg·h^{-1} on day 1 of storage at 25 °C to a maximum of 0.3 mL CO_2 kg·h^{-1} after 5 days. Then the values decreased close to 0.05 mL CO_2 kg·h^{-1} by day 14.

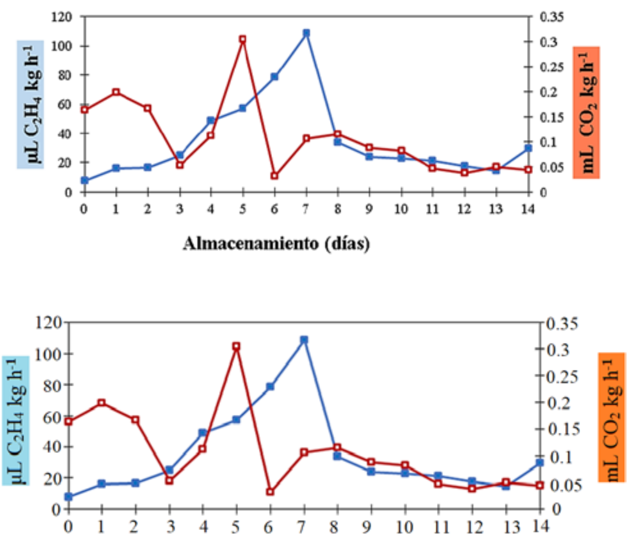

Figure 3. Respiration rate (mL CO_2 kg·h^{-1}) and ethylene production (µL C_2H_4 kg·h^{-1}) in pitaya with 40 DAF stored for 14 days at 25 °C and 80% RH. n = 10.

Ethylene production started with an average of 20 µL C_2H_4 kg·h^{-1} and for the following days of storage at 25 °C the production reached a maximum at 7 days (110 µL C_2H_4 kg·h^{-1}). The production of this gas decreased to reach approximately 30 µL C_2H_4 kg·h^{-1} by day 14. This behavior is very similar to that found by Muy[6] and Ojeda and Barrera[5]. In these works, the maximum ethylene production occurred at 6 and 4 days of storage, respectively. This difference in the delay of the appearance of the ethylene maximum in our study could explain the low values in weight, and the other quality variables analyzed. The results of the present study reinforce that the behavior of pitaya corresponds to a climacteric pattern.

4. Conclusions

In general, there are large variations in the values reported for the parameters of weight, diameter, pH, titratable acidity and TSS for ripe *Stenocereus* spp. fruits.

S. thurberi fruits at 40 DAF show a climacteric pattern of ripening based on respiration rate and ethylene production recorded during storage at 25 °C and 80% RH for 14 days.

Both the behavior of fruits in water and the color parameters L* and b* in peel, and L* and a* for pulp are good indicators of the ripening progress of *S. thurberi* fruits.

Conflict of interest

The authors declare that they have no conflict of interest.

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