**ABSTRACT**

Open pitaya (*Stenocereus thurberi*) flowers were marked at 10, 20, 30 and 40 days after flowering (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 (CO2) 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
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 km² 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.


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 (C₂H₄)

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
VARIANT gas chromatograph (Star 3400) fitted with
a Hayesep N 80/100 Mesh column and equipped
with flame ionization and thermal conductivity de-
tectors. Results were expressed as mL CO₂ kg⁻¹·h⁻¹
and μL C₂H₄ kg⁻¹·h⁻¹. For the observation of the cli-
maacteric peak, ten fruits of 40 DAF were stored for
14 days in a chamber at 25 °C and 80% RH, evaluat-
ing 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 individu-
als. 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.

3. Results

3.1 Quality parameters

Variations in firmness, weight, fruit size (equa-
torial 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 ma-
turity, especially the pulp which becomes softer as
the sugars are split[8]. However, this was not re-
lected 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 in-
fluenced 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 culti-
vars of Stenocereusspp, although in already im-
proved populations. On the other hand, equatorial di-
ameter increased equally at 20 DAF, but significantly
more at 40 DAF. While polar diameter, despite hav-
ing resulted greater (p ≤ 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 in-
creases. 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 ob-
erved 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)

<table>
<thead>
<tr>
<th>DDF</th>
<th>Firmness (kgf)</th>
<th>Weight (g)</th>
<th>Diameter (cm)</th>
<th>In-shell color</th>
<th>Pulp color</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Equator</td>
<td>Polar</td>
<td>$L^*$</td>
<td>$a^*$</td>
<td>$b^*$</td>
</tr>
<tr>
<td>10</td>
<td>6.66 ± 1.75</td>
<td>8.09 ± 2.86</td>
<td>2.75 ± 1.74</td>
<td>45.17 ± 8.88</td>
<td>24.59 ± 74.62</td>
</tr>
<tr>
<td>1.74</td>
<td>0.34 ± 0.19</td>
<td>1.95 ± 1.19</td>
<td>2.94 ± 1.72</td>
<td>2.05 ± 0.25</td>
<td>2.78 ± 1.06</td>
</tr>
<tr>
<td>20</td>
<td>6.27 ± 0.92</td>
<td>16.60 ± 4.05</td>
<td>3.73 ± 3.54</td>
<td>51.84 ± 6.14</td>
<td>20.58 ± 81.19</td>
</tr>
<tr>
<td>5.67</td>
<td>0.45 ± 0.45</td>
<td>3.62 ± 4.54</td>
<td>5.67 ± 2.78</td>
<td>27.88 ± 1.06</td>
<td>2.78 ± 2.06</td>
</tr>
<tr>
<td>30</td>
<td>631 ± 1.35</td>
<td>18.87 ± 3.41</td>
<td>3.70 ± 3.54</td>
<td>43.34 ± 6.41</td>
<td>17.31 ± 42.69</td>
</tr>
<tr>
<td>8.70</td>
<td>0.63 ± 0.71</td>
<td>2.93 ± 2.87</td>
<td>3.57 ± 4.57</td>
<td>10.44 ± 4.57</td>
<td>4.57 ± 4.07</td>
</tr>
<tr>
<td>40</td>
<td>7.44 ± 2.29</td>
<td>18.08 ± 5.86</td>
<td>3.25 ± 3.73</td>
<td>37.41 ± 6.25</td>
<td>14.67 ± 33.51</td>
</tr>
<tr>
<td>6.95</td>
<td>± 7.72 ± 0.44</td>
<td>11.75 ± 6.70</td>
<td>11.22 ± 10.15</td>
<td>7.19 ± 7.19</td>
<td>11.78 ± 11.78</td>
</tr>
</tbody>
</table>

*: 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. pruninosus the pH was 5.8[10] and in S. griseus 5.2[11], 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

<table>
<thead>
<tr>
<th>Pitaya</th>
<th>40 FDD</th>
<th>Unmarked Fruit</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>pH*</td>
<td>% SST</td>
</tr>
<tr>
<td>Mature</td>
<td>7.57 ± 0.78b</td>
<td>16.03 ± 1.3b</td>
</tr>
<tr>
<td>Overripe</td>
<td>7.57 ± 0.78b</td>
<td>16.03 ± 1.3b</td>
</tr>
</tbody>
</table>

*: 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 (C2H4)

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, CO2 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 CO2 levels during sampling did not reach even mL·kg⁻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, Rodriguez-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)

<table>
<thead>
<tr>
<th>DAF</th>
<th>Respiration rate (mL CO(_2) kg(^{-1}) h(^{-1}))</th>
<th>Ethylene production (μL C(_2)H(_4) kg(^{-1}) h(^{-1}))</th>
</tr>
</thead>
<tbody>
<tr>
<td>10</td>
<td>0.036 ± 0.007(\text{**}^a)</td>
<td>0.826 ± 2.190(^a)</td>
</tr>
<tr>
<td>20</td>
<td>0.229 ± 0.080(^c)</td>
<td>0.446 ± 0.210(^a)</td>
</tr>
<tr>
<td>30</td>
<td>0.371 ± 0.079(^d)</td>
<td>-</td>
</tr>
<tr>
<td>40</td>
<td>0.164 ± 0.024(^b)</td>
<td>7.908 ± 17.55(^a)</td>
</tr>
</tbody>
</table>

*: 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\(^{-1}\) h\(^{-1}\) on day 1 of storage at 25 °C to a maximum of 0.3 mL CO\(_2\) kg\(^{-1}\) h\(^{-1}\) after 5 days. Then the values decreased close to 0.05 mL CO\(_2\) kg\(^{-1}\) h\(^{-1}\) by day 14.

Ethylene production started with an average of 20 μL C\(_2\)H\(_4\) kg\(^{-1}\) h\(^{-1}\) and for the following days of storage at 25 °C the production reached a maximum at 7 days (110 μL C\(_2\)H\(_4\) kg\(^{-1}\) h\(^{-1}\)). The production of this gas decreased to reach approximately 30 μL C\(_2\)H\(_4\) kg\(^{-1}\) 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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