Impact of storage conditions and variety on quality attributes and aroma volatiles of pitahaya (Hylocereus spp.)

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Pitahaya are increasing in popularity but knowledge on the effects of storage and the potential impact of variety on subsequent quality following storage is incomplete, particularly in terms of the potential effects on sensory acceptability. In this study six varieties of pitahaya, having white, pink, and red internal flesh coloration, were harvested and evaluated for sensory and quality attributes at harvest and following storage for two weeks at either 5 °C or 10 °C. Storage did not influence overall visual liking or color of the external portion of the fruit as discerned by the panelists. Alterations in the internal flesh color, such as a slight darkening, were noted to occur by instrumental measurement, but these differences were not noticeable to the panelists. Losses in sugars and acids occurred in the flesh during storage at both storage temperatures and were related to declines in fructose, glucose and malic acid. In contrast, antioxidant activity was reduced by storage at 5 °C but was unchanged at 10 °C, with betacyanin concentration not differing from that determined at harvest. Aldehydes were the most abundant aroma volatiles detected in juice from the flesh, with storage increasing total aldehyde amount, particularly at 10 °C. Total alcohols, on the other hand, were reduced by storage, the amount of reduction not dependent on storage temperature. Regardless of the storage-induced changes in the various components measured, panelists did not report any significant differences in overall liking, flavor, sweetness, tartness or texture. There were substantial varietal differences in sensory and quality attributes, regardless of the impact of storage. ‘Cebra’ had very low sweetness relative to the other varieties and had low flavor and overall liking scores. Panelist perception of flavor quality was most closely linked with varietal differences in SSC and TA, although there were clear differences in aroma volatiles as well. Mexicana, a white-fleshed variety, had the lowest antioxidant activity, corresponding to low amounts of the red betacyanin pigments. The study indicated that storage, and particularly that at 10 °C, caused a variety of measureable changes in a range of pitahaya quality parameters but that these changes did not substantially alter the sensory quality of the fruit. Further research is needed to determine whether or not varietal or storage-induced differences in aroma volatile content have an impact on pitahaya flavor.

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1. Introduction

Pitahaya, pitaya or dragon fruit are general names for a diverse group of genera of the family Cactaceae. The major genus, Hylocereus, has as many as 16 different species that are commercially cultivated (Le Bellec et al., 2006). These differ in a variety of characteristics, one of the most notable being the color of the pulp. Pitahaya are native to Central and South America (Ortiz-Hernández and Carillo-Salazar, 2012) and are commercially cultivated in a wide range of countries including Mexico, Nicaragua, Guatemala, United States, Taiwan, Vietnam, Philippines and Israel. The fruit
have gained popularity at least in part as a result of the attractive appearance of the flesh and due to the potential health benefits of the high levels of betacyanins that are characteristic of the red- or purple-colored pitahaya varieties (Stintzing et al., 2002; Wybraniec and Mizrahi, 2002). Betacyanins, as well as polyphenols in the pitahaya flesh, have been shown to have strong antioxidant activity (Wu et al., 2006) and could potentially help protect against disorders in the body mitigated by oxidative stress.

Storage of pitahaya at temperatures above 20 °C leads to rapid softening and a loss of both sugar and acidity (Punitha et al., 2010), therefore the fruit are generally stored at temperatures of 14 °C and below to slow the occurrence of these changes. Nerd et al. (1999) reported that storage of Hyllocereus polyrhizus from Israel for up to 2 weeks at 6 °C and 14 °C effectively maintained quality, although the fruit stored at 6 °C for 2 weeks became unacceptably soft upon after transfer to 20 °C for a further week. The same authors found that Hyllocereus undatus, however, lost flavor quality after two weeks at 14 °C and developed chilling injury to the peel following storage for 2 weeks at 6 °C plus 1 week at 20 °C, indicating the potential for differential species tolerance. Growing location may also affect the response to cold temperature as H. undatus grown in California withstood storage at 5 °C for 20 days with good external quality and only minor internal injury (Freitas and Mitcham, 2013). Hoa et al. (2006), using H. undatus from Vietnam, stored fruit for three weeks at 5 °C with almost no loss in flavor and acceptable external quality. In an attempt to further extend the possible storage time at low temperature modified atmosphere packaging and the use perforated plastic bags have also been employed (To et al., 1999; Freitas and Mitcham, 2013).

Aroma volatiles are often key components involved in the determination of fruit flavor but are inadequately studied in pitahaya. Célis et al. (2012) isolated volatile components from yellow pitahaya (Selenicereus megalanthus) using steam distillation and then used aroma extract dilution analysis (AEDA) to identify nine odor-active compounds that could potentially influence flavor. In this brief paper there was no attempt to link this information to sensory analysis to try to determine if these compounds were important to pitahaya flavor. Storage of pitahaya is associated with losses in acidity and firmness (Nerd et al., 1999; Nerd and Mizrahi, 1999) that likely have a role in causing the loss in flavor quality that occurs. Changes to aroma volatiles in response to storage have been previously found to be important in other fruit (Obenland et al., 2011; Obenland et al., 2013), but this has not been explored in pitahaya.

Pitahaya is currently produced in California on a relatively small scale but increasing interest in the crop has lead to a need to better understand the factors that influence its postharvest quality. The main objectives of this study were to examine the impact of cold storage on the sensory and quality attributes of a diverse group of pitahaya varieties from the genus Hyllocereus grown in California and to evaluate the potential impact of aroma volatiles on differences in flavor due to both variety and storage regime. Prior sensory evaluation of pitahaya had focused only on liking of flavor or external appearance so it was also of particular interest to do a more detailed examination of differences in other sensory parameters that may be influenced by storage.

2. Materials and methods

2.1. Fruit and storage treatments

Approximately 65 commercially-mature pitahaya fruit per variety were harvested from experimental plots at the University of California South Coast Research and Extension Center in Irvine, CA on September 30, 2013. The following varieties (Fig. 1) and associated flesh colors were used: Cebra (C, red, H. costaricensis); Lisa (L, red, H. costaricensis); Rosa (R, red, H. costaricensis); San Ignacio (SI, red, H. costaricensis); Physical Graffiti (PG, light pink, H. polyrhizus x H. undatus); Mexican (M, white, H. undatus). The fruit were then transported the same day in an air-conditioned vehicle to the University of California Kearney Agricultural Center (UCKAC) in Parlier, California, a distance of 426 km. The fruit were held overnight at ambient conditions (20 °C). On the following day the fruit were equally divided into three treatments lots: 1) Initial evaluation (on October 2, 2013) following an additional overnight storage at 20 °C; 2) 14 d storage at 5 °C; 3) 14 d storage at 10 °C. Fruit from the two cold storage treatments were allowed to warm to ambient (20 °C) temperature prior to quality or sensory evaluation.

2.2. Color evaluation

Twelve fruit from each treatment were divided into four replicates with three fruit per replicate. Two types of color readings were taken with a Minolta CR-400 colorimeter (Ramsey, NJ) from each fruit using single measurements: 1) skin surface at the equator; 2) interior flesh color from a longitudinal cut at the equator.

2.3. Sample preparation

Samples were prepared by peeling one half of each longitudinally-cut fruit per replicate and freezing samples of pulp while juicing the remaining tissue using a blender. Tissue from three fruit were pooled and utilized for each of the four replications. The blended pulp mixture was passed through a filter under vacuum to obtain the juice. Five ml of the resulting juice was placed into a 12 mm × 32 mm glass headspace vial with 5 mL saturated CaCl2 and 1-pentanol at a final concentration of 490 μg.L−1. The mixture was kept frozen at −20 °C until aroma volatile analysis was performed. The remainder of the juice was frozen at −20 °C in plastic vials and later used for analysis of soluble solids concentration (SSC) and titratable acidity (TA). The frozen pulp tissue was transported to the University of California Davis (UCD) and used to assay sugars, organic acids, antioxidant activity and betacyanins.

2.4. Sugars and acids

Soluble solids concentration (SSC) was measured using an Atago digital refractometer (Bellevue, WA) and titratable acidity (TA) by titration with 0.1 mol.L−1 NaOH with an automatic titration system (Mettler T50A, Columbus, OH). Acidity values were expressed on a malic acid basis. Pulp samples (10 g) for sugar and organic

Fig. 1. Varieties of pitahaya used in this study.
acid determination were mixed with 20 mL ultrapure water and thoroughly mixed for 1 min. The diluted samples were then centrifuged at 3500 rpm for 3 min and the supernatant removed and subjected to an additional 10 min centrifugation at 14,000 rpm. The supernatant (200 μL) was diluted with 1800 μL ultrapure water, passed through a C18 Sep-Pak and a 0.45 μm filter and then used for analysis of soluble sugars and organic acids. Sugars were analyzed using a HPLC equipped with a 300 mm × 7.8 mm Aminex HPX-87C column (Bio-Rad, Hercules, CA) and a ELSD detector at 40 °C. The mobile phase was deionized water and the flow rate 0.01 mL s⁻¹ with a column temperature of 80 °C. Quantification was done by the use of glucose and fructose standard curves. Organic acids were analyzed using a HPLC with a UV detector at 210 nm and a 300 mm × 7.8 mm Aminex HPX-87H column (Bio-Rad) maintained at 50 °C. The mobile phase was 0.01 mol L⁻¹ sulfuric acid and the flow rate 0.01 mL s⁻¹. Quantification was done by the use of standard curves generated for oxalic, citric and malic acids. Analyses for both sugar and acids were replicated four times using separate fruit samples.

2.5. Antioxidant activity and betacyanins

Preparation of an extract for measurement of antioxidant activity was initiated by adding 25 mL of methanol to 10 g pulp sample and homogenizing the mixture for 1 min, followed by centrifugation at 3500 rpm for 3 min. The supernatant was then centrifuged at 14,000 rpm for 10 min at 4 °C. From the final supernatant 50 μL was removed and added to 4 mL ferric reducing antioxidant power (FRAP) solution. The mixture was vortexed and then incubated for 30 min in a 37 °C water bath. Antioxidant activity was quantified by measuring the absorbance of the solution at 593 nm and comparison to standard curves. The assay for betacyanin was based upon the methods of Phebe et al. (2009) with some modifications. Ten g of pulp was combined with 20 mL 80% ethanol and homogenized for 1 min and then the mixture centrifuged at 3500 rpm for 5 min. The pellet was re-extracted in the same manner two more times with 10 mL 80% ethanol and all supernatants were combined. The combined supernatants were made up to 50 mL with water and the absorbance measured at 538 nm with a spectrophotometer. Betacyanin concentration was determined by the following formula: mg g⁻¹ = A538 × (MW) × V × DF × 100/[(ε × L × W)]; where A538 is the absorbance at 538 nm, MW the molecular weight of betacyanin (550), V the volume of the extract in mL, DF the dilution factor, ε the mean molar absorptivity, L the path length (1 cm), and W the fresh weight of the material being extracted. Analyses for both antioxidant activity and betacyanins were replicated four times using separate fruit samples.

2.6. Aroma volatiles

Volatile juice samples in headspace vials were thawed and the vials placed into a cooled 4 °C rack to maintain the samples prior to analysis. Aroma volatile measurement was performed using solid phase microextraction (SPME) aided by a Gerstel MPS-2 robotic system (Linthicum, MD, USA). Trapping of the volatiles utilized 75-μm carboxen/polydimethylsiloxane fibers (Supelco, St. Louis,
Table 1
Concentrations of sugars and acids in six varieties of pitahayas evaluated at harvest or following two weeks of storage at either 5 °C or 10 °C.

<table>
<thead>
<tr>
<th>Variety</th>
<th>SSC* (10g kg⁻¹)</th>
<th>Sugars (g kg⁻¹)</th>
<th>TA* (10g kg⁻¹)</th>
<th>Organic acids (g kg⁻¹)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Fructose</td>
<td>Glucose</td>
<td>Oxalic</td>
<td>Citric</td>
</tr>
<tr>
<td>Cebra</td>
<td>10.89b</td>
<td>41.07b</td>
<td>53.50c</td>
<td>51.94b</td>
</tr>
<tr>
<td>Rosa</td>
<td>11.78b</td>
<td>40.80b</td>
<td>52.79c</td>
<td>51.94b</td>
</tr>
<tr>
<td>Lisa</td>
<td>11.38b</td>
<td>37.39b</td>
<td>50.13c</td>
<td>50.75b</td>
</tr>
<tr>
<td>San Ignacio</td>
<td>12.27ab</td>
<td>39.80b</td>
<td>49.64c</td>
<td>49.24b</td>
</tr>
<tr>
<td>Mexicanita</td>
<td>13.29a</td>
<td>48.22a</td>
<td>70.06a</td>
<td>68.27a</td>
</tr>
<tr>
<td>Physical Graffiti</td>
<td>12.17ab</td>
<td>41.09b</td>
<td>58.88b</td>
<td>59.97b</td>
</tr>
</tbody>
</table>

Storage

| None            | 12.21a          | 45.49a          | 58.84a         | 51.44a                 | 39.25a                 | 30.85a              |
| 2 weeks 5 °C   | 12.29b          | 41.17b          | 54.33b         | 53.85b                 | 42.66b                 | 34.26b              |
| 2 weeks 10 °C  | 11.39b          | 37.52c          | 54.34b         | 51.86b                 | 40.67b                 | 32.27b              |

Source*  

| Variety (V)    | *              | *              | *              | *              | *              | *              |
| Storage (S)    | NS             | NS             | *              | NS             | *              | NS             |

V’S  

| *              | *              | NS             | *              | NS             | NS             | NS             |

Statistically significant (P < 0.05) differences among varieties or storage conditions are indicated by values being followed by different letters.

* SSC:soluble solids concentration, TA: titratable acidity.

† Indicates statistical significance (P < 0.05) while NS indicates a lack of significance.

MO, USA). Chromatographic runs and analyte quantification were performed using an Agilent 7980 gas chromatograph (Agilent, Palo Alto, CA) paired with an Agilent 5975 mass spectrometer. Details of the hardware used and both trapping and chromatographic protocols are as previously described (Obenland et al., 2008; Obenland et al., 2013) except that only the mass spectrometer was used for quantification in this study. In addition to utilizing Wiley/NBS library spectra, peak identification was performed by comparison of compound retention indices to published values. Semi-quantification of the peaks was conducted by comparison of peak areas to a standard curve generated in pitahaya juice using 3-methyl butanal with the resulting concentrations being expressed as 3-methyl butanal equivalents. Variability between the runs was compensated for by comparison of 1-pentanol internal standard values and appropriately adjusting the analyte values. Volatile analyses were replicated four times with each replicate being a separate fruit sample.

2.7. Sensory evaluation

Sensory evaluation was conducted at UCKAC in the Sensory Testing Facility. After equilibration to ambient temperature (20 °C) the fruit were then washed and allowed to dry. Fruit used for the visual assessment were selected based upon uniformity of size and external characteristics across the six varieties. Panelists were seated in individual booths illuminated with daylight spectrum light. Panelists were employees of UCKAC and had extensive experience with sensory evaluation of fruit but not with pitahaya. In the month prior to initiating sensory testing a roundtable discussion was conducted and samples of various pitahaya varieties examined to provide a baseline on what should be evaluated and to develop the proper vocabulary. Further instruction was provided on the days of actual sensory testing. Approximately 12–15 panelists were available each day for the sensory evaluations. For visual assessment whole or longitudinally-cut fruit were placed onto white plastic plates that had been labeled with random three-digit numbers. Sample were placed in random order so that each panelist received the set of samples in a different order. Panelists evaluated whole and cut fruit with 9-point hedonic ratings for both overall appearance and color where 1 = extremely dislike, 5 = neither like nor dislike, and 9 = extremely like. For flavor assessment the top and bottom one-third of the fruit was removed and not utilized for testing in order to lessen variability among the samples. The center third of each fruit was cut into slices approximately 1.3 cm thick and then cut into six equal size pieces. Eight pooled fruit were used for each variety and treatment. One piece of each was served in a white 30-ml soufflé cup labeled with a unique three-digit number. Samples were presented in random order to each panelist. Prior to the initial tasting and between samples panelists were instructed to rinse their mouths with water to cleanse the palate. Panelists scored the fruit for overall liking, flavor, sweetness, tartness and flesh texture using the same 9-point hedonic scoring system as outlined for visual evaluations.

2.8. Statistical analysis

Quality and sensory data were analyzed with SPSS (Chicago, IL, USA) using a general linear model with variety and storage being fixed effects. Mean comparisons among varieties and storage times were determined using Tukey’s test at the 0.05 level of significance.
3. Results

Changes in skin color due to storage were relatively minor, with chroma slightly increasing for PG at 10°C and hue angle decreasing during cold storage for SI (5°C and 10°C) and C (10°C) (data not shown). Storage-induced changes in flesh color were, however, more pronounced (Fig. 2). In four of the six varieties L declined, this being especially prominent at 10°C, indicating a slight darkening in color due to this storage treatment. An increase in chroma was observed in M stored at 10°C, whereas increases were seen in SI (5°C and 10°C) and PG (5°C). In all but two varieties hue angle decreased during cold storage, most commonly at 10°C and with large changes being observed for M, the white fleshed variety.

Mexicana had the highest SSC, although the amount was not statistically-different from SI and PG (Table 1). This was also reflected in M having considerably greater amounts of both fructose and glucose in comparison to the other varieties which, except in the case of PG, were very similar to each other in the amounts of these two sugars. Titratable acidity differed among the varieties, with C, R and L having the highest TA values, S and P having lesser concentrations, and M with the lowest TA (Table 1). Differences in the individual organic acids between the varieties did not clearly mirror what was observed for TA. In the case of malic acid, the overwhelmingly dominant organic acid, the only significant differences observed were between C and PG. For oxalic acid SI and M had the highest amounts, while C and L had the highest concentration of citric acid in comparison to the other varieties. Storage for 2 weeks at 5°C did not alter SSC, while there was a slight reduction due to storage at 10°C. A decline in fructose occurred at both storage temperatures, with the loss at 10°C greater than 5°C. In the case of glucose, there was also a storage-induced decline in amount, although there was no difference in response due to temperature. Similarly to SSC, TA declined in storage at 10°C but not at 5°C. Both oxalic and citric acids were unchanged by storage but malic acid concentration declined during storage, with 10°C storage exhibiting the largest loss in TA.

The antioxidant activity for M was noteworthy in that it was more than two-fold lower than the other varieties (Fig. 3). The other five varieties were similar to each other, although C had slightly higher activities than R, S or PG. Mexicana, a white-fleshed variety, not unexpectedly, had very low levels of red-pigmented betacyanins as did PG, the pink-fleshed variety. Of those varieties with red flesh, SI had a slightly higher concentration of betacyanins that did C, R or L. There was poor correspondence between betacyanin concentration and antioxidant activity as PG had low amounts of betacyanins and yet had fairly high overall antioxidant activity. Storage for 2 weeks at 5°C slightly reduced the antioxidant activity, while storage for 2 weeks at 10°C did not change it. There was no effect of storage duration on the betacyanin concentration.

A total of 34 aroma volatiles were identified in the pitahaya juice samples (data not shown). Of these compounds 19 were found to have significant differences due to either variety or storage treatment and are shown in Table 2 along with characteristic descriptors of each volatile. Aldehydes were by far the most abundant volatiles identified, representing on average 90% of the total amount, with various hydrocarbons, alcohols, a ketone, an ester and a furan making up the rest of the identified volatiles (Table 3, Fig. 4). There were large varietal differences in total aldehydes with L having at least double the concentration present in C, M or PG (Fig. 4). By far the most abundant compound was hexanal which accounted for 92% of the total amount of this chemical class. Varietal differences in individual aldehydes generally followed the trend for total aldehydes with the exceptions of octanal and nonanal that had significantly higher amounts in M as compared to L. For the hydrocarbon class compounds the only sizable varietal difference was the significantly greater amount of tridecane in PG as compared to the other varieties, resulting in a greater level of total hydrocarbons. Mexicana was significantly higher in total alcohols that the other varieties, primarily due to the greater amount of hexanol present in the flesh of this variety. The ester, butyl butanoate, was more abundant in C, R, SI and SI than in M and PG and 2-pentyl furan was present to a higher degree in R and L than in the rest of the varieties.

Storage enhanced total aldehyde concentration with fruit stored at 10°C having a greater concentration than that stored at 5°C (Fig. 4), this being primarily due to increases in hexanal (Table 3). There was no trend in overall hydrocarbon levels as a result of storage, although limonene increased and dodecane decreased in amount relative to fruit that had not been stored. Alcohols declined in amount during storage driven by losses in both ethanol (5°C) and hexanol (5°C and 10°C). Methyl heptenone, butyl butanoate and 2-pentyl furan all were present in greater concentrations in fruit stored for 2 weeks at 10°C relative to no storage or storage for 2 weeks at 5°C. Butyl butanoate was also enhanced in concentration by storage at 5°C compared to fruit that were not stored.

In terms of eating quality overall liking of R and SI was superior to that of C (Table 4). This was largely a result of the relatively poor flavor of C, although only SI had flavor that was statistically better. A low perception of the sweetness of C relative to all of the other
varieties likely played a major role in the poor degree of liking of its flavor. Tartness and texture, on the other hand, did not differ among the varieties. Additionally, there were no significant differences in any parameters related to eating quality due to storage treatment (Table 4). Panelists liked the external appearance of L better than SI, which was itself preferred to PG (data not shown). Color was the dominant factor involved as ratings for color among the varieties were closely related to those of overall liking (data not shown). Storage had no impact on external overall liking or color. Internal appearance, judged from sectioned halves of the fruit, did not differ among the varieties or storage treatments for overall likability, although panelists liked the color of C, L or R better than that of PG (data not shown). Storage did not alter the color perceived by the panelists.

4. Discussion

A number of prior studies have been conducted to examine the effects of storage on pitahaya and have provided recommendations regarding the optimal storage conditions and times to ensure that quality is maintained (Nerd et al., 1999; Nerd and Mizrahi, 1999; Hoa et al., 2006; Corrales-García and Canche-Canche, 2008; Punitha et al., 2010; Freitas and Mitcham, 2013). Information on the full impact of storage on the fruit has, however, been somewhat limited as, to the best of our knowledge, there had never previously been a study which performed a full sensory panel evaluation comparing pitahaya following different storage protocols. In this research we conducted a comprehensive assessment of the impact of storage on six pitahaya varieties grown in California, including evaluation of standard quality parameters, antioxidant status, aroma volatile profile and sensory quality.

Sensory panelists judged there to be no differences in either overall external liking or color due to storage, in accordance with the relatively small differences found in colorimeter readings among the storage regimes for the different varieties (data not shown). Others have also found no loss in pitahaya external visual quality during 14 days of storage at temperatures from 10 °C to 14 °C (Nerd et al., 1999; Nerd and Mizrahi, 1999) but the devel-

Fig. 3. Antioxidant activity and betacyanin concentration in six pitahaya varieties at harvest or following storage for two weeks at either 5 °C or 10 °C. Statistically significant \( P \leq 0.05 \) differences among varieties (A) or storage conditions (B) are indicated by different letters, antioxidant activity is capitalized.
Table 4  
Sensory quality of six varieties of pitahayas immediately after harvest or following 2 weeks of storage at either 5°C or 10°C.

<table>
<thead>
<tr>
<th>Variety</th>
<th>Overall likinga</th>
<th>Flavor</th>
<th>Sweetness</th>
<th>Tartness</th>
<th>Texture</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cebra</td>
<td>6.1b</td>
<td>5.9b</td>
<td>5.1b</td>
<td>6.5a</td>
<td>5.7a</td>
</tr>
<tr>
<td>Rosa</td>
<td>7.2a</td>
<td>7.0ab</td>
<td>6.5a</td>
<td>7.2a</td>
<td>6.6a</td>
</tr>
<tr>
<td>Lisa</td>
<td>6.7ab</td>
<td>6.8ab</td>
<td>6.4a</td>
<td>6.6a</td>
<td>6.1a</td>
</tr>
<tr>
<td>San Ignacio</td>
<td>7.4a</td>
<td>7.3a</td>
<td>7.1a</td>
<td>7.1a</td>
<td>6.3a</td>
</tr>
<tr>
<td>Mexicana</td>
<td>6.5ab</td>
<td>6.3ab</td>
<td>6.4a</td>
<td>6.5a</td>
<td>5.5a</td>
</tr>
<tr>
<td>Physical Graffiti</td>
<td>6.3ab</td>
<td>6.2ab</td>
<td>6.4a</td>
<td>6.3a</td>
<td>5.9a</td>
</tr>
</tbody>
</table>

Storage

| None         | 7.0a           | 6.9a   | 6.4a      | 7.0a     | 6.1a    |
| 2 weeks 5°C  | 6.6a           | 6.5a   | 6.2a      | 6.7a     | 6.2a    |
| 2 weeks 10°C | 6.4a           | 6.4a   | 6.2a      | 6.4a     | 5.8a    |

Sourcea

| Variety (V)  | *              | *      | NS        | NS        | NS      |
| Storage (S)  | NS             | NS     | NS        | NS        | NS      |
| V’S          | NS             | NS     | NS        | NS        | NS      |

Statistically significant (P ≤ 0.05) differences among varieties or storage conditions are indicated by values being followed by different letters.

a Sensory scores on a 9-point scale where 1: extremely dislike, 5: neither like nor dislike, and 9: extremely like.

b Asterisk indicates statistical significance (P ≤ 0.05) while NS indicates a lack of significance.

opment of brown surface lesions can occur at lower temperatures of 4°C to 8°C that indicates the development of chilling injury (Corrales-García and Canche-Canche, 2008). Frietas and Mitcham (2013) reported that storage at 5°C was superior to either 7°C or 10°C for maintaining pitahaya visual appearance. In that study the fruit were held for an additional 5 days at 20°C following cold storage whereas in this test the time was less than 24 h. It is possible that differences in external appearance would have been more marked in our test had the time at 20°C been extended. Low temperature injury is also manifested in pitahaya by regions of the interior flesh that become somewhat translucent and have a darkened appearance (Corrales-García and Canche-Canche, 2008; Frietas and Mitcham, 2013). Although sensory evaluation performed in this study did not reveal any differences in the internal appearance of the fruit among the storage regimes (data not shown), colorimeter readings did indicate an effect of storage on internal flesh color, although it apparently was not noticeable to the panelists, even in the case of M where there was substantial change in hue angle.

Flavor evaluations indicated that cold storage at either 5°C or 10°C did not influence the overall liking of the fruit, this conclusion being accompanied by the panelists being unable to identify any differences in flavor, sweetness, tartness or texture as a result
of storage (Table 4). Apparently the losses in sugar and larger decreases in acid that occurred during cold storage (Table 1) were insufficient to influence any of the sensory parameters. This may have been a consequence of the high SSC:TA ratio present in the fruit at harvest (average across varieties of 27.8) making any further changes difficult to detect in the already low-acid fruit. Changes were observed in aroma volatile concentration due to storage (Table 3), primarily an increase in aldehydes and loss in alcohols, but these also did not impact the overall liking or flavor of the fruit. These results, indicating a lack of impact of cold storage on flavor, are in agreement with those of Nerd et al. (1999) who reported no loss of flavor for either *H. undatus* or *H. polyrhizus* after up to 3 weeks at 6 °C. The authors also noted, however, a rapid decline in flavor quality during storage at higher temperatures of either 14 °C or 20 °C.

While not influenced by cold storage, there were significant differences in sensory attributes present among the six pitahaya varieties, most notable being a greater liking for R and SI than for C. Closely linked to the lesser liking was a reduced sweetness in C relative to the other two varieties and a poorer flavor in comparison to SI. The reason for the lack of sweetness is, however, unclear as there are no obvious differences in either sugars or acids to account for this (Table 1). There is also no evidence that volatiles contributed to the dissimilarity in liking as there were no consistent significant differences among the individual volatile components between C, R, and SI (Table 3). Published sensory analyses of pitahaya varietal flavor are not readily available and we were unable to find any other prior instances in the literature that attempted to understand the basis of varietal differences.

To date, Célis et al. (2012) is the only published study that describes the volatiles present in pitahaya. These authors identified a total of 121 volatiles in samples of yellow pitahaya (*Selenicereus megalanthus*) with the sample composition consisting of terpenes, alcohols, parafins, esters, acids, ketones and other miscellaneous compounds. Although many of the same volatiles were identified in the two studies, aldehydes were more predominant in this study, constituting more than 90% of the total volatile amount. This difference in reported composition could have been both due to differences in the pitahaya tissue analyzed and to the methods used for extraction. Célis and co-workers utilized solvent extraction and subsequent concentration, while SPME, a headspace analytical technique, was used in this study. Although volatile composition in this study substantially varied due to both storage conditions and variety the differences could not be definitively linked to any difference in flavor.

Given that there has been substantial attention devoted to the potential health benefits conferred by the red betacyanin pigments in pitahaya (Wu et al., 2006; Tenore et al., 2012), it was of interest to examine both the effects of cold storage and variety on betacyanin content and overall antioxidant activity provided by these pigments and other components in the flesh. Unsurprisingly, M, the white-fleshed variety, had little or no betacyanin content and corresponding low antioxidant activity (Fig. 3). Physical Graffiti, the pink-fleshed variety, on the other hand, also had low amounts of betacyanins but had much higher antioxidant activity that was equivalent to that of all the red-fleshed varieties except C. The inability of the greater amount of betacyanin in the red varieties to provide additional antioxidant activity may indicate the influence of other active components in PC. Wu et al., (2006) reported that although extract fractions from red pitahaya composed mainly of betacyanins had the highest antioxidant activity, fractions with flavonoids and phenolics were also present that had substantial activity. Betacyanin content in the current study did not differ due to storage duration, although a slight reduction in antioxidant activity occurred at 5 °C but not 10 °C. The stability of betacyanin content in cold storage had been previously shown (Ortiz-Hernández and Carillo-Salazar, 2012), although this was following the application of 1-methylcyclopentene at harvest.

In summary, cold storage of pitahayas for two weeks at either 5 °C or 10 °C caused a loss in sugars and organic acids, accompanied by a shift in the quantities of aroma volatiles present. Regardless of these changes in composition, however, panelists were unable to differentiate the flavor of stored fruit from that freshly harvested in terms of liking, overall flavor, sweetness, tannins or texture. Betacyanin content and antioxidant activity were also relatively insensitive to storage as was exterior color and appearance. Differences in flavor liking noted by panelists were variety-based with the strongest liking being associated with high overall flavor ratings and high sweetness. Aroma volatile concentrations also differed by variety but more research is needed to determine what influence these compounds have on pitahaya flavor.

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### References


