Food Research 6 (2) : 423 - 433 (April 2022)
Journal homepage: https://www.myfoodresearch.com

FOOD RESEARCH

FULL PAPER

Harvest maturity affects the quality and storage behavior of white-fleshed dragon fruit [*Hylocereus undatus* (Haworth) Britton and Rose]

[1,]*Franco, R.K.G., [1,2]Esguerra, E.B., [1]Tababa, J.L. and [1,2]Castro, A.C.

[1]*Postharvest Horticulture Training and Research Center, College of Agriculture and Food Science, University of the Philippines Los Baños, 4031, College, Laguna, Philippines*
[2]*Postharvest and Seed Sciences Division, Institute of Crop Science, College of Agriculture and Food Science, University of the Philippines Los Baños, 4031, College, Laguna, Philippines*

Article history:
Received: 14 May 2021
Received in revised form: 11 June 2021
Accepted: 23 August 2021
Available Online: 25 April 2022

Keywords:
Dragon fruit,
Maturity,
Quality,
Total phenolic content,
Sensory Characteristics,
Storage

DOI:
https://doi.org/10.26656/fr.2017.6(2).268

Abstract

Depending on the buyer's demand, dragon fruit is harvested at three maturity stages which may affect the quality and storability of the fruit. This study was conducted to determine the physico-chemical changes at harvest and during low-temperature storage of white-fleshed dragon fruit harvested at 31, 33, and 35 days after anthesis (DAA). The fruit was then stored at 5ºC for 5 weeks or at 13ºC for 3 weeks followed by post-storage at 20ºC. At harvest, fruit harvested at 35 DAA had the highest value of TSS/TA ratio, while 31 DAA fruit had the highest total phenolic content. Dragon fruit harvested at 33-35 DAA can be stored at 5°C for three weeks with post-storage life of 9 days at 20ºC. Fruit harvested at 31 DAA exhibited flesh translucency after three weeks at 5ºC, an indication of chilling injury. When stored at 13ºC, the fruit was of good quality for 2 weeks regardless of maturity with a shelf life of 5 days for 31 and 33 DAA and only 3 days for 35 DAA. Physico-chemical changes did not vary significantly during storage at 5ºC and 13ºC except for the marked decrease in acidity in all maturity stages. When presented to sensory panellists, preference was higher in fruit harvested at 35 DAA than at 33 and 31 DAA. All things considered, the best harvest maturity stage for prolonged storage at 5ºC is 35 DAA, while 31-33 DAA for 13ºC storage.

1. Introduction

Dragon fruit (*Hylocereus* spp.), also known as pitaya or pitahaya, is one of the most exotic and popular tropical fruits due to its attractive appearance and colour as well as its organoleptic, nutritional, and therapeutic properties (Harivaindaran *et al*., 2008). It is a non-climacteric fruit (Nerd *et al*., 1999; To *et al*., 2002) and has to be harvested at its eating-ripe stage. At a mean growing temperature of 28.1ºC, it takes 25 to 30 days from flowering to the colour break stage in which the optimum maturity ranges from 32 to 38 days after flowering (Wu, 2014). Nerd *et al*. (1999) reported that the eating quality of the flesh approaches a maximum at 33 to 37 days after flowering. In the Philippines, dragon fruit is generally harvested at 28 to 35 days from flowering, but harvesting at mixed maturity stages often results in consumer dissatisfaction.

Dragon fruit is a seasonal crop with July to October as the harvesting months (Rodeo *et al*., 2018) thus the need to extend its availability in the market. To *et al.* (2002) reported that the optimum storage temperature for white-fleshed dragon fruit grown in Vietnam was 5ºC. When harvested close to full peel colour, visual acceptance and marketing quality were kept for at least 3 weeks at 6ºC, 2 weeks at 4ºC, or one week at 20ºC (Nerd *et al*., 1999). However, they indicated that fruits are subject to chilling injury upon exposure to 20ºC after the 5ºC storage. Chilling injury is characterized by wilting, darkening of the bracts, softening, flesh translucency, browning of the outer flesh and inferior taste. In the study of Obenland *et al*. (2016), no significant variation was recorded in the overall sensory quality of dragon fruit during storage at 5ºC and 10ºC for 22 weeks.

The stage of maturity at harvest influences the eating quality of the fruit as well as the response to its postharvest environment. Immature fruits have inferior quality, do not last long in storage, and are susceptible to chilling injury (To *et al*., 2002). For the variety grown in the Philippines, there is still a need to establish the optimum storage life of dragon fruit at low temperatures. This study determined the physiological and physicochemical quality attributes of white-fleshed

*Corresponding author.
Email: *rgfranco1@up.edu.ph*

eISSN: 2550-2166 / © 2022 The Authors.
Published by Rynnye Lyan Resources

dragon fruits harvested at three maturity stages and their storage behaviour at low temperatures.

2. Materials and methods

2.1 Plant materials

White-fleshed dragon fruits grown in Cavite, Philippines were tagged at 3-4 days after anthesis (DAA) when the fruit set was assured. Fruit maturity, however, was reckoned based on the date of anthesis as follows: 31, 33 and 35 DAA. For each maturity stage, a total of 101 large-sized (400 to 600 g) dragon fruits that were free from defects and diseases and with green and firm bracts were selected. Only one trial was done for this experiment. To avoid variability in response as may be affected by preharvest factors, the fruit used in the experiment came from the same block in one farm where climatic, edaphic and cultural management practices were the same.

2.2 Postharvest treatments

After field sorting, the fruit was sleeved individually in polystyrene fruit cups, packed in plastic crates, and transported in an air-conditioned vehicle to the PHTRC laboratory at UP Los Baños for evaluation and storage experiment. The fruit was then packed in corrugated boxes and stored at 5ºC or 13ºC with a relative humidity of 95-99%. Withdrawal of samples from 13ºC was done weekly for 3 weeks while at week 1, 3, and 5 for 5ºC-stored fruit followed by subsequent shelf-life evaluation at 20ºC.

2.3 External and internal quality attributes

Peel and pulp colour, the thickness of the peel (subjective), fruit weight, firmness, total soluble solids (TSS) content, titratable acidity (TA), ascorbic acid content, total phenolic content and antioxidant activity were evaluated one day after harvest.

2.4 Storage behaviour

During low-temperature storage, visual and physiological changes were evaluated every 4 days at 5ºC, and every 2 days at 13ºC and during post-storage at 20ºC. Physico-chemical analyses were done upon withdrawal from low-temperature storage, and at the limit of marketability (VQR 5) at 20ºC. Translucency was rated as slight or severe based on the extent of the water-soaked appearance of the flesh.

2.5 Respiration rate

Fruit samples were sealed individually for 2 hrs in a container hermetically sealed with a rubber stopper. Approximately 1 mL headspace gas was taken using an airtight syringe immediately after sealing the container and after 2 hrs of the enclosure. Gas samples were injected into a gas chromatograph (Shimadzu GC-2014) fitted with Thermal Conductivity Detector (TCD) and silica gel column.

2.6 Visual quality changes.

External quality was assessed using the following ratings: 9-8 = excellent, field fresh, 7-6 = good, defects minor, 5-4 = fair, defects moderate, limit of marketability, 3 = poor, defects serious, 2 = limit of edibility, and 1 = non-edible under usual conditions. Defects considered are those that occur after harvest including shrivelling, decay and bract discolouration.

Bract colour was evaluated subjectively using the following indices (Woolf *et al*., 2006): 0 = bright green, no browning/blackening, 1 = green colour fading, moderate yellow, slight browning of margins, 2 = green tips, most bracts are yellow, moderate browning, 3 = no green, severe yellowing and/or browning, some blackening of margins, and 4 = no green, complete yellowing and/or browning/blackening

2.7 Physico-chemical changes

Firmness was determined as the maximum penetration force reached during tissue breakage and was measured using the 0.5 mm probe of a digital penetrometer (AIKOH Digital Force Gauge SX Series Model-2256). Measurements on intact fruit were taken from the middle portion at two opposite sides of the fruit. Firmness was expressed as kg-force.

Titratable acidity (TA) was measured by acid-base titration and was expressed as % malic acid. Using the same pure aliquot, total soluble solids (TSS) content was measured using a digital hand-held refractometer (Atago Pocket Refractometer PAL-1).

2.7.1 Total phenolic content

TPC was determined using the Folin-Ciocalteau method of Bae and Suh (2007). Folin-Ciocalteau phenol reagent (0.25 N, 2.0 mL) was added to 0.1 mL ethanolic extract and 0.9 mL of distilled water and stirred using a vortex mixer (WITEG Labortechnik GmbH, VM-10). Approximately 2 mL 1 N sodium carbonate was added and then incubated for 1 hr after which absorbance was measured in a spectrophotometer (Hitachi UH5300) at 760 nm against gallic acid as standard.

2.7.2 Antioxidant activity

This was measured using the 2,2-diphenyl-1-picrylhydrazyl (DPPH) free radical scavenging activity following the modified method of Khamsah *et al*. (2006)

as cited by Nurliyana *et al*. (2010). Approximately 2 mL of 0.1 mM DPPH reagent were added to 0.1 mL ethanolic extract and 0.9 mL distilled water, incubated at room temperature in the dark for 30 mins then the absorbance at 517 nm was read (Hitachi UH5300).

2.8 Sensory evaluation

Organoleptic attributes (sweetness, sourness, juiciness) were evaluated every withdrawal from low-temperature storage and at the limit of marketability during post-storage at 20ºC. Sensory attributes were rated based on a scale of 1–5 with 5 representing the most favourable response. Sensory evaluation was done by 12 untrained panellists who are familiar with the fruit, that is, dragon fruit-consumers and are the regular "in-house" panellists in the laboratory.

2.9 Statistical analysis

The experiment was laid out following a Completely Randomized Design (CRD) with three replicates for analyses of physiological and physico-chemical changes, and 10 replicates for visual quality changes. Collected data were subjected to ANOVA, and Least Significant Difference (LSD) was used to test the significant differences of means at 5% level. For visual parameters and sensory characteristics, Kruskal-Wallis test was conducted and means were compared using Dwass, Steel, Critchlow-Fligner (DSCF) method. All statistical analyses were done using SAS University Edition.

3. Results and discussion

3.1 Quality attributes of dragon fruit harvested at three maturity stages

Distinct differences in peel colour and thickness were observed among the 3 maturity stages. Fruit harvested at 31 DAA had a reddish-brown peel, reddish-pink at 33 DAA, and full red at 35 DAA. The thickness of the peel decreased with maturity (Figure 1). However, firmness did not vary among maturity stages even though the peel of 31 DAA fruit was thicker. As the fruit matures, there is an increase in weight.

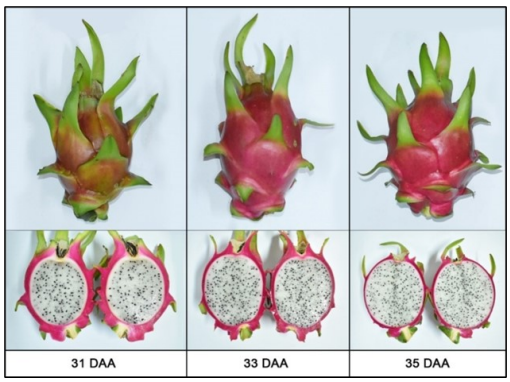

Figure 1. The appearance of white-fleshed dragon fruit at harvest at three different maturity stages

TSS ranged from 12 to 13ºBx with no significant differences among maturity stages. TA, however, was highest in 31 DAA fruit and decreased with increasing maturation. With the increasing health and wellness concerns of consumers, sweetness is not a highly desirable quality attribute (To *et al*., 2002). Accordingly, the harvest maturity should be based on the TSS/TA ratio which is an important factor that indicates the value of the fruit. In Vietnam, TSS/TA ratio was established at 40 which was attained 31 days after flowering (To *et al*., 2002). While this value was not attained in this study due to the difference in variety and growing condition, fruit harvested at 35 DAA had a TSS/TA ratio of 31.8 which is already acceptable. Similar to TA, ascorbic acid content was highest at 31 DAA and decreased with fruit maturity (Table 1).

Table 1. Physico-chemical properties of white-fleshed dragon fruit at different harvest maturities

Parameter	Harvest Maturity (Days After Anthesis)		
	31	33	35
Fruit weight (g)	531.6	542	569
Firmness (kg-Force)	2.72	2.74	2.88
Total Soluble Solids (ºBx)	12.4	13.02	13.02
Titratable Acidity (% malic acid)	0.74^{a}	0.55^{ab}	0.41^{b}
TSS/TA ratio	16.8^{b}	23.7^{ab}	31.8^{a}
Ascorbic acid (mg 100/g FW)	4.59^{a}	2.71^{b}	1.29^{c}
Total phenolic content (mg GAE 100/g)	29.65^{a}	23.82^{b}	24.04^{b}
Antioxidant activity (%)	80.77	81.22	80.86

Values with different letter within rows are significantly different, LSD at 5% level.

The popularity of dragon fruit as healthy food is due to its high total phenolic content (TPC) which possesses antioxidant properties (Jamilah *et al*., 2011). TPC was highest at 31 DAA while those harvested at 33 and 35 DAA did not vary. The antioxidant activity, however, was the same in all maturity stages implying that the desired nutritional benefits from dragon fruit can be met even at earlier harvest maturity.

3.2 Storage behaviour at low temperature

3.2.1 Respiration rate

There was no specific pattern observed and no sudden peak detected in CO_2 production of dragon fruit during continuous storage at 5ºC and 13ºC implying that dragon fruit is a non-climacteric fruit (To *et al*., 2002; De Frietas and Mitcham, 2013). The highest respiration rate was exhibited by fruit harvested at 31 DAA and the lowest with 35 DAA. There was a drastic decrease in respiration rate from 20.7-26.06 mg CO_2 $kg^{-1}h^{-1}$ down to 2.75 mg CO_2 $kg^{-1}h^{-1}$ for 35 DAA and 5.91 mg CO_2 $kg^{-1}h^{-1}$ for the 33 and 35 DAA-harvested fruit after a day of storage at 5ºC (Figure 2). No further dramatic increase in respiration was observed at 5ºC regardless of the

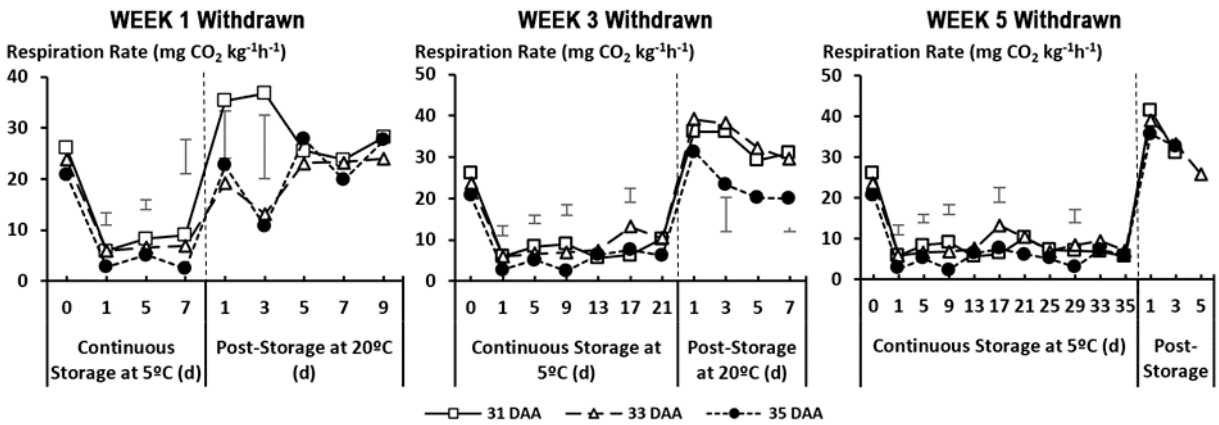

Figure 2. Respiration rate of dragon fruit harvested at different maturity stages stored at 5ºC for 5 weeks followed by post-storage at 20ºC. Bars indicate LSD at 5% level (n = 3).

duration of storage indicating very slow fruit metabolism due to reduced respiratory enzyme activity resulting in reduced utilization of substrates (Silva, 2008). An increase in respiration rate immediately upon transfer to 20ºC was observed regardless of maturity and length of storage at 5ºC which is a typical response since high temperature enhances fruit metabolism. During the 1st week of withdrawal, the respiration rate initially was 2.41 to 9.02 mg CO_2 $kg^{-1}h^{-1}$ and increased to 19.20 to 35.34 mg CO_2 $kg^{-1}h^{-1}$ with 31 DAA fruit having the highest respiration rate. On the 5th week, the fruit initially had a 5.57 to 7.15 mg CO_2 $kg^{-1}h^{-1}$ production rate and increased to 35.69 to 41.40 mg CO_2 $kg^{-1}h^{-1}$ upon transfer to 20ºC.

At 13ºC, respiration rate was also maintained at a low level during storage, but at a relatively higher rate as compared with 5ºC-stored fruit, indicating that fruit metabolism was not markedly retarded at 13ºC (Figure 3). When the fruit was transferred to 20ºC, respiration rate likewise drastically increased, with the more mature fruit (35 DAA) exhibiting the highest and early onset of increase when withdrawn from low-temperature storage.

3.2.2 Visual quality changes

Externally, fruit stored at 5ºC was of good quality (VQR 6-7) until the 5th week of storage (Figure 4A). A slower decline in visual quality was observed in 31 DAA fruit, which remained at VQR 7 until the 37th day of storage. Fruit harvested at 35 DAA had the fastest decline in VQR during the early part of storage and remained fairly constant at VQR 7 until day 29 of storage. Extending the storage period to 41-45 days resulted in the fruit reaching its limit of marketability.

In the case of 13ºC-stored fruit, the decline in visual quality was faster than at 5ºC. During the first week of storage, a slower decline in visual quality was again observed in 31 DAA fruit. However, there were no differences in the rate of decline in visual quality among maturity stages towards the end of storage (Figure 4B). On the 3rd week of storage, the fruit was already at the limit of marketability characterized by complete yellowing and drying of the tip of the bracts.

When the fruit was transferred to 20ºC for shelf-life evaluation, fruit withdrawn after one week at 5ºC took 11 days to reach the limit of marketability (VQR 5), and 9 days when withdrawn after 3 weeks at 5ºC (Table 2). Extending the storage to 5 weeks at 5ºC resulted in short shelf life (3 to 4 days) at 20ºC. Moreover, although the external appearance of the fruit was still good in the 5th week, internally, flesh translucency has already occurred slightly in the 33 and 35 DAA fruits and was severe in 3

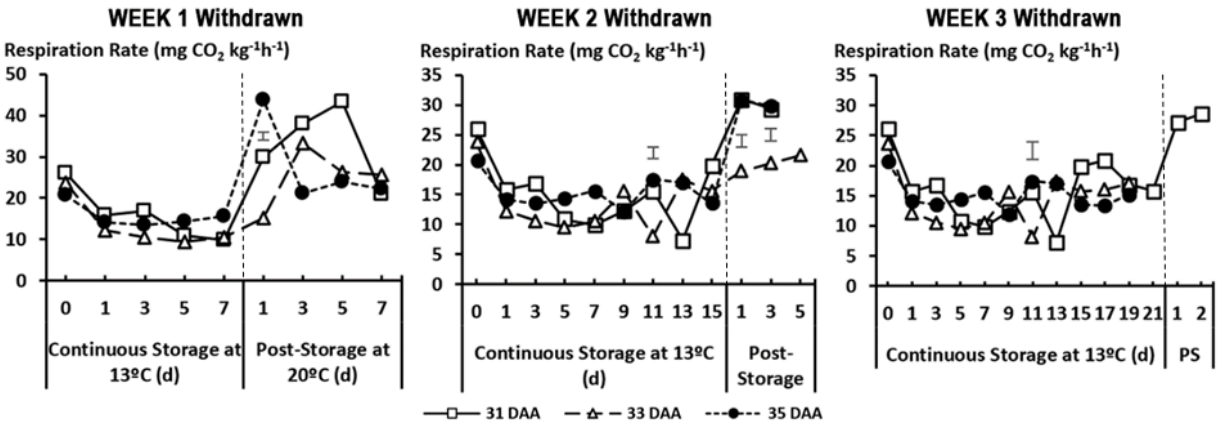

Figure 3. Respiration rate of dragon fruit harvested at different maturity stages stored at 13ºC for 3 weeks followed by post-storage at 20ºC. Bars indicate LSD at 5% level (n = 3).

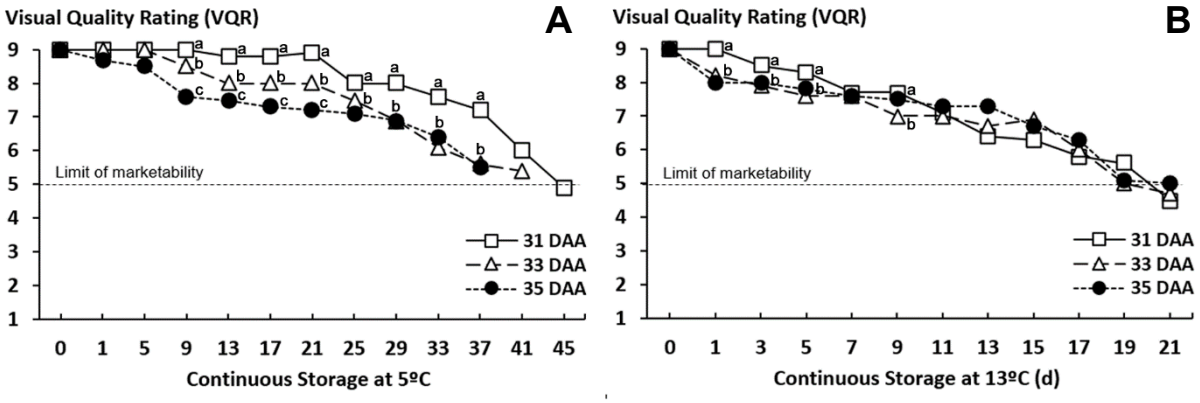

Figure 4. Change in the visual quality rating of dragon fruit harvested at different maturity stages then stored at 5ºC for 5 weeks (A) or at 13ºC for 3 weeks (B). Means with different letters within each storage time indicate significant differences, Kruskal-Wallis 5% level. Each point represents the mean of 10 replicates with one fruit per replicate.

DAA fruit (Figure 5). In the case of 31DAA fruit, slight translucency was already apparent on the 3rd week of storage at 5ºC. In dragon fruit, flesh translucency is an indication of chilling injury (De Freitas and Mitcham, 2013).

Table 2. Days to the attainment of VQR 5 (limit of marketability) upon transfer to 20ºC.

Maturity	Days to attainment of VQR 5 at 20ºC					
	Withdrawal from 5ºC			Withdrawal from 13ºC		
	Week 1	Week 3	Week 5	Week 1	Week 2	Week 3
31 DAA	11	9	3	9	5	2
33 DAA	11	9	4	9	5	-
35 DAA	11	9	3	7	3	-

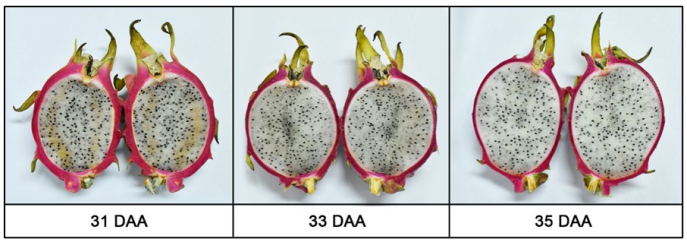

Figure 5. Flesh translucency in dragon fruit during post-storage at 20ºC after five weeks of storage at 5ºC. Flesh translucency in 31 DAA fruit was characterized as severe while that of the 33 and 35 DAA fruit occurred only slightly.

When the fruit was withdrawn after one week of storage at 13ºC, the shelf life at 20ºC was 9 days (Table 2). This was shortened to 5 and 3 days for 31-33 DAA and 35 DAA, respectively, when fruit was stored for 2 weeks. Only the fruit harvested at 31 DAA were withdrawn on the third week of storage, with a subsequent shelf life of 2 days at 20ºC. More mature fruit (31 and 35 DAA-harvested) were already unmarketable on the 19th day of storage.

One of the major quality attributes of dragon fruit desired by consumers is the greenness of the bracts against the deep red peel, which also serves as a gauge of freshness. During storage at 5ºC and 13ºC, the main contributory factor to the decline in visual quality was the deterioration of the bract quality which started as yellowing at the basal portion towards the tip, followed by drying. Bracts of dragon fruit have 3 to 4 times stomatal density than the peel (Kammapana *et al*., 2013; Mizrahi, 2015) which enhanced water loss leading to discolouration and eventual drying.

Bract discolouration was faster in 35 DAA fruit when stored at 5ºC (Figure 6A). After four weeks of storage, fruit harvested at both 33 and 35 DAA exhibited a faster rate of bract discolouration than the 31 DAA fruit. Bract colour of the more mature fruit was rated 2 (yellow bracts with remaining green colour at the tip) while that of 31 DAA were still green at the end of storage. At 13ºC, bract discolouration was faster and more pronounced than at 5ºC (Figure 6B). Unlike the 5ºC-stored fruit, those harvested at 35 DAA exhibited a slower rate of bract yellowing at 13ºC.

The disease was not prevalent in all maturity stages during cold storage until the limit of marketability and only affected less than 5% of fruit surface thus it did not contribute to the decline in visual quality.

3.3 Weight loss

The thin peel of dragon fruit makes it susceptible to water loss (De Freitas *et al*., 2011). Cumulative weight loss increased linearly throughout storage at both storage conditions, with fruit harvested at 31 DAA having the highest weight loss among the 3 maturity stages. At 5ºC, weight loss reached 2.76 to 3.25% at week 3, and 5.9 to 7.1% at week 5. The same trend was observed in fruit stored at 13ºC with 3.08 to 3.61% weight loss incurred on week 3 (data not shown). Weight loss, however, did not manifest as fruit shrivelling.

3.4 Physico-chemical changes

Firmness. Softening in dragon fruit takes place prior to harvesting, with a constant decline in firmness from 16 to 25 DAA, and relatively constant firmness thereafter until 37 DAA (Ortiz and Takahashi, 2011).

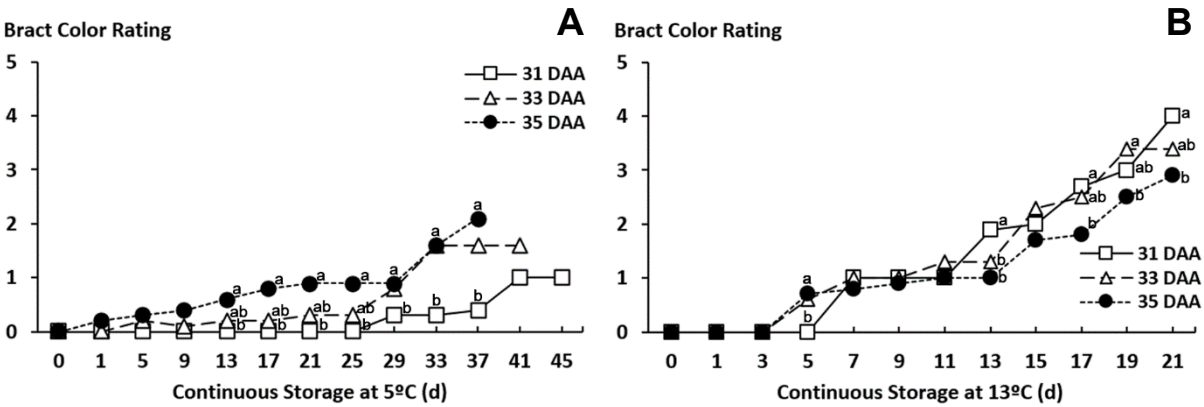

Figure 6. Change in bract color of dragon fruit harvested at different maturity stages stored at 5ºC for 5 weeks (A) or at 13ºC for 3 weeks (B). Means with different letters within each storage time indicate significant differences, Kruskal-Wallis 5% level. Each point represents the mean of 10 replicates with one fruit per replicate.

Dragon fruit exhibited a slow decline in firmness from 3.03 to 2.67 kg-force throughout storage at both temperatures regardless of fruit maturity (data not shown). Likewise, when transferred to 20ºC, firmness did not markedly decrease, with the range of 2.23 to 2.70 kg-force in all withdrawal periods at 5ºC with no significant differences among maturity stages. At 13ºC, firmness remained relatively constant at 2.51 to 2.71 kg-force during storage and even during transfer to 20ºC.

3.4.1 Total phenolic content

Phenolic compounds are naturally present in fruits which contribute largely to their antioxidant property by neutralizing free radicals. Gallic acid is a well-known antioxidant and constitutes the main phenolic compound in dragon fruit (Esquivel *et al*., 2007). At 5ºC, there were no significant differences obtained among maturity stages until the 3rd week of storage, but on the 5th week, higher TPC was obtained in 31 DAA fruit (Table 3). No significant decline in TPC was observed when fruit was transferred to 20ºC. At the limit of marketability on day 9 at 20ºC, TPC increased for 31 and 33 DAA fruit.

At 13ºC, differences in TPC among maturity stages were only observed on the 2nd week of storage where 31 DAA fruit had higher TPC than 35 DAA fruit. A significant decrease in TPC was observed in all maturity stages when transferred to 20ºC after one week of storage at 13ºC. The results showed that TPC did not dramatically decrease when fruit was transferred to warmer temperatures after an extended period of cold storage.

3.4.2 Antioxidant activity

Exposure of dragon fruit to suboptimal temperatures like 5ºC for an extended period is a form of stress which can induce the generation of free radicals that would result in cellular damage (Haliwell, 2006). However, plant cells are protected from stress by an antioxidant system that works as scavengers of free radicals. In this study, more mature fruit had higher antioxidant activity during the 1st week of storage at both temperatures. Although antioxidant activity decreased throughout storage, dragon fruit harvested at any maturity stage then stored for 3 - 5 weeks at 5ºC retained their high

Table 3. Total phenolic content of white-fleshed dragon fruit upon withdrawal from low-temperature storage and at VQR 5 (limit of marketability) at 20ºC

Maturity	Total Phenolic Content (mg GAE 100/g)					
	WEEK 1 Withdrawn		WEEK 3 Withdrawn		WEEK 5 Withdrawn	
	Upon	VQR 5 at	Upon	VQR 5 at	Upon	VQR 5 at
Storage at 5ºC						
31 DAA	30.14	29.01	28.01	32.14[a]	30.35[a]	33.04
33 DAA	31.43	30.31	28.35	30.80[a]	24.98[b]	28.28
35 DAA	29.2	28.13	26.61	26.12[b]	25.50[b]	29.23
	WEEK 1 Withdrawn		WEEK 2 Withdrawn		WEEK 3 Withdrawn	
	Upon Withdrawal	VQR 5 at 20ºC	Upon Withdrawal	VQR 5 at 20ºC	Upon Withdrawal	VQR 5 at 20ºC
Storage at 13ºC						
31 DAA	31.46	28.03	30.59[a]	28.20[a]	31.22	30.93
33 DAA	31.3	26.67	27.26[ab]	25.13[ab]	ND	ND
35 DAA	29.63	25.67	25.17[b]	23.74[b]	ND	ND

Values with different superscript within columns for each storage temperature are significantly different, LSD at 5% level.

antioxidant activity as compared to those stored at 13ºC (Table 4).

Antioxidant activity generally decreased when fruit was transferred from low-temperature storage to 20ºC, and the highest decrease in antioxidant activity was observed in week 1 withdrawn fruit from both 5ºC and 13ºC (Table 4).

3.4.3 Titratable acidity

TA was highest in 31 DAA fruit at harvest up to the limit of marketability at both storage conditions (Figure 7). The same trend was observed by Nerd *et al*. (1999) in *H. undatus* and *Hylocereus polyrhizus* with fruit harvested earlier having higher acidity as compared to those harvested at advanced colour change (more mature).

TA generally decreased throughout storage, with a more pronounced decline observed in fruit stored at 13ºC than at 5ºC. Initially, at 0.41 to 0.74%, TA decreased to 0.17% at 13ºC on the 3rd week of storage (Figure 7B). On the other hand, the TA of fruit at 5ºC was still in the range of 0.34% to 0.56% during this period. The drastic decrease in TA of fruit corresponds to a higher respiration rate at 13ºC than at 5ºC, suggesting that organic acids were utilized as substrates for respiration.

3.4.4 Total soluble solids content

TSS did not change markedly during cold storage and there were no significant differences among maturity stages (Table 5). TSS of dragon fruit was maintained in the range of 12-13ºBx. Moreover, there was no definite pattern of change in TSS content when fruit was transferred from low temperature to post-storage at 20ºC. At 5ºC, consistently higher TSS in more mature fruit (35 DAA) was obtained when fruit was transferred to 20ºC and when fruit was at VQR 5 (Table 5). At 13ºC however, no consistent pattern of change in TSS content was observed both upon removal from storage and at VQR 5 except for the 31 DAA fruit wherein TSS drastically dropped from 13.4ºBx to 10.7ºBx when transferred to 20ºC.

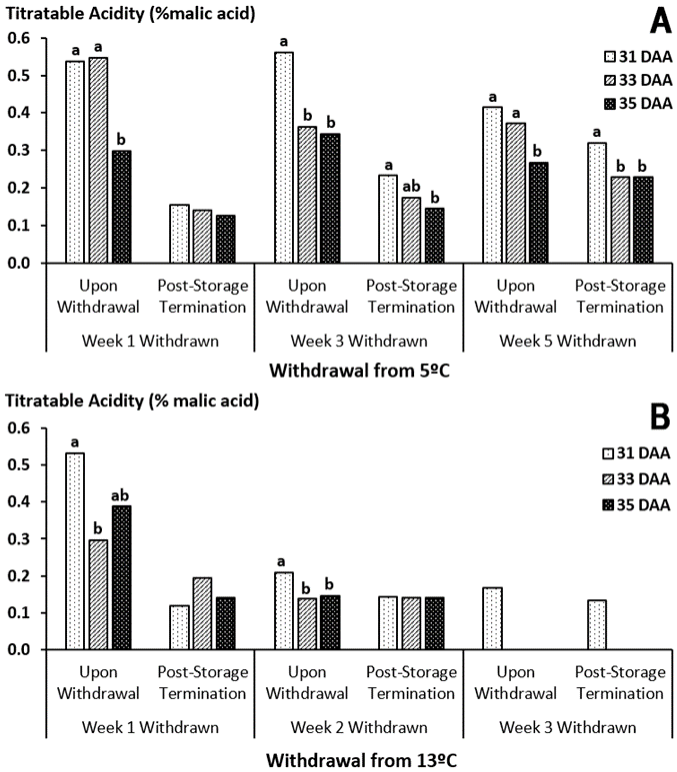

Figure 7. Titratable acidity of dragon fruit harvested at different maturity stages then stored at 5ºC for 5 weeks (A) or 13ºC for 3 weeks (B) followed by post-storage at 20ºC. Means with different letters at each evaluation period indicate significant differences at 5%, LSD (n = 3).

A better indicator of fruit acceptability or likeness by the consumer is the TSS/TA ratio. As shown in Table 6,

Table 4. Antioxidant activity of white-fleshed dragon fruit upon withdrawal from low temperature storage and at VQR 5 (limit of marketability) at 20ºC

Maturity	Antioxidant activity (%)					
	WEEK 1 Withdrawn		WEEK 3 Withdrawn		WEEK 5 Withdrawn	
	Upon Withdrawal	VQR 5 at 20ºC	Upon Withdrawal	VQR 5 at 20ºC	Upon Withdrawal	VQR 5 at 20ºC
Storage at 5ºC						
31 DAA	80.02[b]	75.90	77.59	77.12[a]	76.06	76.67
33 DAA	83.42[a]	77.22	76.63	73.27[b]	75.56	78.27
35 DAA	83.42[a]	77.63	77.01	73.68[b]	76.67	77.12
	WEEK 1 Withdrawn		WEEK 2 Withdrawn		WEEK 3 Withdrawn	
	Upon Withdrawal	VQR 5 at 20ºC	Upon Withdrawal	VQR 5 at 20ºC	Upon Withdrawal	VQR 5 at 20ºC
Storage at 13ºC						
31 DAA	79.57[b]	71.06	75.45[a]	71.18	69.70	69.33
33 DAA	83.05[a]	70.28	72.17[b]	69.38	ND	ND
35 DAA	83.05[a]	69.70	70.69[b]	69.66	ND	ND

Values with different superscript within columns for each storage temperature are significantly different, LSD at 5% level.

Table 5. Total soluble solids content of white-fleshed dragon fruit upon withdrawal from low temperature storage and at VQR 5 (limit of marketability) at 20ºC

Maturity	Total soluble solids (ºBx)					
	WEEK 1 Withdrawn		WEEK 3 Withdrawn		WEEK 5 Withdrawn	
	Upon Withdrawal	VQR 5 at 20ºC	Upon Withdrawal	VQR 5 at 20ºC	Upon Withdrawal	VQR 5 at 20ºC
Storage at 5ºC						
31 DAA	13.4	11.4[b]	12.8	11.3[b]	12.5[b]	12.1
33 DAA	13.1	12.6[b]	12.9	11.3[b]	12.4[b]	12.1
35 DAA	13.1	14.7[a]	13.9	15.8[a]	15.1[a]	13.2
	WEEK 1 Withdrawn		WEEK 2 Withdrawn		WEEK 3 Withdrawn	
	Upon Withdrawal	VQR 5 at 20ºC	Upon Withdrawal	VQR 5 at 20ºC	Upon Withdrawal	VQR 5 at 20ºC
Storage at 13ºC						
31 DAA	12.7	12.6[b]	12.2	12.4	13.4	10.9
33 DAA	12.6	14.4[a]	13.2	12.9	ND	ND
35 DAA	12.1	13.5[ab]	12.5	13.5	ND	ND

Values with different superscript within columns for each storage temperature are significantly different, LSD at 5% level.

Table 6. TSS/TA ratio of white-fleshed dragon fruit upon withdrawal from low temperature storage and at VQR 5 (limit of marketability) at 20ºC

Maturity	TSS/TA ratio					
	WEEK 1 Withdrawn		WEEK 3 Withdrawn		WEEK 5 Withdrawn	
	Upon Withdrawal	VQR 5 at 20ºC	Upon Withdrawal	VQR 5 at 20ºC	Upon Withdrawal	VQR 5 at 20ºC
Storage at 5ºC						
31 DAA	25.2[b]	74.8[b]	22.8[b]	48.3[b]	30.0[b]	38.5
33 DAA	24.6[b]	90.0[b]	35.7[ab]	67.6[b]	33.3[b]	56.0
35 DAA	44.0[a]	118.3[a]	41.6[a]	110.6[a]	57.1[a]	58.0
	WEEK 1 Withdrawn		WEEK 2 Withdrawn		WEEK 3 Withdrawn	
	Upon Withdrawal	VQR 5 at 20ºC	Upon Withdrawal	VQR 5 at 20ºC	Upon Withdrawal	VQR 5 at 20ºC
Storage at 13ºC						
31 DAA	32.2	122.7	60.2 [b]	87.5	80.8	81.9
33 DAA	43.4	76.9	97.0 [a]	93.3	ND	ND
35 DAA	25.4	98.4	86.2 [ab]	95.9	ND	ND

Values with different superscript within columns for each storage temperature are significantly different, LSD at 5% level.

fruit harvested at 35 DAA had the highest TSS/TA ratio regardless of the withdrawal period and whether analyzed upon removal from 5ºC storage or upon reaching the limit of marketability at 20ºC (post-storage). On the other hand, no consistent pattern was obtained in 13ºC-stored fruit both upon withdrawal from storage and at the limit of marketability.

3.5 Sensory characteristics

When the fruit was presented to sensory panellists upon withdrawal from one week of storage at 5ºC, no significant differences were perceived on sweetness and juiciness among harvest maturity stages but sourness was rated as significantly higher in 31 DAA fruit (Figure 8A). When withdrawn on the 3rd week, 33 and 35 DAA fruit were perceived as significantly sweeter and juicier than 31 DAA fruit hence are more liked by the panellists (Figure 8B). Withdrawal on the 5th week further showed the significantly higher sweetness of 35 DAA fruit thus its higher overall acceptability than the less mature fruit (Figure 8C). A similar pattern among maturity stages was observed when fruit was transferred to 20ºC and evaluated at the limit of marketability (Figures 8D and E).

In the case of 13ºC-stored fruit, there were no significant differences obtained among fruit maturity stages for all sensory parameters except for the higher sourness scores of 33 DAA fruit on week 1 (Figure 9A). An extended period at 13ºC and transfer to a warmer temperature (20ºC) decreased the intensity of sourness which was disliked by the panellists, but the fruit was still rated as acceptable with overall acceptability of 4 (Figure 9B). Post-storage at 20ºC decreased the overall acceptability rating to 3 (fairly acceptable) when fruit was withdrawn on the 2nd week of storage (Figure 9C and D).

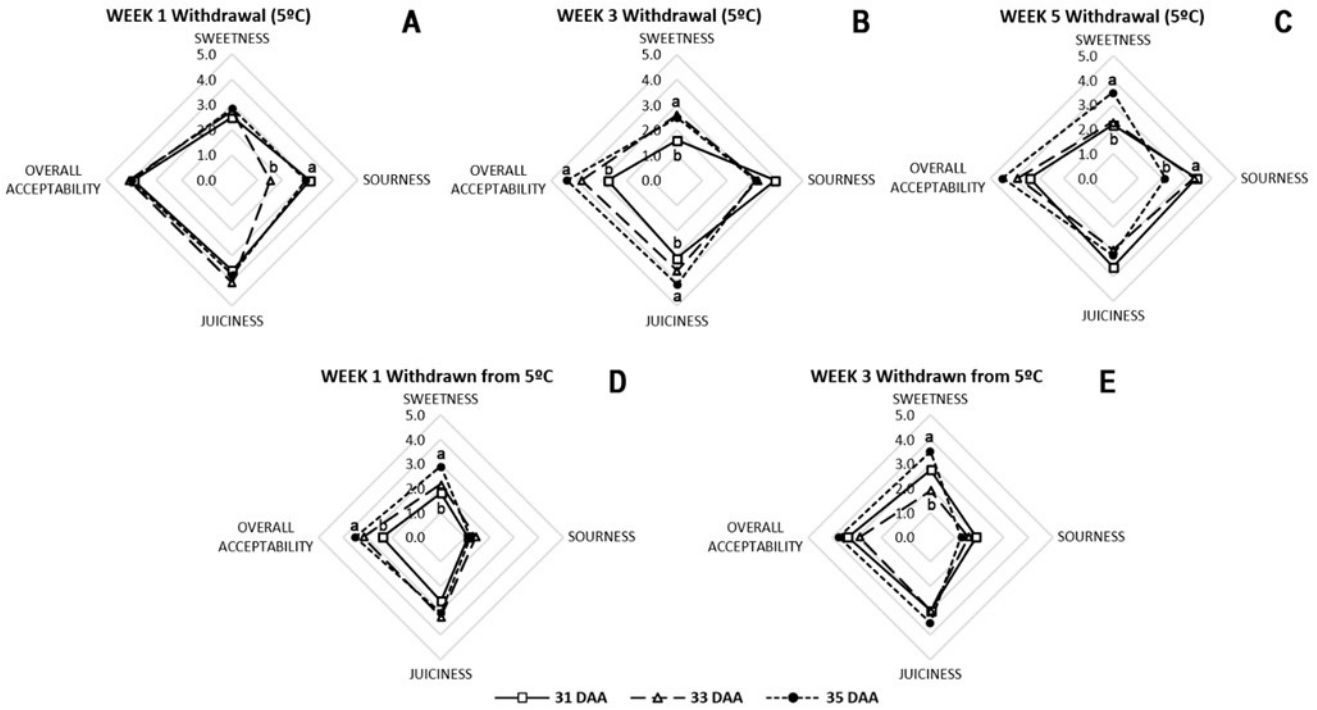

Figure 8. Sensory scores of panelists for sweetness, sourness, juiciness, and overall acceptability of dragon fruit harvested at three maturities upon withdrawal at 5ºC after one week (A), three weeks (B), and five weeks (C) of continuous storage, and at limit of marketability at 20ºC post-storage after first week (D) and third week (E) withdrawal from 5ºC storage.

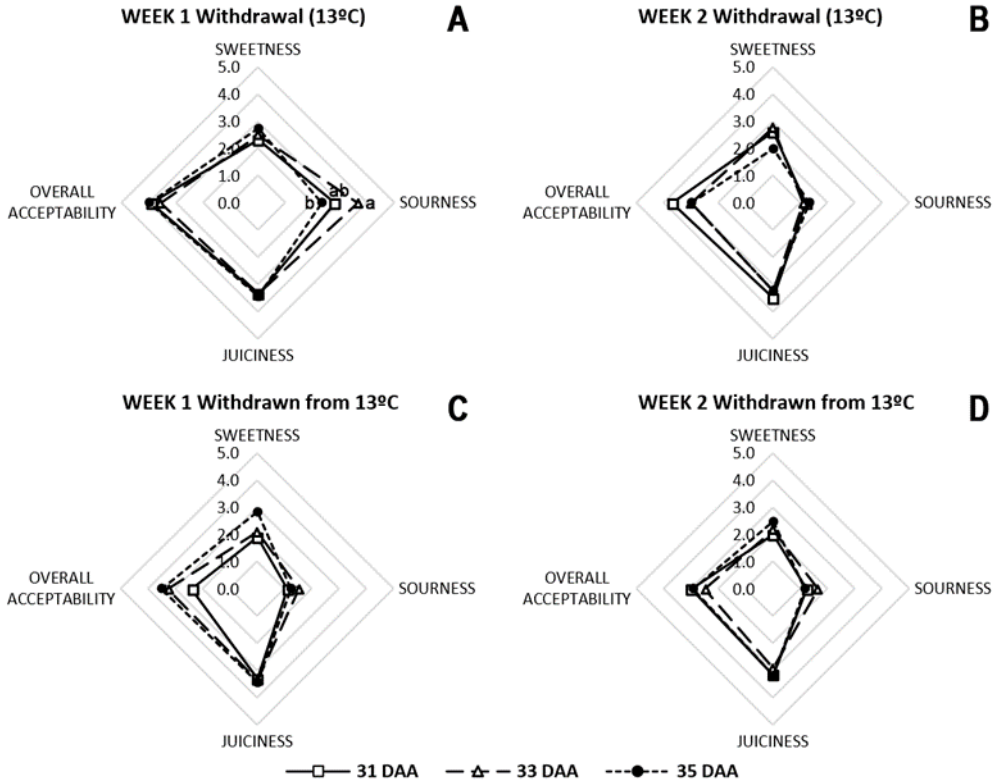

Figure 9. Sensory scores of panelists for sweetness, sourness, juiciness, and overall acceptability of dragon fruit harvested at three maturities upon withdrawal at 13ºC after one week (A) and two weeks (B) continuous storage, and at limit of marketability at 20ºC post-storage after first week (C) and second week (D) withdrawal from 13ºC storage. There were no significant differences among treatments.

4. Conclusion

Based on the extrinsic (peel color) and the intrinsic (TSS and TSS/TA) quality attributes, dragon fruits are best harvested at 35 DAA. For 13°C storage, 31, 33 and 35 DAA can be considered as appropriate harvest maturity since there were no significant differences in the internal and eating qualities. When stored for one week at 13°C, post-storage life at 20°C was 9 days for 31 and 33 DAA fruit, and only 7 days for 35 DAA fruit. Storage at 13°C can be extended up to two weeks but post-storage life at 20°C was only 3-5 days for all maturity stages. At 5°C, dragon fruit harvested at 33 and

35 DAA can be stored for three weeks, with post-storage life of 9 days at 20°C before reaching the limit of marketability. Better eating qualities, however, were noted in 35 DAA fruit thus, it can be considered as best maturity stage for 5ºC storage. Fruit harvested at 31 DAA and stored at 5°C for three weeks exhibited flesh translucency when transferred to 20°C retail condition. Thus, 31 DAA is not recommended as harvest maturity if to be stored at 5°C.

Acknowledgements

The research work was funded by the Department of Agriculture – Bureau of Agricultural Research (DA-BAR) through the project entitled "Quality Systems Improvement of Dragon Fruit, Soursop and Apple Guava through Value Chain Analysis and Management". The authors would like to acknowledge Mr Edilberto Silan of Silan'sAgri-Farm for allowing the researchers to conduct the tagging of flowers and fruits on his farm and for providing information on the management practices of dragon fruit.

References

Bae, S.H. and Suh, H.J. (2007). Antioxidant activity of five different mulberry cultivars in Korea. *Lebensmittel-Wissenschaft and Technologie*, 40(6), 955-962. https://doi.org/10.1016/j.lwt.2006.06.007

De Freitas, S.T., Nham, N.T. and Mitcham, E.J. (2011). Pitaya (Pitahaya, Dragon Fruit). Recommendations for maintaining postharvest quality. University of California, Davis. Retrieved on March 25, 2018 from UC Davis website: http://postharvest.ucdavis.edu/PFfruits/Pitaya.

De Freitas, S.T. and Mitcham, E.J. (2013). Quality of pitaya fruit (*Hylocereus undatus)* as influenced by storage temperature and packaging. *Scientia Agricola*, 70(4), 257-262. https://doi.org/10.1590/S0103-90162013000400006

Esquivel, P., Stintzy, F.C. and Carle, R. (2007). Phenolic compound profile and their corresponding antioxidant capacity of purple pitaya genotypes. *BioScience*, 62(9-10), 636-644. https://doi.org/10.1515/znc-2007-9-1003

Haliwell, B. (2006). Reactive oxygen species and antioxidants. Redox biology is a fundamental theme of aerobic life. *Plant Physiology,* 141(2), 312-322. https://doi.org/10.1104/pp.106.077073

Harivaindaran, K.V., Rebecca, O.P.S. and Chandran, S. (2008). Study of optimal temperature, pH and stability of dragon fruit (*Hylocereus polyrhizus*) peel for use as potential natural colorant. *Pakistan Journal of Biological Sciences*, 11(18), 2259-2263. https://doi.org/10.3923/pjbs.2008.2259.2263

Jamilah, B., Shu, C.E., Kharidah, M., Dzulkifly, M.A. and Noranizan, A. (2011). Physico-chemical characteristics of red pitaya (*Hylocereus polyrhizus*) peel. *International Food Research Journal*, 8, 279-286.

Kammapana, L., Jitareerat, P., Wong-Aree, C., Srilaong, V. and Yamauchi, N. (2013). Chlorophyll degradation in the bract of dragon fruit (*Hylocereus* spp.). *Acta Horticulturae*, 1088, 79-84. https://doi.org/10.17660/ActaHortic.2015.1088.8

Khamsah, S.M., Akowah, G. and Zhari, I. (2006). Antioxidant activity and phenolic content of Orthosiphon stamineus benth from different geographical origin. *Journal of Sustainability Science and Management*, 1(2), 14-20.

Mizrahi, Y. (2015). Thirty one years of research and development in the vine cacti pitaya in Israel. In: Jiang, Y.L., Liu, P.C. and Huang, P.H. (Eds). Improving Pitaya Production and Marketing, p. 1-18. Taipei, Taiwan: Food and Fertilizer Technology Center.

Nerd, A., Gutman, F. and Mizrahi, Y. (1999). Ripening and postharvest behaviour of fruits of two *Hylocereus* species (Cactaceae). *Postharvest Biology and Technology,* 15(1), 99-105. https://doi.org/10.1016/S0925-5214(98)00080-5

Nurliyana, R., Syed Zahir, I., Mustapha Suleiman, K., Aisyah, M.R. and Kamarul Rahim, K. (2010). Antioxidant study of pulps and peels of dragon fruits: a comparative study. *International Food Research Journal*, 17, 367-375.

Obenland, D., Cantwell, M., Lobo, R., Collins., S., Sievert, J. and Arpaia, M.L. (2016). Impact of storage conditions and variety on quality attributes and aroma volatiles of pitahaya (*Hylocereus* spp.). *Scientia Horticulturae*, 199, 1522. https://doi.org/10.1016/j.scienta.2015.12.021

Ortiz, T.A. and Takahashi, L.S.A. (2015). Physical and chemical characteristics of pitaya fruits at physiological maturity. *Genetics and Molecular Research*, 14(4), 14422-14439. https://doi.org/10.4238/2015.November.18.5

Rodeo, A.J.D., Castro, A.C. and Esguerra, E.B. (2018). Postharvest handling of dragon fruit (*Hylocereus* spp.) in the Philippines. Presented at the Dragon fruit Regional Network Initiation Workshop and Steering Committee Meeting, p. 125-131. Taipei, Taiwan.

Silva, E. (2008). Respiration Rate and Ethylene and their Relationship to Postharvest Handling. Retrieved from Family Farmed website: bit.ly/familyfarmed-retail.

To, L.V., Ngu, N., Duc, N. and Huong, H. (2002). Dragon fruit quality and storage life: effect of harvesting time, use of plant growth regulators and modified atmosphere packaging. *Acta Horticulturae*, 575(575), 611-621. https://doi.org/10.17660/ ActaHortic.2002.575.72

Woolf, A., Do, M., Hoa, T., Nguyen, M., Jackman, R. and Clark, C. (2006). Hort Research and SOFRI Dragon Fruit Assessment Manual. 1st ed., p. 1-30. Auckland, New Zealand: The Horticulture and Food Research Institute of New Zealand Ltd.

Wu, C. (2014). Fruit Maturity Index Implementation. Retrieved June 14, 2018 from APEC website: http:// apec.flows.ntu.edu.tw/tool/kits-detail.aspx?/seg=37

eISSN: 2550-2166