

Fruit quality and harvest point determination in white-fleshed dragon fruit

Qualidade de frutos e determinação do ponto de colheita de pitaita de polpa branca

Calidad del fruto y determinación del punto de cosecha de pitaita de pulpa blanca

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Ivan Marcos Rangel Junior

ORCID: <https://orcid.org/0000-0001-5878-3819>
Federal University of Lavras, Brazil
E-mail: juniorrangel2@hotmail.com

Deniete Soares Magalhães

ORCID: <https://orcid.org/0000-0003-1487-3163>
Federal University of Lavras, Brazil
E-mail: denieteagro@yahoo.com.br

Filipe Almendagna Rodrigues

ORCID: <https://orcid.org/0000-0003-2433-4374>
Federal University of Lavras, Brazil
E-mail: filipealmendagna@yahoo.com.br

Moacir Pasqual

ORCID: <https://orcid.org/0000-0001-5612-9186>
Federal University of Lavras, Brazil
E-mail: mpasqual@ufla.br

Leila Aparecida Salles Pio

ORCID: <https://orcid.org/0000-0001-5246-5035>
Federal University of Lavras, Brazil
E-mail: leilapio.ufla@gmail.com

Abstract

The objective of this study was to evaluate the quality of white-fleshed dragon fruit (*Hylocereus undatus*) at harvest and postharvest to determine fruit quality and the feasibility of harvesting the fruits at different outer fruit color stages. The treatments consisted of four peel color stages – S1 (<25% red peel), S2 (25%-49% red peel), S3 (50% to 75% red peel) and S4 (>75% red peel) – and two evaluation times (at harvest and one day after full red peel color), which corresponded to 1, 3, 5 and 7 days after harvest for the S4, S3, S2 and S1 color stages, respectively. The total, peel and pulp weights, pulp yield, peel thickness, pulp firmness, pH, total soluble solids and peel, scale and pulp colors were evaluated. The peel and scale colors are reliable indicators of fruit quality. It is possible to extend the postharvest shelf life of the fruits by harvesting at the S1 stage, but this negatively affects yield and final quality; the fruits are smaller and less sweet, making harvesting unfeasible at this timepoint. Despite the higher yield and quality of fruits harvested at a more advanced ripeness stage (S4), the postharvest shelf life is considerably reduced. Thus, fruits at stages S2 or S3 should be harvested to obtain higher yield and quality.

Keywords: *Hylocereus undatus*; Tropical fruit growing; Pitaya.

Resumo

O estudo teve como objetivo avaliar a qualidade de frutos de pitaita na colheita e pós-colheita visando verificar sua qualidade e viabilidade da colheita em diferentes estágios de coloração externa do fruto. Os tratamentos foram compostos por quatro estágios de coloração do fruto - E1 (até 25% de coloração avermelhada), E2 (mais que 25% e menos que 50% da coloração da casca de coloração avermelhada), E3 (mais que 50% e menos que 75% de coloração da casca avermelhada) e E4 (acima de 75% de coloração avermelhada na casca) - e duas épocas de avaliação (na colheita e um dia após a completa coloração avermelhada da casca), o que correspondeu a 1, 3, 5 e 7 dias após a colheita para os estágios de coloração E4, E3, E2 e E1, respectivamente. Foram avaliadas massas totais do fruto, da casca e da polpa, rendimento em polpa, espessura da casca, firmeza da polpa, pH, sólidos solúveis totais, coloração da casca, escamas e polpa. A coloração da casca e escamas pode ser um indicador confiável na determinação da qualidade dos frutos. Além disso, é possível estender a vida útil pós-colheita dos frutos em E1, porém afeta negativamente o rendimento em produção e qualidade final, bem como menor tamanho e doçura dos frutos, inviabilizando a colheita nesse ponto. Apesar do maior rendimento e qualidade dos frutos colhidos em estágios mais avançados de maturação (E4), a vida útil pós-colheita é reduzida consideravelmente. Dessa forma, deve-se colher os frutos nos estágios E2 ou E3 visando maior rendimento e qualidade.

Palavras-chave: *Hylocereus undatus*; Fruticultura Tropical; Pitaita.

Resumen

El estudio tuvo como objetivo evaluar la calidad de los frutos de pitaya en la cosecha y poscosecha con el fin de verificar su calidad y viabilidad de la cosecha en diferentes etapas de coloración externa del fruto. Los tratamientos consistieron en cuatro etapas de coloración del fruto: E1 (hasta un 25% de color rojizo), E2 (más del 25% y menos del 50% de la coloración de la piel rojiza), E3 (más del 50% y menos más del 75% de coloración rojiza de la piel) y E4 (por encima del 75% de la coloración rojiza de la piel) - y dos períodos de evaluación (en la cosecha y un día después de la coloración rojiza completa de la piel), que correspondieron a 1, 3, 5 y 7 días después de la cosecha para las etapas de tinción E4, E3, E2 y E1, respectivamente. Se evaluó la masa total de fruta, cáscara y pulpa, rendimiento de pulpa, grosor de cáscara, firmeza de la pulpa, pH, sólidos solubles totales, color de piel, escamas y pulpa. El color de la piel y las escamas pueden ser un indicador confiable para determinar la calidad de los frutos. Además, es posible alargar la vida útil poscosecha de los frutos en E1, pero afecta negativamente el rendimiento en producción y calidad final, así como el menor calibre y dulzor de los frutos, haciendo inviable la recolección en este punto. A pesar del mayor rendimiento y calidad de los frutos recolectados en etapas más avanzadas de maduración (E4), la vida útil poscosecha se reduce considerablemente. Por lo tanto, los frutos deben recolectarse en las etapas E2 o E3, con el objetivo de obtener un mayor rendimiento y calidad.

Palabras clave: *Hylocereus undatus*; Cultivo de frutas tropicales; Pitaya.

1. Introduction

Dragon fruit (*Hylocereus* spp.) is a cactus native to the Americas that has expanded to several tropical and subtropical regions of the world. In addition to having a pleasant and unique flavor, the fruit draws attention due to its exotic appearance and is considered one of the most beautiful fruits in the world.

Although only recently introduced in Brazil, dragon fruit has great potential for cultivation and commercialization, and in addition to the fruit, the peel, flower and cladode can be utilized (Ortiz & Carrillo, 2012). However, the unique characteristics of dragon fruit raises doubt regarding its cultivation because it is an unusual plant compared to other fruit plants grown in Brazil. Thus, studies on its production, from seedling preparation to processing, are important to facilitate crop propagation.

Fruit quality and postharvest preservation state are closely related to harvest time, especially the degree of ripeness at the time of cutting, which determines the final quality of the product, which in turn can be negatively affected when harvesting is performed early or late (Chitarra & Chitarra, 2005; Wanitchang et al., 2010).

There is still no consensus regarding the climacteric behavior of dragon fruit. However, published studies consider dragon fruit to be climacteric (Gómez, et al., 2008), while other studies characterize it as nonclimacteric (Nerd et al., 1999; Zee et al., 2004; Chien et al., 2007). Although there are disagreements about its climacteric behavior, it is certain that dragon fruit is highly perishable and presents a series of postharvest problems arising from mechanical injury, rot, chilling and drying, resulting in decreased fruit quality and a shorter shelf life (Nerd et al., 1999; Wall & Khan, 2008; Castro et al., 2014).

Peel color stage has been used as the main marker for dragon fruit harvest. The peel color changes from green to red during ripening, becoming completely red in the 4 to 5 days following the first color change, when the fruit is still attached to the mother plant. At the apex of ripening, dragon fruit turn pinkish red. Ripe fruits can be harvested at 30 to 52 days after floral bud opening (Castillo & Ortiz, 1994; Weiss et al., 1994; Pushpakumara et al., 2005), which can vary according to several factors, such as climatic conditions, soil, management and harvest time.

Therefore, the objective of this study was to evaluate the quality of dragon fruits at harvest and postharvest to assess fruit quality and the feasibility of harvesting the fruits at different outer fruit color stages.

2. Methodology

The study was conducted at the departments of Agriculture and Food Science of the Federal University of Lavras, located in the city of Lavras, southern Minas Gerais, Brazil. The local climate is characterized by rainy summers and dry winters, with a mean temperature of 22 °C, and is considered Cwa according to the Köppen classification.

Fruit harvesting, selection and classification

A total of 48 dragon fruits were harvested, at four different visual ripeness stages, from different plants belonging to the collection of the Fruit Sector of the Department of Agriculture; the fruits were placed in plastic bags and stored in a Styrofoam box. Next, the fruits were transported to the Post-Harvest Laboratory of the Department of Food Science, where they were washed with water and 5% sodium hypochlorite sanitizing solution for five minutes and dried using paper towels.

The fruits were then selected and classified based on peel color into stages S1 (<25% red peel), S2 (25% -49% red peel), S3 (50% to 75% red peel) and S4 (>75% red peel).

Analyses were performed at two different times: on the day of harvest and after the entire peel became red (visual observation). At each evaluation time, six fruits from each peel color stage were used. All analyses were performed concomitantly after harvest. The evaluations performed when the peel become completely red occurred at 1, 3, 5 and 7 days after harvest, corresponding, respectively, to stages S4, S3, S2 and S1.

Physicochemical analysis

The fruits were evaluated for total weight (g), pulp weight (g) and peel weight (g). The data were obtained on a digital scale.

Pulp yield (%) was obtained by applying the following formula:

$$PY\% = \frac{(\text{pulp weight} \times 100)}{\text{total weight}}$$

Fruit peel thickness (mm) was measured with a digital caliper; pulp firmness (N) was determined with a hand-held penetrometer at the equatorial region of the fruit.

The following chemical analyses were performed: pH (using a digital pH meter; the sample was ground and homogenized at a ratio of 1:4 (10 g of pulp to 40 mL of distilled water) with a Polytron homogenizer and subsequently filtered for analysis) and soluble solids (%) (using a digital refractometer based on an AOAC method (2007)).

Color analysis

The color of the peel, scales and pulp was determined with the aid of a Minolta colorimeter (model CR-400, with D65 illuminant and in the CIELAB color space). The readings were performed at four random points of each replicate to obtain the coordinates of luminosity, a^* , b^* , chroma and hue angle.

Luminosity (L^*) ranges from 0 to 100 and indicates the degree of color brightness, which refers to the ability of the object to reflect or transmit the light incident on it; the closer the value is to zero, the darker the sample. In fruits, luminosity is related to freshness, and the higher the luminosity value is, the fresher the fruits tend to be.

The variable a^* is the coordinate indicative of the color variation from green to red. Negative values indicate greener colors, and positive values indicate redder colors. The variable b^* is the coordinate indicative of the color variation from yellow to blue. Negative values indicate bluer colors, and positive values indicate yellower colors.

Chroma indicates color intensity, and the higher the value is, the more intense and purer the color being examined. The hue angle is the coordinate that shows where the color falls on a 360° color wheel.

Experimental design

The experimental design was completely randomized in a 4 × 2 factorial scheme, with four ripeness stages and two evaluation time points, with six replicates and one fruit per experimental plot.

The data were subjected to analysis of variance using SISVAR software (Ferreira, 2011). The means of the evaluation time points were subjected to Tukey's test at 5% probability.

3. Results and Discussion

Physicochemical analysis

There was no significant effect of the interaction between color stage and evaluation time on any of the analyzed variables ($p < 0.05$). For the color stage factor, significant differences were detected in all analyzed variables, except peel weight and pulp firmness. For the evaluation time factor, there were significant differences in fruit weight, peel weight, yield, peel thickness and soluble solids (Table 1).

Table 1. Mean values for fruit weight (FW), peel weight (PeW), pulp weight (PuW), yield (YD), peel thickness (PT), pH and soluble solids (SS) at four different peel redness stages (S1 (<25%), S2 (25-49%), S3 (50-75%) and S4 (>75%)) and two evaluation times.

Stage	FW (g)	PeW (g)	PuW (g)	YD (%)	PT (mm)	pH	SS (%)
S1	363.82 b	138.55 a	225.27 b	62.29 b	4.64 c	3.55 c	12.17 c
S2	482.91 a	166.31 a	316.61 a	65.58 b	4.36 bc	3.89 b	14.07 b
S3	457.91 ab	152.98 a	304.94 a	65.95 b	3.62 ab	3.95 b	14.58 b
S4	478.25 a	125.11 a	353.14 a	74.10 a	3.20 a	4.41 a	15.67 a
Time	FW (g)	PeW (g)	PuW (g)	YD (%)	PT (mm)	pH	SS (%)
Time 1	460.64 a	163.66 a	303.00 a	64.20 b	4.30 b	3.95 a	13.59 b
Time 2	430.81 b	127.81 b	296.98 a	69.76 a	3.61 a	3.95 a	14.65 a
CV (%)	21.3	29.87	23.30	20.00	22.09	5.06	6.18
Mean	445.72	145.73	299.99	65.93	3.96	3.95	14.12

*Means followed by the same letter in columns do not differ significantly by Tukey's test at 5% probability.
 Source: Authors.

No significant differences were detected in pulp firmness, and the overall mean was 3.81 N (CV = 11.48%), ranging from 3.71 to 3.95 N. In fruits, tissue softening is one of the first signs of ripening and is related to changes in fruit structure and metabolism (Chitarra & Chitarra, 2005). Thus, it is possible to infer that the stability in peel firmness values (3.83, 3.95, 3.71 and 3.74 N for stages 1, 2, 3 and 4, respectively) indicates that all analyzed treatments had already entered the initial pulp ripening phase.

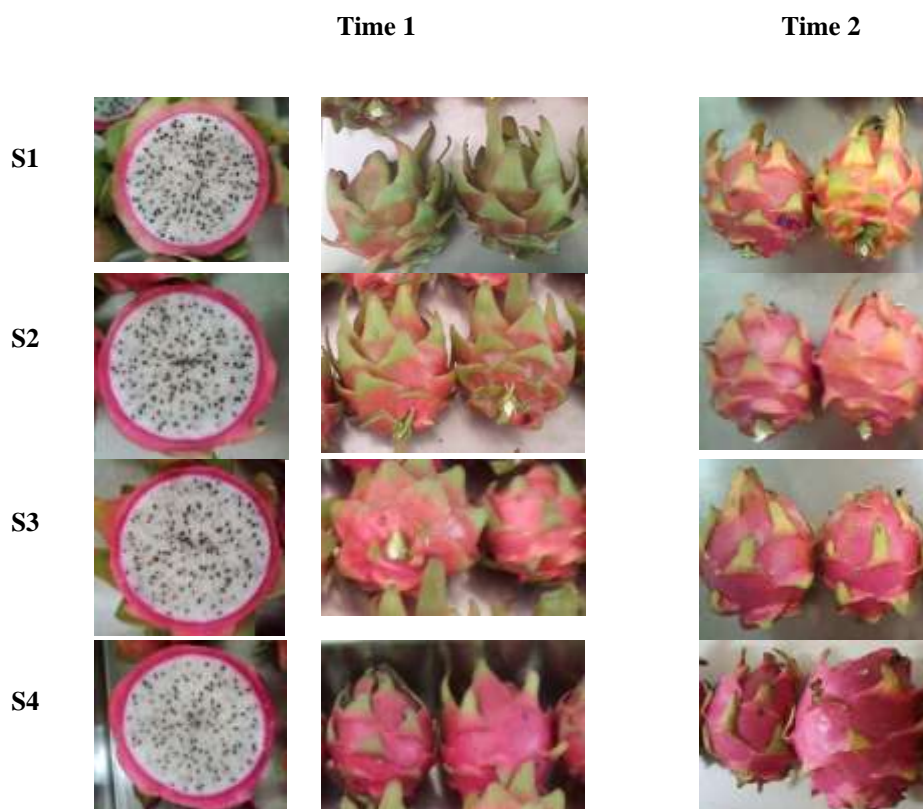
Moreover, even at a certain time after harvest, there was little variation in peel firmness values (3.70 N for time 1 and 3.91 N for time 2), regardless of fruit color. This stability can be explained by the fact that at the same time as tissues begin to soften, there is an increase in the degree of fruit ripening resulting from the action of hydrolytic enzymes and other

processes. The wilting and drying of fruits also increase the concentration of substances that stiffen tissues, such as fibers, conferring greater resistance to fruits.

Fruit weight differed significantly ($p < 0.05$) both among the color stages and between the evaluation times (Table 1). In addition, there was a greater discrepancy between color stages S1 and S2, with an increase in the total fruit weight of approximately 120 g in the later, then remaining stable in the subsequent stages. This finding suggests that harvesting at stage S1 has a direct effect on fruit weight gain, interrupting its increase. Fruit size is an important variable from the commercial view point because larger fruits may be more attractive for commercialization because they affect the individual preference of consumers.

Peel weight was significantly different only between the evaluation times, with time 1 showing higher values (Table 1). Similar to pulp weight, it is possible that these results are due to postharvest drying, which can be confirmed by the reduction in peel thickness at time 2 (Figure 1).

Figure 1. White-fleshed dragon fruit at time 1 (on the day of harvest) and time 2 (after the change in outer fruit color).



Source: Authors.

A significant difference was detected for pulp weight only for the color stage factor, with the weight at S1 being lower than at the other stages. Stage S1 contained the most immature fruits among the evaluated stages; the fruits were possibly still in the growth phase, contributing to the fruit and peel weight results. According to Chitarra and Chitarra (2005), when immature, fruits are still in the growth and expansion phase, and as soon as they reach physiological maturity, growth begins to slow or ceases, and metabolites are rerouted to the development of organoleptic characteristics. Yah et al. (2008) evaluated dragon fruit postharvest at three maturation stages and observed that during the change in outer color, there was significant pulp accumulation and peel weight loss.

Pulp yield differed significantly among color stages and evaluation times. Regarding color stage, there was an increase in pulp yield as the peel redness increased (Table 1). However, only stage S4 differed significantly, with a higher pulp yield of 74.10%, which is an approximately 12% increase compared to the stage with the lowest yield (62.29%, S1), which is especially important for fruits intended for industry. For evaluation time, a higher pulp yield was observed in the second evaluation, with an approximately 5% increase. However, this increase resulted from the loss of water due to drying of the peels and scales after harvest, causing a reduction in peel weight between the different evaluation times.

Significant differences in peel thickness were observed among the color stages and between the evaluation times, with a reduction with advancing ripeness both at harvest and after harvest. In this study, the fruits were at different development stages when harvested, and according to Magalhães et al. (2019), thinning of the peel indicates progression in fruit development, which indicates that changes in the degree of redness also indicate variations in the fruit ripeness stage.

During fruit growth and development, there is an initial gain in peel and pulp weight concomitant with seed development and maturation. This process is a plant defense strategy to prevent microorganism proliferation and protect the seeds to ensure the perpetuation of the species. Cordeiro et al. (2015) found a similar result for red-fleshed dragon fruit (*Hylocereus polyrhizus*) when evaluating fruit quality postharvest.

In the pH analysis, a significant difference was observed only among the color stages, with an increase in pH with advancing ripeness (Table 1). Generally, the pH of fruits increases as they ripen. This occurs in response to the concentration of organic acids present in the fruits, which declines with the progression of ripeness, and to the concentration of soluble solids, which increases. When fruits reach physiological maturation, their energy is rechanneled from growth to maturation. Metabolic processes begin to take place and improve organoleptic properties, such as flavor, color and aroma (Chitarra & Chitarra, 2005). The pH was higher in the fruits with a higher proportion of reddish pigmentation – more advanced maturation stage – and differed significantly from stage S1, which had the lowest pH value. Stage S4 also differed from stages S2 and S3, which showed intermediate pH values.

There was an increase in total soluble solids with color stage and evaluation time (Table 1). A difference of only 1.06% was detected between times 1 and 2, while for color stage, this increase was 3.5% between S1 and S4. The intensification of soluble solids in dragon fruit after harvest seems to be slower than that of fruits still hanging from the mother plant. Chitarra & Chitarra (2005) state that organic acids present in a fruit are converted into sugars during ripening. That is, the dragon fruit ripens after being harvested, although it has not reached the same soluble solids content of fruits harvested when fully ripe. According to Centurión et al. (2000), total soluble solids content is strictly related to the development of the outer peel color of *Hylocereus undatus* and can be used as a visual marker of the ideal harvest point. In fruits harvested with fully pigmented outer color, Ortiz & Takahashi (2015) obtained a maximum total soluble solids content of 12.2% in dragon fruit at 31 days after anthesis. Magalhães et al. (2019) observed similar results, reaching a maximum value of 15.44% in white-fleshed dragon fruit (*Hylocereus undatus*). Osuna Enciso et al. (2011) observed higher total soluble solids in fruits at medium and complete ripeness, as in the present study.

The postharvest shelf life of fruits can be extended by harvesting at the S1 stage, but this negatively affects yield and final quality because they may not reach adequate weight and size for commercialization and have a lower amount of pulp and soluble solids.

In contrast, fruits harvested at a more advanced ripeness stage (S4), despite having higher yield, weight and soluble solids, in addition to being more pleasant to the palate, may have a considerably reduced postharvest shelf life because they have already reached their highest potential and tend to senesce, which becomes more important when considering the distance to the final point of sale, often preventing transport to more distant sites.

Conversely, the intermediate ripeness stages (S2 and S3) allow a more adequate balance between the organoleptic quality of the fruits and their postharvest shelf life, being considered the most indicated stages when simultaneously seeking to fulfill yield and quality requirements.

Color analysis

In the color analysis, the L*, a*, b* and chroma coordinates and hue angle were analyzed in the fruit pulp, peel and scales. The fruits are shown in Figure 1.

Peel color

There were significant differences in luminosity (color stage), a* (interaction), b* (color stage and evaluation time), chroma (interaction) and hue (interaction). In addition, the fruits showed a significant color change from time 1 to 2, reaching a similar color between the color stages in the second evaluation time (Tables 2 and 3).

Table 2. Mean values for the a* and chroma color coordinates and hue angle of the peel.

Stage	a*		Chroma		Hue	
	Time 1	Time 2	Time 1	Time 2	Time 1	Time 2
S1	10.72 dB	42.37 abA	18.89 cB	43.77 abA	58.62 cB	14.02 aA
S2	23.59 cB	44.22 abA	26.48 bB	45.61 aA	27.77 bB	13.84 aA
S3	31.46 bB	44.73 aA	33.21 aB	45.51 aA	18.73 aB	10.51 aA
S4	37.39 aA	39.11 bA	38.21 aA	39.66 bA	11.20 aA	9.15 aA
CV (%)	10.41		9.02		27.00	
Mean	34.20		36.42		20.48	

*Means followed by the same letter in the same column and/or in the same row do not differ significantly by Tukey's test at 5% probability. Source: Authors.

In general, when breaking down the effect of the degree of ripeness within the evaluation times, at time 1, there was an increase in the values of the a* coordinate and hue angle and a concomitant increase in the chroma coordinate as ripeness increased, indicating an increase in red color and its intensity. In addition, the a* coordinate differed significantly among all treatments, increasing according to the degree of ripeness, indicating that the selection criteria for the differentiation of the stages were effective. The higher the a* coordinate value and the closer the hue angle is to the 0° coordinate, the redder the fruit peel will be, and the higher the chroma values are, the greater the color intensity. For time 2, the hue angle values did not differ significantly among the ripeness levels, placing all of them in the same color range within the 360° color wheel. Although significant differences were detected for the a* and chroma coordinates, the difference in values among the treatments was small, indicating a tendency toward stabilization of the peel color when pigmentation was complete, which also ensures the reliability in the correct determination of the second evaluation time for each stage (Table 2).

In addition, the data from the b* coordinate analysis, in which significant differences were detected among the ripeness levels and between evaluation times, confirmed the trend of a reduction in the values with the increase in ripeness, also indicating a reduction in green color between the evaluation periods (Table 3). Regarding luminosity, there was a significant difference only among ripeness levels, but it was not considerable because the variation was less than three units,

which is slightly or not noticeable to human eyes, indicating that the freshness of the fruits remained stable over the evaluation periods, without considerable differences in the visual quality of the peel (Table 3).

When breaking down the effect of evaluation time within the color stages, the results were similar for the a* and chroma coordinates and for the hue angle, with significant differences among stages S1, S2 and S3, which had higher values at time 2, and without significant differences for stage S4. These results indicate that the increase in red color was noticeable between the evaluation times, except for treatment S4, as the fruits were already completely red at harvest (Table 2). Ortiz & Takahashi (2015) observed an increase in the chroma value during ripening from 28.5 to 45.1. Osuna Enciso et al. (2011) evaluated *H. undatus* and obtained similar results, noting that the hue angle values decreased with the ripeness levels and 12 days after harvest. Phebe et al. (2009) found a negative correlation between the concentration of betacyanins in the peel of *H. polyrhizus* and hue, with an increase of 65% in betacyanins and 90 in hue between 25 and 30 days after anthesis. According to Le Bellec et al. (2006), pigments called betalains are responsible for the red color of dragon fruit peel. According to To et al. (2002), for the commercialization of dragon fruit in Mexico, the hue must be less than or equal to 30.

Table 3. Mean values for the L* and b* color coordinates of the peel.

Stage	L*	b*
S1	49.93 a	12.95 c
S2	47.52 b	11.27 bc
S3	49.35 ab	9.44 b
S4	48.17 ab	6.78 a
Time	L*	b*
Time 1	48.71 a	11.27 b
Time 2	48.78 a	8.95 a
CV (%)	4.36	21.94
Overall mean	48.75	10.11

*Means followed by the same letter in the same column do not differ significantly by Tukey's test at 5% probability. Source: Authors.

This result was expected because with the intensification of reddish pigmentation in the fruit peel, the synthesis of pigments naturally results in the degradation and masking of the green color of chlorophyll. Yah et al. (2008) found no significant differences in luminosity during dragon fruit development. In turn, Ortiz & Takahashi (2015) obtained luminosity values between 50.7 and 37.8 for dragon fruit (*Hylocereus undatus*) and observed a decrease in the b* value in their treatments.

Scale color

In the analyzed fruit scales, there was a significant difference in L* (degree of ripeness), a* (interaction), b* (interaction), chroma (interaction) and hue angle (interaction), as shown in Tables (4 and 5).

Table 4. Mean values for the variables a*, b*, chroma and hue angle of the scales.

Stage	a*		b*	
	Time 1	Time 2	Time 1	Time 2
S1	-11.70 cB	40.09 aA	46.06 aB	14.73 aA
S2	-0.68 bB	41.50 aA	15.26 bA	17.34 aA
S3	17.74 aB	40.37 aA	14.01 bA	13.56 aA
S4	23.24 aB	29.53 bA	12.78 bA	13.06 aA
CV (%)	20.64		81.06	
Mean	22.76		18.35	
Stage	Chroma		Hue	
	Time 1	Time 2	Time 1	Time 2
S1	24.17 aB	42.74 aA	118.53 cB	20.22 aA
S2	15.82 bB	45.07 aA	86.85 bB	22.42 aA
S3	24.89 aB	42.69 aA	38.33 aB	18.69 aA
S4	26.61 aB	32.37 bA	28.65 aA	24.00 aA
CV (%)	13.94		19.36	
Mean	31.79		44.71	

*Means followed by the same letter, in the same column and/or in the same row do not differ significantly by Tukey's test at 5% probability. Source: Authors.

When analyzing the effect of degree of ripeness within the evaluations times, at time 1, fruits in stages S1 and S2 showed negative a* coordinate values, the latter with values close to 0, while fruits in stages S3 and S4 showed positive values. These results indicate that the center of the fruit scales changed from green to red, according to the degree of ripeness, and that fruits in stages S1 and S2 had predominantly green scales, whereas the fruits in stages S3 and S4 had predominantly red scales, although with higher proportions of green in the former and red in the latter.

During ripening, the pigmentation process begins in the fruit, first in the peel then progressing to the scales, from the base to the ends, so the more advanced the degree of fruit ripening, the higher the a* coordinate values are expected to be. The hue angle values are consistent with the a* coordinate results, which confirms the preceding statement.

Regarding the b* coordinate, at time 1, all results showed positive values, indicative of the presence of yellow color. Only stage S1 differed significantly, with a higher b* value than the others, indicating a more pronounced yellow color. This result is likely due to the fact that at more immature stages, chlorophyll and anthocyanins, which correspond to the green and yellow pigments, respectively, are present in the scales. However, starting at the S2 stage, with the increase in the reddish pigmentation of the scales, due to the synthesis of betalains, the yellow color is the first to be masked in the scales, resulting in lower and stable values of this color coordinate.

Regarding chroma, at time 1, only stage S2 showed significant differences, with lower values than the other stages, indicating lower color intensity. This result can be explained by the fact that this stage is the one that most represents the transition between the green and red colors, reducing fruit purity and consequently chromaticity values.

Conversely, the hue angle tended to decrease with increasing ripeness, although stages S3 and S4 did not differ from each other, as occurred with the a^* coordinate, also at time 1. These findings result from the lower variation detected in the values between these stages compared to the others.

When analyzing the effect of degree of ripeness within time 2, the a^* , b^* and chroma coordinates and hue angle did not differ significantly among the treatments, except a^* and hue at S4. These results indicate that all initial ripeness levels reached similar scale colors in the second evaluation time, demonstrating that harvesting at different ripeness levels has little effect on color change after harvest. They also indicate that scale color is a good morphological marker to evaluate the ideal harvest point of dragon fruit.

Regarding the effect of evaluation time within the color stages, there was a significant difference in a^* , chroma and hue angle at all ripeness stages between times 1 and 2, with higher values observed at time 2, but there were no significant differences between evaluation times for the b^* coordinate, except for the a^* coordinate at S1 at the hue angle at S4. These results indicate that there was an increase in red color, as well as in color intensity, with advancing ripeness after harvest. Regarding the b^* coordinate at S1, this result is explained by the greater color change between the two evaluation times when compared to the other stages, which already had greater reddish pigmentation (7 days). The opposite occurred for the hue angle at S4, as there was little change in color from one day to the next.

Magalhães et al. (2019) obtained negative a^* coordinate values in the scales in fruits up to 34 days after anthesis and stated that the reddish color appears later in the scales, at more advanced ripening stages, suggesting a visual way to detect the harvest point. Values below 90 are indicated for the scales. Mello et al. (2015) attributed the color of dragon fruit to the presence of betalains.

S1 is the stage with the most green peel color, making this stage differ most from the others 2 days after harvest. Magalhães et al. (2019) observed a decrease in b^* values, from 27.43 to 16.94. In turn, Ortiz & Takahashi (2015) found values between 30.6 and 7.6. At time 2, the color of all treatments intensified, indicating ripening. The largest difference in hue angle was observed in stage S1, as the scales changed from the green to the red quadrant (Table 4). For stage S4, no significant difference was observed between the evaluations times because the color remained in the red quadrant. Magalhães et al. (2019) also found a decrease in hue values as the fruit ripened, moving from the green to the red quadrant.

For luminosity, although the results showed significant differences, there was no considerable variation in the values, with a mean of 48.54 (Table 5).

Table 5. Mean L* values for the scales.

Stage	L*
S1	50.56 a
S2	47.46 b
S3	48.62 ab
S4	47.52 b
CV (%)	5.34
Overall mean	48.54

*Means followed by the same letter in the column do not differ significantly by Tukey's test at 5% probability.
Source: Authors.

The results indicate color close to grayscale, i.e., intermediate values between light and dark, suggesting that the fruits remained fresh during the evaluation period. Magalhães et al. (2019) observed a decrease in L* values in the peel and scales during ripening, and the greatest range was observed in the values for the scales, which were between 52.73 and 42.59, close to those found in the present study.

Pulp color

There were no significant differences in the luminosity, a*, b* or chroma coordinates or hue angle of the pulp, with means of 50.03 (CV = 8.27%), 0.61 (CV = 44.93%), 2.23 (CV = 23.08%), 2.36 (CV = 25.57%) and 73.63 (CV = 13.40%), respectively. The lack of betalains in the pulp of white-fleshed dragon fruit explains the almost null values of the a*, b* and chroma parameters due to the lack of reddish and bluish color. The neutrality of these colors, together with the mean luminosity and hue angle values found, indicate a slightly grayish white color, characteristic of the white color of the pulp, with influence of the black color of the seeds surrounded by the pulp.

Based on the results of this study, the color of the peel and scales of the fruits are important markers for determining the degree of fruit ripeness and the ideal harvest point because they are closely related to the internal quality and weight of the fruits. In addition, the study identified that both early and late harvesting can lead to losses in fruit quality or reduce the postharvest shelf life.

4. Conclusion

Peel and scale color are reliable indicators of dragon fruit quality. It is possible to extend the postharvest shelf life of the fruits by harvesting at the S1 stage, but this negatively affects production yield and final quality, and the fruits are smaller and less sweet, making harvesting unfeasible at this timepoint. Despite the higher yield and quality when fruits are harvested at a more advanced ripeness stages (S4), the postharvest shelf life is considerably reduced. Therefore, dragon fruit should be harvested at stages S2 or S3 for greater yield and quality.

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