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IVAN MARCOS RANGEL JUNIOR

DETERMINATION OF FRUIT QUALITY IN DIFFERENT METHODS AS AN INDICATOR OF PITAIA (*Hylocereus undatus*) HARVESTING AND PROCESSING

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Tese apresentada à Universidade Federal de Lavras, como parte das exigências do Programa de Pós-Graduação em Agronomia/Fitotecnia, área de concentração Produção Vegetal, para a obtenção do título de Doutor.

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DETERMINATION OF FRUIT QUALITY IN DIFFERENT METHODS AS AN INDICATOR OF PITAIA (*Hylocereus undatus*) HARVESTING AND PROCESSING

DETERMINAÇÃO DA QUALIDADE DOS FRUTOS EM DIFERENTES MÉTODOS COMO INDICADOR DE COLHEITA E PROCESSAMENTO DE PITAIA (*Hylocereus undatus*).

Tese apresentada à Universidade Federal de Lavras, como parte das exigências do Programa de Pós-Graduação em Agronomia/Fitotecnia, área de concentração Produção Vegetal, para a obtenção do título de Doutor.

APROVADA em 29 de julho de 2021

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“Happiness is only real when shared”
Christopher McCandless

ABSTRACT

Pitaya is a species belonging to the Cactaceae family of American origin, which over time has been geographically distributed in tropical and subtropical regions due to its high degree of rusticity and adaptation. The objective of this work was to identify and evaluate the quality of pitaya fruits during harvest and post-harvest, as well as the physiological changes during their development and to evaluate the potential for replacement of pulp fraction by pitaya peel and its sensory acceptability. For harvesting the fruits, the degree of peel color was used as an indicator and extracted in four degrees: E1 (up to 25% of reddish color), E2 (approximately 50% of reddish color), E3 (between 50 and 75% of reddish coloration) and E4 (above 75% reddish color) at two evaluation times (at harvest and one day after visual detection of complete skin pigmentation). For the indicator time between anthesis and harvest, fruits were collected at 7, 14, 21, 28, 35 and 42 days after flower pollination. In addition, the potential for replacing the fruit pulp by different percentages of peel (0, 20, 40 and 60%) for the production of jelly was evaluated, which made it possible to verify the viability and acceptability of the final product. It was observed that fruits harvested at stage E4, although showing higher yield and quality, also showed higher perishability in post-harvest, being E2 and E3 the ideal stages. Considering the quality of fruits harvested on different days after anthesis, those harvested at 35 days had an ideal harvest point. The jelly with 20% replacement of the fruit pulp by peel allowed greater acceptance by the tasters.

Keywords: Pitaya. Jelly. Maturation. Post-harvest. Pulp.

RESUMO

A pitaia é uma espécie pertencente à família Cactaceae de origem americana, e que ao longo do tempo foi distribuída geograficamente em regiões tropicais e subtropicais por possuir alto grau de rusticidade e adaptação. O objetivo do trabalho foi identificar e avaliar a qualidade dos frutos de pitaia durante a colheita e pós-colheita, assim como as mudanças fisiológicas ao longo do seu desenvolvimento e avaliar o potencial de substituição de fração da polpa por casca de pitaia e sua aceitabilidade sensorial. Para colheita dos frutos foi realizada como indicador o grau de coloração da casca e extraídos em quatro graus: E1 (até 25% de coloração avermelhada), E2 (aproximadamente 50% de coloração avermelhada), E3 (entre 50 e 75% de coloração avermelhada) e E4 (acima de 75% de coloração avermelhada) em duas épocas de avaliação (na colheita e um dia após detecção visual da completa pigmentação da casca). Para o indicador tempo entre a antese e a colheita, frutos foram coletados aos 7, 14 21, 28, 35 e 42 dias após a polinização das flores. Além disso, foi avaliado o potencial de substituição da polpa da fruta por diferentes porcentagens de casca (0, 20, 40 e 60%) para a produção de geleia, o que possibilitou verificar a viabilidade e aceitabilidade do produto final. Foram observados que frutos colhidos no estágio E4, embora apresentasse maior rendimento e qualidade, também, apresentaram maior perecibilidade na pós-colheita, sendo E2 e E3 os estágios ideais. Considerando-se a qualidade dos frutos colhidos em diferentes dias após a antese, aqueles colhidos aos 35 dias apresentaram ponto ideal de colheita. A geleia com substituição de 20% da polpa da fruta por casca permitiu maior aceitabilidade pelos degustadores.

Palavras-chave: Pitaia. Geleia. Maturação. Pós-colheita. Polpa.

SUMÁRIO

PRIMEIRA PARTE

INTRODUCTION

Pitaya (*Hylocereus* spp.) is a cactus that originated in the Americas and has expanded to several tropical and subtropical regions of the world due to its high degree of rusticity and easy adaptation to the widest edaphoclimatic variations. Due to its acceptability and profitability, its cultivation can be made viable by the most varied types of farmers.

With a pleasant taste and versatility in different uses, pitaya has achieved prestige both in fresh consumption and in the processed food industry, as well as in cooking. In addition, products such as juices and vitamins, fermented beverages, jellies, ice cream and others are potentially produced from the fruit as a raw material (Esquivel and Ayara-Quesada, 2012).

Medicinal properties are also observed in the fruit, such as vitamins, minerals, antioxidants, among others. As a result, pitaya becomes highly valued in the nutraceutical field due to its many benefits to human health, such as the prevention of cancer, diabetes and Alzheimer's disease (Li et al., 2017).

In Brazil, the economic exploitation of the crop is relatively recent, despite having potential for cultivation and commercialization in the national territory. However, the peculiarities of the plants end up generating doubts and questions regarding their management. Thus, research involving the crop in order to elucidate these problems is needed from planting to final harvest processing (Ortiz-Hernández and Carrillo-Salazar, 2012).

One of the main obstacles of the culture is the post-harvest of the fruits, where the quality of the fruits and the conservation are closely aligned with the time of harvest, more precisely with the degree of maturity at the moment when the fruit is disconnected from the plant, which will determine the final quality of the product and may reflect negatively when harvesting occurs early or late (Chitarra and Chitarra, 2005, Wanitchang et al., 2010).

Although the maturity factor is essential for the final quality of the pitaya, there is still no consensus among researchers regarding the climacteric character of the fruit. However, high perishability is observed, as well as several problems in the post-harvest phase caused by mechanical damage, rotting, chilling and dehydration, which will directly result in lower quality and shelf life of the fruits (Nerd et al., 1999; Wall and Khan, 2008; Castro et al., 2014).

As a starting point for an ideal harvest, some authors report that the best time for this operation occurs when the fruit has a completely pigmented and intensely colored skin. In Brazil, producers have been opting for harvesting in different degrees of fruit pigmentation, ranging from the minimum color observed to full color. This strategy takes place in order to minimize the damage caused by attacks by birds and other predators in the orchard and results in the loss of fruit quality, reducing its commercial value. In addition, this type of management is also seen as an attempt by farmers to prolong the shelf life of the product in the marketing centers.

Despite these practices adopted by most producers, there are still no studies that prove the effectiveness of this technique to ensure the quality of the final product properly and that expresses the maximum potential of the fruit. However, the fruit scales can be considered as a reliable indicator to help determine the ideal harvest point in the crop.

Also considering the skin color, this factor has been used as the main marker for fruit harvesting, where the change in pigmentation from green to red indicates the beginning of the maturation process, completing this cycle from 4 to 5 days after observing the first color changes and being considered fully mature when it presents a pinkish-red color.

Another indicator that can be used to determine maturity in the pitaya crop is the time elapsed after flower anthesis and its pollination. On this occasion it is possible to observe fruits in full maturity stage after 30 to 52 days after the opening of the flower buds, this time interval is influenced by several factors, such as climate, soil and management (Castillo and Ortiz, 1994; Weiss et al., 1994; Pushpakumara et al., 2005).

However, counting the days after flower anthesis alone does not guarantee the final quality of the fruits, since there is all the interaction with biotic and abiotic factors that will influence their development and maturation.

In this context, the assessment of the pattern of development from anthesis to harvest helps to establish maturity indices in the search for understanding the physical and chemical changes undergone by the fruits and that are noticeable throughout their development, ensuring the production of high quality fruits (Coombe, 1976).

Thus, knowing such changes becomes essential both for planning the harvest at the right time and for the development of strategic management measures aimed at improving production and reducing post-harvest losses, respecting the peculiarities of the crop and especially increasing the useful life of the final product.

One of the most used strategies to reduce post-harvest losses is through fruit processing, which allows for the optimal use of production and adding value to the product.

Among many products that can be originated from pitaya, jelly has shown itself to be promising because it has excellent sensory acceptance by consumers, high added value and a market in constant expansion (Oliveira et al., 2016).

The quality of the processed product is due to the pitaya having pulp and peels rich in polyphenols and antioxidants (Wu et al., 2006). The peel corresponds to approximately 1/3 of the fruit mass, consisting on average of 69.3% of dietary fiber, but its final destination is disposal (Jamilah et al., 2011). This disposal, in addition to generating economic losses of raw material with potential for use, often ends up becoming solid waste that does not receive proper treatment.

The peel represents a fraction of the fruit that often tends to be neglected by consumers and industry. Although it has a functional potential equal to or greater than that of pulp, this functionality can be directly translated into adding both nutritional and economic values to the products processed for its processing.

In light of this, the use of the peel, previously treated as a residue in agribusiness and by many consumers of the fruit *in natura*, can generate economic return, in addition to nutritional and functional benefits, as well as reduce environmental impacts. However, for the use of the peel in the production of processed products, especially in jellies, it is necessary to analyze whether the properties of the product and its sensory acceptance will not be compromised, which can lead to rejection by consumers.

Therefore, the replacement of part of the pulp by the husk can represent the optimization of the use of natural resources, adding value and economic development and reducing the environmental impacts arising from the incorrect disposal of solid waste, directly impacting the production chain of pitaya and its forms of processing and reduction of post-harvest losses.

In view of the above, the objective was to identify and evaluate the quality of pitaya fruits during harvest and post-harvest, as well as the physiological changes throughout development using two indicators such as harvest index, the degree of peel color and time between anthesis and harvesting, and to evaluate the potential for replacing the pulp fraction with pitaya peel and its sensory acceptability in order to adapt the operations in the culture to obtain quality fruits and reduce post-harvest losses.

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SEGUNDA PARTE – ARTIGOS

PAPER 1

FRUIT QUALITY AND HARVEST POINT DETERMINATION IN WHITE-FLESHED DRAGON FRUIT

Full paper published in the Research, Society and Development Journal and formatted in accordance with the rules of the journal

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

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

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

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 pitaia 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 total 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; Pitaia.

Resumen
El estudio tuvo como objetivo evaluar la calidad de los frutos de pitaia 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:

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

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.

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).

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.

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.

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.

	a*		b*	
Stage	**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	
	Chroma		**Hue**	
Stage	**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.

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.

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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PAPER 2

GROWTH AND MATURATION OF WHITE-FLESHED DRAGON FRUIT

Full paper published in the Research, Society and Development Jornal and formatted in accordance with the rules of the journal

Growth and maturation of white-fleshed dragon fruit

Crescimento e maturação de frutos de pitaia de polpa branca

Crecimiento y maduración de frutos de pitaya de pulpa blanca

Abstract

Pitaya has great potential for marketing and processing. However, the lack of knowledge about its cultivation is still a barrier that prevents its diffusion in the country. The objective of this study was to analyze the changes that occur during the growth and ripening of white-fleshed dragon fruit. Physical and physicochemical and chemical fruit characterization analyzes were conducted at several development stages (7, 14, 21, 28, 35 and 42 days after anthesis). Increases in length, fruit mass and pulp, yield and soluble solids were observed, as well as reductions in skin thickness, strength and pulp pH. Significant and important levels in mineral for the human diet were found, especially nitrogen, potassium, calcium, manganese, iron and zinc. Intense changes in seed maturation and biomass accumulation occoured during the fruit growth phase, while in the maturation stage the main changes are related to the improvement of the organoleptic characteristics such as acidity reduction and content of soluble solids, besides the reduction of the mass and thickness of the skin. The ideal harvest point, whereas organoleptic characteristics and visual aspects, is around 35 days, when fruit reached physiological maturity; however, at 42 days, the fruit pulp still had sufficient quality for consumption.
Keywords: Cactus; *Hylocereus undatus*; Physiology; Pitaya.

Resumo

A pitaia apresenta grande potencial de mercado e processamento. Porém, a falta de conhecimento sobre seu cultivo ainda é uma barreira que impede sua difusão no país. Assim, objetivou-se avaliar as alterações físico-químicas dos frutos de pitaia (*Hylocereus undatus*) colhidos em diferentes estágios de desenvolvimento bem como determinar o período ideal de colheita. Foram realizadas análises visuais e de caracterização física, físico-química e química em diferentes estádios de desenvolvimento (7, 14, 21, 28, 35 e 42 dias após a antese). As análises foram: massa do fruto, polpa e casca, rendimento, diâmetro longitudinal e transversal, índice de formato, espessura da casca, firmeza da polpa, sólidos solúveis, pH, acidez, ratio, coloração da casca e teor de minerais na polpa dos frutos. De modo geral, observa-se incrementos no comprimento, massa do fruto e polpa, rendimento e sólidos solúveis e reduções na espessura da casca, firmeza e pH da polpa. A coloração da casca muda de tons verde-amarelo em frutos imaturos para vermelho intenso ao amadurecerem. Embora ocorra redução de minerais com o desenvolvimento do fruto, são encontrados teores significativos e importantes para a dieta humana, com destaque para nitrogênio, potássio, cálcio, manganês, ferro e zinco. São observadas mudanças marcantes nas características dos frutos com o desenvolvimento. As máximas de massa do fruto, diâmetros e ratio ocorrem aos 35 dias, enquanto que a massa da polpa, rendimento e sólidos solúveis ocorrem aos 42 dias após antese. O ponto ideal de colheita, levando-se em conta características organolépticas e aspectos visuais é em torno dos 35 dias, quando alcança maturidade fisiológica, porém, aos 42 dias, a polpa do fruto ainda se encontra com qualidade para consumo.
Palavras-chave: Cactus; *Hylocereus undatus*; Fisiologia; Piataia.

Resumen

La pitaia tiene un gran potencial de mercado y procesamiento. Sin embargo, el desconocimiento sobre su cultivo sigue siendo una barrera que impide su difusión en el país. Así, el objetivo fue evaluar los cambios fisicoquímicos de los frutos de pitaia (*Hylocereus undatus*) recolectados en diferentes etapas de desarrollo así como determinar el período ideal de cosecha. Se realizaron análisis visuales y físicos, físico-químicos y químicos en diferentes etapas de desarrollo (7, 14, 21, 28, 35 y 42 días después de la antesis). Los análisis fueron: masa de frutos, pulpa y piel, rendimiento, diámetro longitudinal y transversal, índice de forma, espesor de piel, firmeza de la pulpa, sólidos solubles, pH, acidez, proporción, color de piel y contenido mineral en la pulpa de los frutos. En general, hay aumentos en longitud, masa de frutos y pulpa, rendimiento y sólidos solubles y reducciones en el grosor de la piel, firmeza y pH de la pulpa. El color de la piel cambia de tonos amarillo verdosos en frutos inmaduros a rojo intenso cuando maduran. Si bien existe una reducción de minerales con el desarrollo del fruto, se encuentran niveles significativos e importantes para la dieta humana, con énfasis en nitrógeno, potasio, calcio, manganeso, hierro y zinc. Se observan cambios marcados en las características de los frutos con el desarrollo. La masa, el diámetro y la proporción máximos de frutos ocurren a los 35 días, mientras que la masa, el rendimiento y los sólidos solubles de la pulpa ocurren a los 42 días después de la antesis.

El punto ideal de cosecha, teniendo en cuenta características organolépticas y aspectos visuales es alrededor de los 35 días, cuando alcanza la madurez fisiológica, sin embargo, a los 42 días, la pulpa del fruto aún se encuentra con calidad para el consumo.
Palabras clave: Cactus; *Hylocereus undatus*; Fisiología; Pitaya

1. Introduction

Pitaya, known worldwide as 'Dragon Fruit', belongs to the family *Cactaceae*, and is a rustic plant that easily adapts to a wide range of edaphoclimatic conditions, which makes it promising for cultivation. In addition to the pleasant taste, exotic appearance and nutritional and functional properties has aroused the interest of investors and consumers concerned about health and well-being (Rodriguez Canto, 2000; Le Bellec et al., 2006; Junqueira et al., 2010). Fruits can be consumed fresh or in the form of wine, juice, jelly, yogurt, jam, dried and other desserts (Shetty et al., 2012).

It is little known in Brazil and, although it has already shown a great potential for commercial exploitation, there remain many doubts regarding its cultivation, mainly due to the scarcity of studies and its peculiar characteristics in relation to the other fruit trees cultivated in the country. The lack of information on this crop still contributes to an increase in the indexes of post-harvest losses. Inadequate handling accelerates senescence processes by significantly affecting quality and limiting the marketing period.

The period between anthesis and fruit ripening varies among species, usually beginning with fertilization, followed by fruit formation, growth, ripening and senescence stages (Biale and Young, 1964). The knowledge about the changes occurring in fruits during their development and the adoption of technologies that maximize production, such as management practices, fertilization, processing and others contribute to quality maintenance and increase product shelf life. According to Coombe (1976), the evaluation of the developmental pattern of a fruit from flowering helps establish maturity indices, which comprise the perceptible physical and chemical changes during development, and ensure the obtention of good quality fruits, quality at harvest season and the conservation period (Chitarra and Chitarra, 2005).

Some studies are found in the literature about the monitoring of dragon fruit development, mainly regarding the maturation stage. However, fruit growth stage is not reported at mostly of these studies, specialy for *Hylocereus undatus* species (Wanitchang et al., 2010, Chang et al., 2016, Phebe et al., 2009, Ortiz and Takahashi, 2015, Menezes et al., 2015, Magalhães et al., 2019). The knowledge about the fruit growth phase is important to assist and maximize crop management, as well as to bring basic and relevant information for further studies. Therefore, there is no report in the literature that encompass the fruit growth stage in *Hylocereus undatus* species under Brazilian conditions, justifying the development of research for this species.

Thus, the objective of this study was to monitoring and characterize the main changes that occur in dragon fruit during its growth and maturation stages.

2. Methodology

The experiment was conducted in the experimental field of the Fruit Farming Sector of the Federal University of Lavras, Lavras, Minas Gerais, Brazil. The climate of the region is Cwa - subtropical climate (21°14’S, 45°00’W and 918 m of average altitude), i.e., a subtropical climate with cold and dry winters and warm and moist summers (Köppen classification). The average environmental data for the experimental period were 24.6 ºC and 74.3% relative humidity.

The orchard used for the experiment has 180 white-fleshed dragon fruit (*Hylocereus undatus*) plants, conducted perpendicularly in 1.80-m wooden posts in an umbrella system, spaced 3 x 3 m.

On the day of flower opening, about 200 flowers, visually homogeneous, were marked in the middle part of the plant. Eight fruits from the marked flowers, were randomly collected at 7, 14, 21, 28, 35 and 42 days after anthesis, and were evaluated for their qualitative, physical, physicochemical and chemical characteristics.

The experimental design was completely randomized, represented by six collection seasons. Each collection consisted of eight replicates, and each one was represented by the average of two pitaya fruits.

Fruit analyses were performed in the Fruit and Vegetable Postharvest Laboratory, at the Food Science Department of the Federal University of Lavras. The variables evaluated were: mass of the fruit, skin and pulp, which were manually separated and weighed using a precision balance (CelTac, FA2104N model), with values expressed in grams; pulp yield (%), calculated with the results of fruit and pulp mass, by the formula: pulp mass x 100/mass of the whole fruit; longitudinal (DL) and transverse diameter (DT), measured using a digital caliper (Astro Mix 150 mm model) and expressed in centimeters, DL/DT ratio to define fruit shape; skin thickness (mm) was obtained by the mean of two measurements on opposite sides, using a digital caliper; pulp firmness (N) was determined using a semi-manual penetrometer (Magness-Taylor, FT 327 model), with an 8-mm tip, in the equatorial region of the fruits.

The pH was determined using a digital pH meter (Digimed, DM-20 model), where each sample was ground and homogenized at a ratio of 1:4 (10 g pulp and 40 mL distilled water) in a polytron, and the filtrate was used for analysis. Soluble solids were obtained using a digital refractometer (Soil Control, RTD-45 model) and the results were expressed in ºBrix. Titratable acidity was determined by titration with 0.1 N NaOH, using, 1% phenolphthalein as an indicator; 10 mL of the filtered homogenate were used for titration, after grinding the pulp in a polytron at a ratio of 1:5 (10 g pulp and 50 mL distilled water). The values were expressed as percentage of malic acid. The ratio SS/AT was obtained by the proportion total soluble solids/total titratable acidity (AOAC, 2007).

The color of the skin was determined using a Minolta colorimeter (CR-400), with illuminant D65 in the CIE L*a*b* system, and L* (luminosity), a*, b*, Chroma and Hue values were obtained.

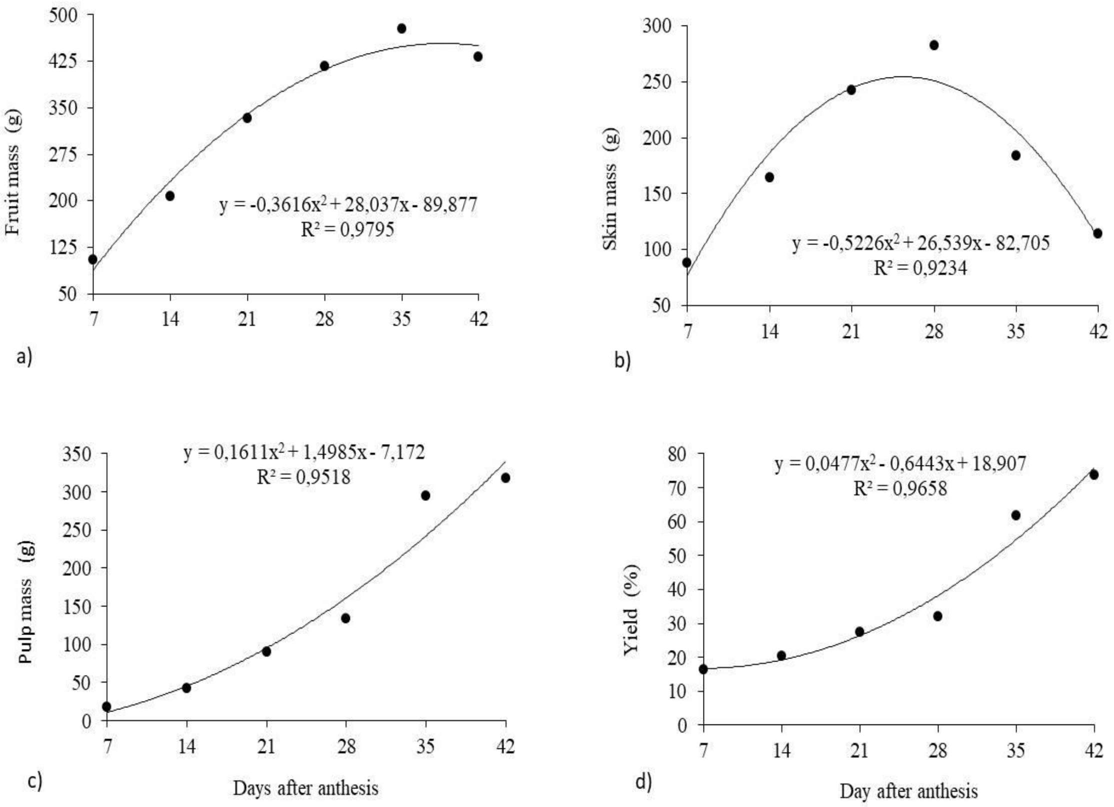
The contents of nutrients in dragon fruit were obtained by the nitric-perchloric extract. P levels were determined by colorimetry; Ca, Mg, Cu, Fe, Mn and Zn, by atomic absorption spectrophotometry, and K by flame photometry. The total N contents were determined by the Kjeldahl semi-micro method. After dry digestion, B was determined by colorimetry (curcumin method) (Malavolta et al., 1997).

Data were submitted to analysis of variance, using the Sisvar® software (Ferreira, 2011). The means of the evaluation periods were submitted to polynomial evaluation, and the models were selected according to the significance of the F test and the coefficient of determination.

3. Results and Discussion

Fresh fruit mass showed a quadratic behavior throughout its development (Figure 1a), reaching maximum growth at 35 days (477.69g), decreasing at 42 days after anthesis (431.74g). Rodríguez (2010), who obtained similar results for native dragon fruit, points out that the maximum fresh mass value was found when the fruit became completely red, with mass loss occurring shortly thereafter. In another study, it was evaluated the maturation phase of dragon fruits from 28 to 42 days after anthesis and no difference on fresh fruit mass was found, probably fruits had already reached the maximum biomass accumulation on this period (Magalhães et al., 2019). The current research shows that the fruit mass increases mainly during the fruit growth stage, previous the maturation phase.

Figure 1. a) Fruit mass (g); b) skin mass (g); c) pulp mass (g) and d) yield (%) of white-fleshed dragon fruit throughout its development.



The phase in which the fruit reaches the maximum fresh mass can be an indicative of physiological maturation, because mass loss indicates the beginning of degradation processes that occur in the senescence phase, such as water loss, which can be easily visualized by dehydration and wilting of bracts or scales (Figure 1b), indicating loss of quality. Lima et al. (2014), evaluating six dragon fruit genotypes of the same species, found fresh mass variations between 343.5 and 752.5g in mature fruits.

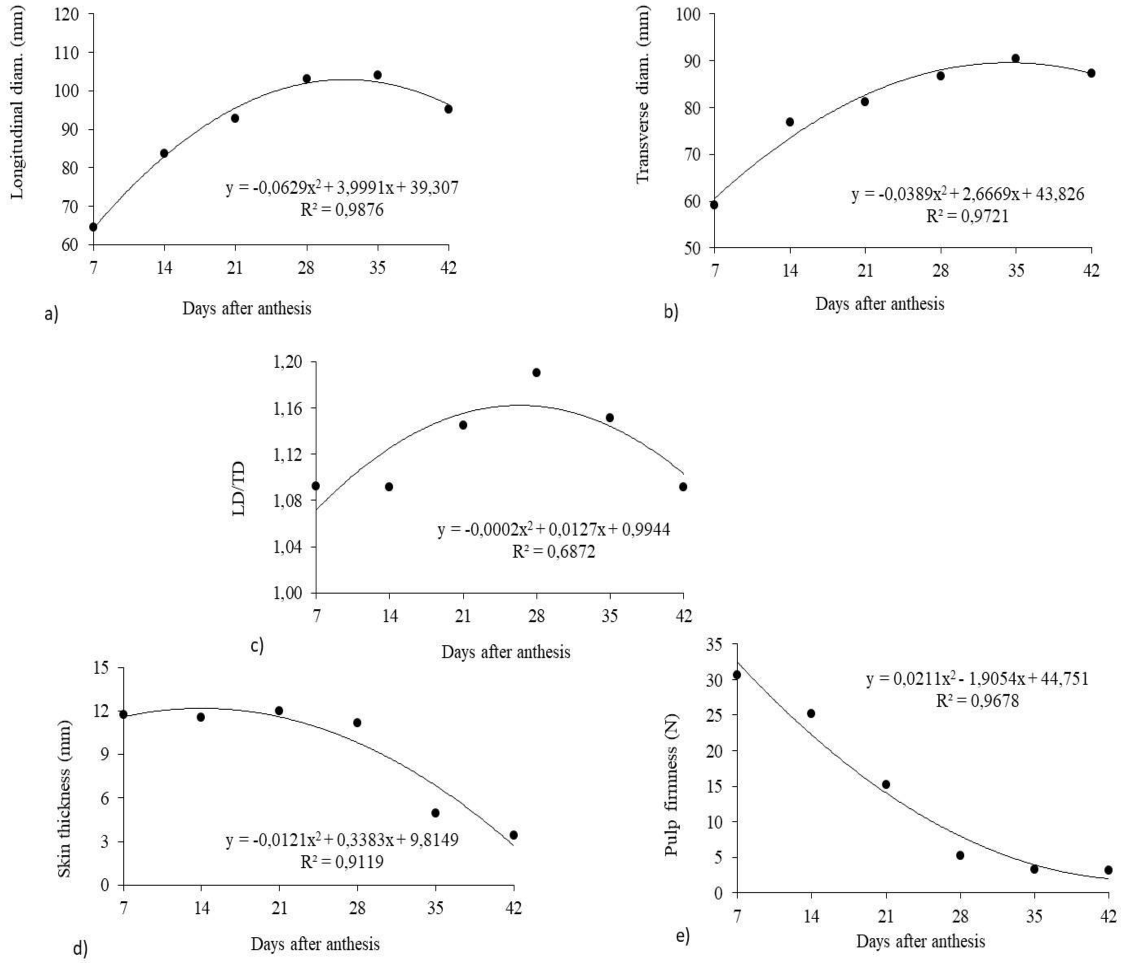
Increases in fresh skin mass (Figure 1c) were observed up to 28 days after anthesis with subsequent losses, showing that fresh skin mass increased predominantly during the growth period. Magalhães et al (2019) and Ortiz and Takahashi (2015) also observed a decrease on fresh skin mass, but the period evaluated by theses authors was only related to the maturation stage.

Fresh pulp mass showed growth with maturation (Figure 1d). Accordingly, Ortiz and Takahashi (2015), who evaluated the development of dragon fruit from 22 to 32 days, obtained maximum values at 26 days of anthesis. Likewise, Centurión et al. (2008), when evaluating fruits from 5 to 35 days after flowering, obtained maximum values at 20 days. The authors also found increasing pulp mass values during fruit development. According to Chitarra and Chitarra (2005), the mass, mainly of the pulp, has cell number, volume and density as determinants; the latter is increased due to the accumulation of water and solutes with its development.

Pulp yield (Figure 1d) followed the fruit mass behavior, reaching its peak at 42 days (73.63%). Ortiz and Takahashi (2015) found maximum yield values of 66% at 32 days after anthesis, while Lima et al. (2014) reported variations from 65.20 to 78.20%, when evaluating fruits of different accessions. According to Cordeiro et al. (2015), dragon fruit has a lot of pulp, when compared to other cacti, and it is an interesting qualitative index for the processing industry.

The measurements of longitudinal and transverse diameter (Figures 2a and 2b), were consistent with the mass gain of the fruits, increasing with fruit maturation up to 35 days, with a slight subsequent decline.

Figure 2. a) Longitudinal diameter (mm); b) transverse diameter (mm); c) longitudinal/transverse diameter ratio; d) skin thickness (mm); e) mean pulp firmness (N) of white-fleshed dragon fruit throughout its development.



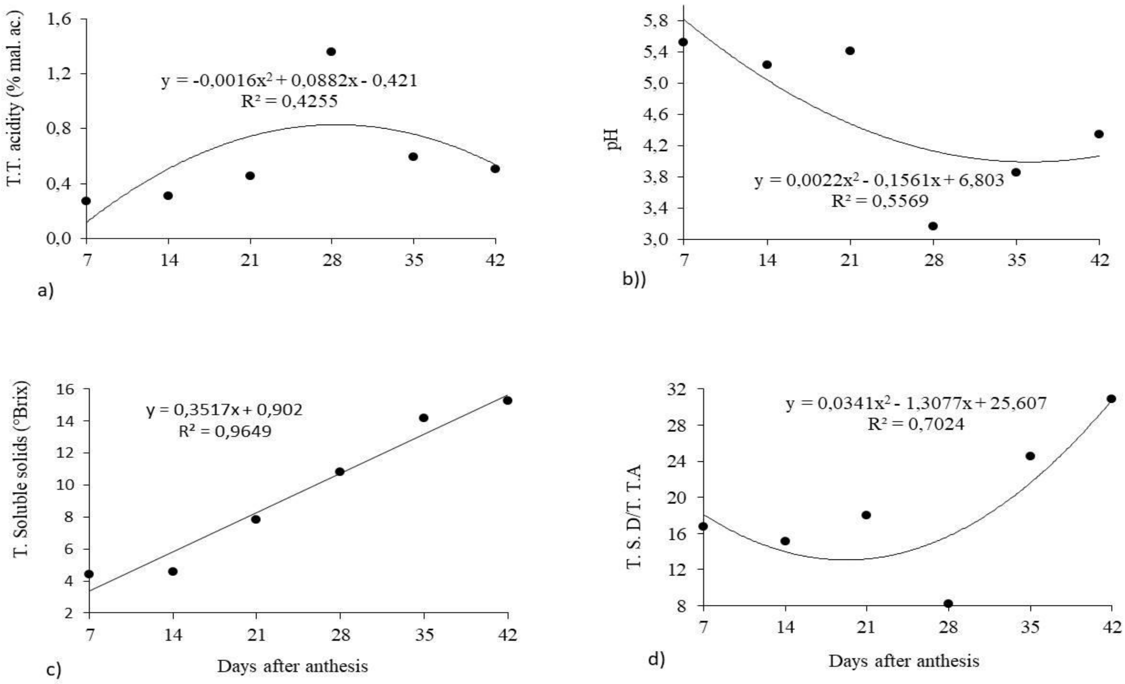
The maximum values of longitudinal and transverse diameter were observed at 35 days of anthesis, corresponding to 104.01 mm and 90.50 mm, respectively. Longitudinal and transverse diameters are important for fruit characterization; however, the DL/DT ratio complements these data, because it indicates fruit shape. The closer to 1.0, indicates a tend to the rounded shape. The DL/DT ratio (Figure 2c) of the evaluated fruits ranged from 1.09 to 1.19, indicating a subglobous shape. The size and shape of fruits are important attributes for commercialization because the variation among the individual units can affect consumer choice of this product; in addition, it directly influences visual attractiveness.

In relation to skin thickness (Figure 2d), it is possible to observe a reduction as the fruit develops, with means of 11.14 to 11.98 mm while the skins showed green color in a period of 7 to 28 days, decreasing to 4.92 and 3.44 mm, at 35 and 42 days, respectively, when the skins already had a pink color. Fruit skin has an important factor from a post-harvest point of view, as it protects against water loss and mechanical, chemical and biological damage. Thus, thinner skins may result in fruits more susceptible to damage. On the other hand, thicker skins tend to reduce pulp yield, since it is a ratio variable.

In relation to pulp firmness (Figure 2e), there was an abrupt decrease up to 28 days, after that a tendency of stabilization was observed. Values ranged from 30.57 to 3.09 N. These results indicated a high pulp tissue softening with ripening, which is confirmed by Chitarra and Chitarra (2005), who affirm that this softening is one of the first signs and one of the main transformations in fleshy fruits, having a marked influence on quality and shelf life, and a direct relationship with the chemical components of cell walls. Still according to these authors, pectin solubilization is the main responsible for tissue softening. In addition, the decomposition of other cell wall components (celluloses and hemicelluloses), as well as starch hydrolysis and the hydration degree of the tissues (cell turgor) help in this process.

For total titratable acidity, represented by the percentage of malic acid, a quadratic behavior is observed, ranging from 0.27 to 1.36%, increasing in early development stages, with a significant increase at 28 days, before the pigmentation stage of the fruit skin (Figure 3a). Subsequently, there is a decrease in the contents of malic acid in the fruit pulp. According to Arévalo-Galarza and Ortíz Hernández (2004), the increase in acidity before color change shows the beginning of maturation processes. Menezes et al. (2015) reported a similar trend, and an acidity showing a marked increase before color change, whereas for Ortiz and Takahashi (2015) found that acidity increased until the 27th day, when it reached maximum values of 1.4% malic acid, followed by a decrease up to 32 days, reaching a minimum value of 0.27% malic acid. In contrast, Centurión et al. (2008) observed an increasing reduction in acidity from 21 to 31 days of flowering, when it reached 0.4% malic acid. In general, organic acids tend to decrease with maturation due to their use as a substrate in respiration or their conversion into sugars (Chitarra and Chitarra, 2005).

Figure 3. a) Mean total titratable acidity (% malic acid); b) pH; c) total soluble solids and d) total soluble solids/total titratable acidity ratio in the pulp of white-fleshed dragon fruit throughout its development.



The results found for pH corroborate the acidity data (Figure 3b). The variations were from 3.16 to 5.52, with a sharp decrease between days 21 and 28, and increase in the subsequent days. The reduction in pH with maturation occurs due to the accumulation of organic acids, and its increase is due to the consumption of these organic acids in respiration (Silva et al., 2005).

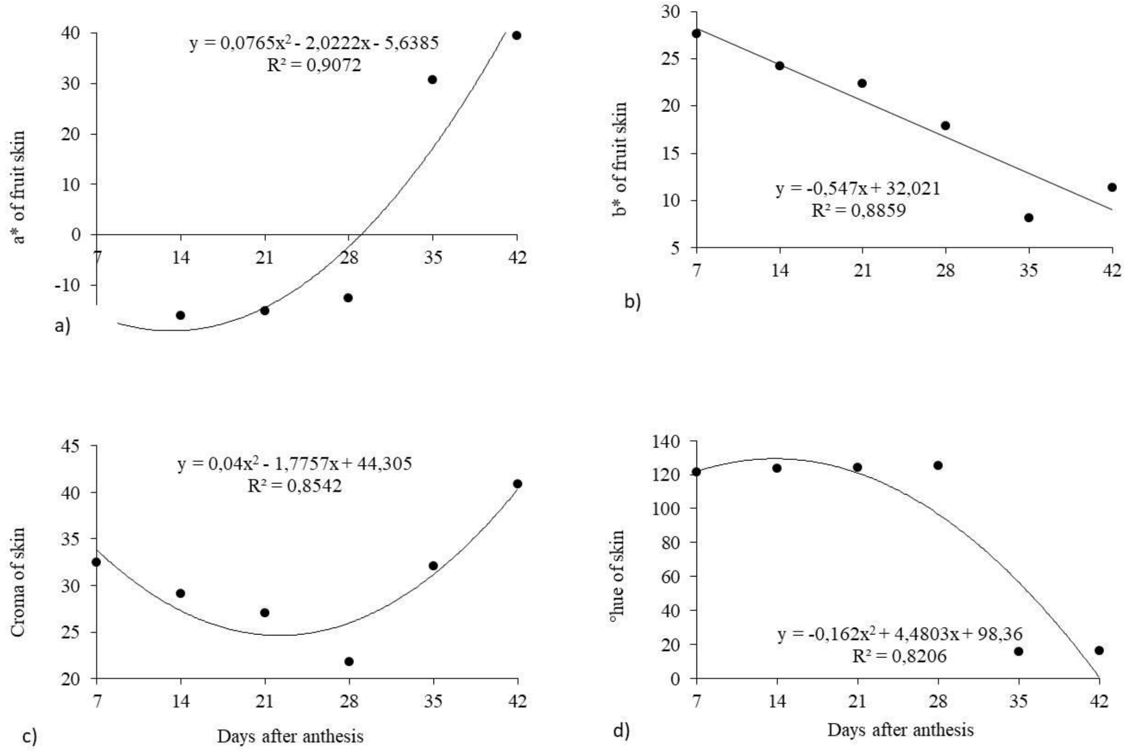
In relation to soluble solids (Figure 3c), values between 4.40 and 7.84 °Brix between days 7 and 21 after anthesis were observed, with a significant increase at 28 days (10.80 °Brix), with a gradual increase in subsequent evaluations, reaching maximum values of 13.24 °Brix at 42 days. Ortiz and Takahashi (2015) obtained maximum soluble solid values at 31 days (12.2 °Brix) of anthesis. For Centurión et al. (2008), the maximum soluble solid content was revealed at 27 days (12.8 °Brix) of flowering, while Menezes et al. (2015), at 42 and 46 days of anthesis, reported values of 19.58 °Brix. Lima et al. (2014), studying the quality of ripe fruits of 6 dragon fruit accessions, found soluble solid values in the median part of the fruit between 11.2 and 14.9 °Brix, consistent with those reported in this study. The content of soluble solids is an indirect measure of the sugar content, since it increases as these contents accumulate in the fruit, which occurs with ripening due to the degradation of polysaccharides, and it is a good indicator of the degree of maturation and taste of the fruits.

The ratio values (SS/AT) showed a quadratic behavior with fruit development (Figure 3d). The maximum value was found at 42 days (30.83), and the minimum at 28 days after anthesis (8.18). Consistent results were reported by Centurión et al. (2008), who found SS/AT ratio of 3.4 to 33.5 from 20 to 31 days of flowering. Acidity and sugars are the main attributes responsible for fruit taste, representing the balance between sweet and sour taste. Thus, the soluble solids/titratable acidity ratio represents a variable of perception of taste intensity, by taste and smell, and is extremely important for the sensory acceptance of the product, for a high sugar content, and low acid content, result in a pleasant flavor (Grierson and Kader, 1986; Chitarra and Chitarra, 2005).

Besides being an important quality requirement in the acceptance of the product by the consumer, color can be used in the determination of maturity indices to indicate the ideal harvest point of the fruits. In the CIE L*a*b* system, colors are three-dimensionally represented. The L* coordinate indicates luminosity, ranging from zero (completely black) to 100 (completely white). The a* coordinate expresses the green-red variation degree and the b* coordinate expresses blue-yellow variations. Chromaticity (C*) indicates the degree of color saturation, while the hue is indicated by the Hue angle.

Regarding dragon fruit skin color, the luminosity index did not show statistical differences ($p<0.05$), with mean values of 51.77. Centurion et al. (2008) did not find differences when evaluating developing pitaya fruits. As for the a* coordinate, its values fit a quadratic curve with increasing values, from 35 positive days (Figure 4a). These results indicate that the red color prevailed after 35 days, evidencing the transformation of green fruits into mature fruits, in agreement with the moment in which the main evolutions in the flavor characteristics such as pH, acidity, soluble solids, ratio and firmness were observed, which is a good indicator in determining fruit maturity.

Figure 4. Fruit skin color: a) a* of fruit skin b) b* of fruit skin c) Chroma of fruit skin and d) Hue of white-fleshed dragon fruit throughout its development.



For the b* coordinate (Figure 4b), there was a linear decrease with fruit development, which is in agreement with a study by Ortiz and Takahashi (2015), who found decreasing values ranging from 30.6 to 7.6, from 21 to 32 days of evaluation. It is possible that this decrease is related to the degradation of skin pigments that occur throughout maturation, such as chlorophylls and carotenoids. The chroma (Figure 4c) showed quadratic behavior, with a reduction up to 28 days, and increase up to 42 days. These results indicate a reduction in green color saturation, and may be indicative of the differentiation process of the colors involved in dragon fruit maturation, such as degradation and synthesis of skin pigments, and later rising as the fruits became pigmented, indicating saturation with the accumulation of reddish pigments, as betalain. The Hue angle (Figure 4d) had values close to 130 up to 28 days, when the fruits were completely green, indicating a green color; subsequently, with fruit ripening, it sharply decreases to values around 20, indicating a more intense reddish-pink color. These results indicate the variation in the fruit hue from yellow to green when immature, and then strongly reddish. To et al. (2002) suggested that hue values are below 30 for fruit harvest; therefore, at 35 days, these are already suitable for harvesting.

Regarding the mineral composition in the fruit pulp (Table 1), there was a reduction in the concentrations of all minerals with fruit development, with the exception of sulfur, which was detected only in the first evaluation at 7 days after anthesis. Regarding macronutrients, fruits had a higher concentration of N, K and Ca in their composition, with averages ranging from 31.0 to 15.0; 26.7 to 12.5 and 7.2 to 4.4 g kg^{-1}, respectively, from 7 to 42 days. Cordeiro et al. (2015) evaluated ripe red-fleshed dragon fruit and found larger amounts of these macronutrients, with averages of 11.3; 12.6 and 8.0 g kg^{-1} of N, K and Ca, respectively. As for micronutrients, Mn, Zn and Fe were found at higher amounts. These results demonstrate that white-fleshed dragon fruit ha significant levels of important minerals in the human diet. Besides, the higher content of minerals, together with their antioxidant and nutritional properties, can guide further studies aiming to evaluate the potential of immature fruits on nutritious flour processing or other nutraceuticals products.

Table 1. Macro- and micronutrient contents in the pulp of white-fleshed dragon fruit throughout its development.

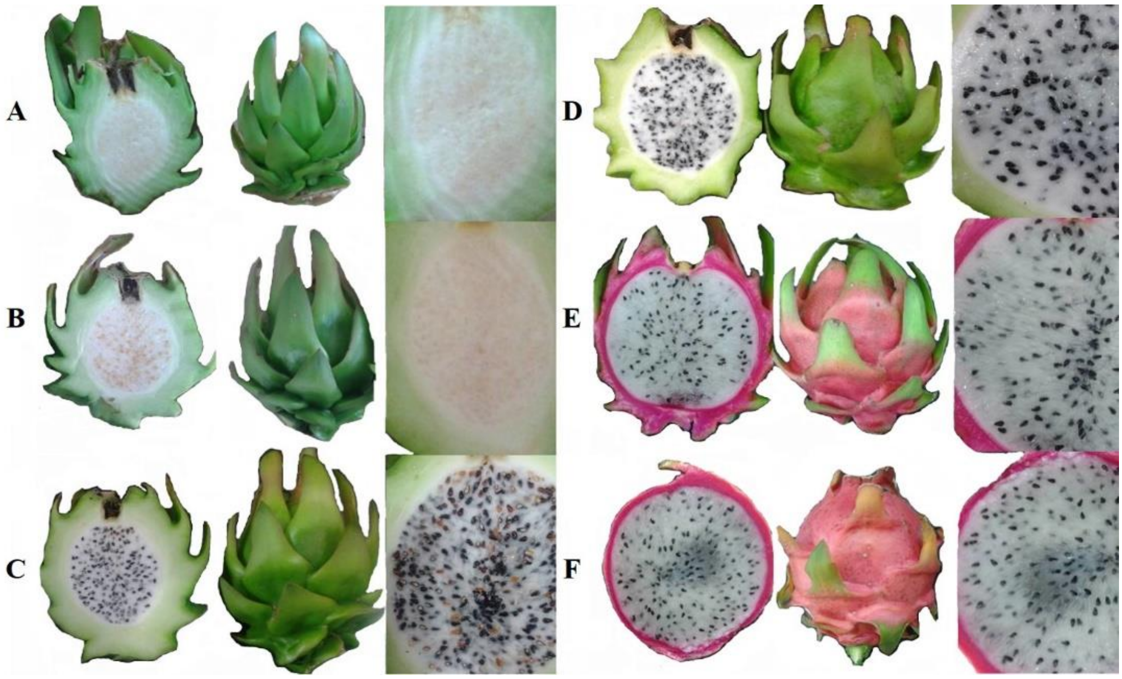
Days	g kg^{-1}						mg kg^{-1}				
	N	P	K	Ca	Mg	S	B	Cu	Mn	Zn	Fe
7	31.0	5.8	26.7	7.2	3.0	2.1	19.6	11.1	66.4	47.1	51.8
14	21.6	4.0	23.4	6.6	2.8	nd	8.8	4.6	68.1	30,2	42.9
21	19.7	2.9	22.8	5.5	2.9	nd	8.2	3.4	43.8	28.9	46.4
28	19	2.6	19.5	4.7	2.7	nd	9.0	3.3	24.1	23.9	64.2
35	11.8	1.8	14.8	4.1	1.5	nd	6.9	0.1	6.0	11.0	33.3
42	15.0	1.9	12.5	4.4	1.4	nd	2.9	0.9	6.0	14.2	27.8

nd = not detect.

In addition to the nutritional aspect, as a mineral source in the human diet, mineral elements are important in the development of fruit properties because they have significant influence on color, aroma, shape, size, appearance, resistance to mechanical damage, disease incidence, physiological disorders, physicochemical characteristics and post-harvest life (Aular and Natale, 2013). In addition, the knowledge about the accumulation of the minerals in the different phenological phases, such as fruiting, is essential to estimate the crop nutritional needs, as well as to identify the most appropriate moments for fertilizer application (Ramirez et al., 2002), which is very important in the case of dragon fruit, where studies are lacking, such as the recommendation for crop fertilization. Nutrient management has been one of the main operations to ensure higher fruit yield and quality (Kishore, 2016).

As for the visual aspects, it is possible to clearly observe the changes suffered during fruit development, with marked characteristics in each phase (Figure 5). The formation and growth of white-fleshed dragon fruit began with flower pollination and fertilization, followed by a rapid growth of the ovary walls, resulting in the initial formation of the fruit in the first days after flower opening, and the mesocarp (pulp) was visualized at 7 days of anthesis (Figure 5a). At this stage, therefore, the pulp forms a white and homogeneous mass, compact and with a low yield.

Figure 5. Development phases of white-fleshed dragon fruit. A: 7 days after anthesis; B: 14 days after anthesis; C: 21 days after anthesis; D: 28 days after anthesis; E: 35 days after anthesis; F: 42 days after anthesis.



A slight color in the seeds is observed only at 14 days after anthesis (Figure 5b), and the progress of its development is clear since then when, at 21 days (Figure 5c), it is possible to observe a transition phase in seed maturation, in which seeds occur from light brown to completely black.

The seeds are completely formed at 28 days (Figure 5d), when the first signs of skin color also appear, although they still occur only in the inner part of the fruit. At this stage, there is also an increase in pulp proportion. It is likely because at this stage, seeds have reached physiological maturity, while the fruit begins its maturation.

At 35 days, there is a great evolution as to the external color of the skin (Figure 5e), which acquires an intense pink color throughout the skin, except the ends of bracts that remain green and turgid. In addition, there is a considerable increase in the edible portion of the fruit, accompanied by a reduction in skin thickness. This stage represents the ideal harvest point, once it is visually more attractive with intense pink color in the skin and, in its majority, it has internal qualities suitable for consumption, evidencing that the fruit reached its physiological maturity.

At 42 days, the first signs indicating the beginning of senescence appear (Figure 5f), when the bracts begin to wilt and depigmentate, acquiring a yellowish coloration. Although the edible part of the fruits still has good organoleptic quality, its visual quality begins to be compromised, which directly affects commercialization, since the visual aspect is one of the criteria used by consumers in the choice and selection of the product.

4. Conclusion

Important changes occurred in dragon fruit during the growth and maturation stages, notably regarding alterations on color, physical and physical-chemical characteristics. Significant changes in seed maturation and biomass accumulation occurred during the fruit growth phase, while in the maturation stage the main changes are related to the improvement of the organoleptic characteristics, such as acidity reduction and increase of soluble solids, besides the reduction of the mass and skin thickness.

Fruit mass, diameters and ratios reached their maximum values at 35 days after anthesis. The maximum pulp mass, yield and soluble solids occurred at 42 days after anthesis. The ideal harvest point was around 35 days, when fruit reached its physiological maturity, parameter that can be associated to the intense pink color of the skin. At 42 days, the pulp still had sufficient quality for consumption.

Acknowledgments

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PAPER 3

POTENTIAL FOR THE USE OF PEEL AS A SUBSTITUTE FOR PULP IN THE PRODUCTION OF PITAYA JAM

Preliminary version submitted to PAB and formatted in accordance with the rules of the journal

Potential for the use of peel as a substitute for pulp in the production of pitaya jam

Abstract - Postharvest loss is one of the most significant barriers to commercialization, especially for fruits with a short harvest cycle and fruits with reduced shelf life, such as pitaya. Thus, processing becomes an important option for increasing the shelf life of the fruit, in addition to adding value to the product and allowing the use of parts that are usually discarded, such as the exocarp and mesocarp. The present study aimed to evaluate the potential use of the peel of pitaya fruits for the production of jam, assessing the effect of replacing different pulp contents with peel in the formulation on the physical, physicochemical, microbiological and sensory characteristics of the final product. Four pitaya jam formulations with different proportions peel used in place of pulp (0, 20, 40 and 60%) were evaluated. The pitaya jams showed high sensory acceptability and good quality characteristics. The jam with 20% peel showed better acceptance by the tasters. In addition, the peel showed use potential. Thus, the use of peel can help to minimize production losses while adding value to the product and reducing waste disposal in the environment.
Index terms: cactaceae, fruit, postharvest, processing, *Hyloreceus polyrhizus.*

Potencial de aproveitamento da casca em substituição a polpa para produção de geléia de pitaia

RESUMO - A perda pós-colheita é um dos entraves mais significativos na comercialização, especialmente em frutíferas de colheita concentrada e frutos com reduzida vida útil, como a pitaia. Dessa forma, o processamento torna-se importante alternativa para aumentar a vida útil do fruto, além de agregar valor ao produto e permitir o aproveitamento de partes que são usualmente descartadas, como o exocarpo e mesocarpo. O trabalho teve como objetivo avaliar o potencial de aproveitamento da casca) de frutos de pitaia para a produção de geleia, verificando a influência da substituição de diferentes teores de polpa por casca na formulação e em relação às características físicas, físico-químicas, microbiológicas e sensoriais do produto final. Quatro formulações de geleias de pitaia com diferentes proporções de casca em substituição a polpa (0, 20, 40 e 60%) foram avaliadas. As geleias de pitaia apresentaram alta aceitabilidade sensorial e boas características de qualidade. A geleia com 20% de casca apresentou melhor aceitação pelos provadores. Além disso, a casca apresentou potencial de aproveitamento. Com isso, o uso da casca pode contribuir para minimizar perdas na produção, bem como agregar valor ao produto e reduzir o descarte de resíduos no meio ambiente.
Termos para indexação: cactaceae, fruta, pós-colheita, processamento, *Hyloreceus polyrhizus***.**

Introduction

Pitaya is a hardy plant of the family Cactaceae that is also known as "dragon fruit". This fruit tree originates from the tropical regions of Mexico and Central and South America (Freitas and Mitcham, 2013) and is found mainly in tropical and subtropical regions (Xu *et al*., 2016). The species *Hyloreceus polyrhizus* has fruits with red peel and pulp and small, dark seeds dispersed throughout the pulp. Pitaya is a tropical fruit that has gained prominence in the exotic fruit market and increasing acceptance by consumers due to its sensory characteristics, especially its sweet and mild flavor (Lima *et al*., 2013). In addition, it has vitamins and minerals and a high potassium content (Abre *et al*., 2012). The fruit can be consumed fresh or transformed into industrialized products such as sweets, syrups, ice cream, juices and jams. Jam is a product with good sensory acceptance, high added value and a growing market (Oliveira *et al*., 2016). Red pitaya pulp and peel are rich in polyphenols and antioxidants, but the highest antioxidant activity is in the peel (Wu *et al*., 2006). The peel constitutes approximately 1/3 of the fruit, and its total dietary fiber content is very high at approximately 69.3% (Jamilah *et al*., 2011), but it is usually discarded.

In addition to the nutritional value, the functional potential of some fruits increases the interest of the consumer who seeks a nutritionally balanced and healthy diet. The peel is a portion of the fruit that is usually neglected by the consumer but has a higher functional potential than the pulp. Thus, the use of fruit peels in the production of jams can be highly effective in the generation of new food products and can increase added value.

The economic use of fruit waste from agroindustries or the fresh fruit market, combined with the nutritional and functional benefits of this waste, can significantly contribute to the country's economy, reducing environmental impacts and improving human health. However, it is necessary to evaluate whether the technological properties and sensory acceptance of the product are compromised by nutritional and functional gains. Given the above considerations, the present study aimed to evaluate the potential use of pitaya peel in the production of jam, assessing the effect of replacing different pulp contents with peel in the formulation on the physical, physicochemical, microbiological and sensory characteristics of the final product

Materials and methods

Sample preparation

Ripe red pitaya fruits (*Hylocereus polyrhizus*) were washed with water and neutral detergent, rinsed in running water and dried at room temperature. Next, the scales were removed and discarded, and the epicarp (outer part of the peel) was removed with a knife. The fruit peel and pulp were then separated into individual plastic bags.

For the formulation of the jams, fruit pulp (or pulp + peel), sugar, water and pectin were used as ingredients. The proportions of the ingredients were determined using previous laboratory tests. To prepare the jams, fruit juices were initially prepared using 60% water to 40% pulp or pulp + peel. The peel was ground in a blender to form a homogeneous mass, and the pulp was cut into pieces so that the seeds remained intact in the jam. In all formulations, 60% juice and 40% sugar were used in the production of the jams, and 1% citrus pectin was added. The variations among the treatments were related to the proportions of pulp and peel in the juice preparation to be used to prepare the jams (Table 1).

After the pulp juices were added to an aluminum pot and heated on an industrial stove, 1/3 of the total proportion of sugar and pectin was introduced and subjected to constant homogenization with a spoon to avoid the formation of clumps. After the pectin was completely dissolved, the remaining sugar was added; the mixture was boiled until it reached 65 °Brix and a gelatinous consistency, and the soluble solids content was immediately monitored. The jam was then removed from the stove and transferred to glass containers that had been sterilized in boiling water. After the jars were filled, they were sealed with a lid and then turned upside down for five minutes. The packaged jams were stored overnight in a cool place at room temperature until sensory analysis. Some of the jams were separated for the other analyses.

Analysis

To analyze the titratable acidity, pH level and soluble solids, a homogenate was prepared with 1 part jam and 2 parts water. The titratable acidity was determined by the titration of 10 mL of the homogenate with 0.1 N NaOH using a pH meter. A pH of 8.2 was adopted as the final titration point, and the results were expressed as the percentage of malic acid. The pH was determined with a digital pH meter using the same homogenate. The soluble solids (%) were measured using a digital refractometer. The soluble solids/titratable acidity ratio was also calculated. The methodologies used were those recommended by the AOAC (2016).

The color of the jams was analyzed using a Minolta CR-400 colorimeter in CIELab mode to evaluate the coordinates L*, a*, b*, C* and h. L* represents the lightness and varies between 0 (completely black) and 100 (completely white); a* represents the color variation from green to red and ranges from -80 (green) to +100 (red); b* represents the variation in the color from blue to yellow and varies between -50 (blue) and +70 (yellow); C* indicates the chroma or purity of the color, and h° represents the hue angle. Samples of each formulation were placed in a white container, and the readings were taken at four different points on the jam.

The sensory analyses were performed at the Laboratory of Sensory Analysis of the Department of Food Science at Federal University of Lavras, Lavras, Minas Gerais (MG). A structured nine-point hedonic scale was used, corresponding to 1 (disliked extremely), 2 (disliked a lot), 3 (disliked moderately), 4 (disliked slightly), 5 (neither liked nor disliked), 6 (liked slightly), 7 (liked moderately), 8 (liked a lot) and 9 (liked extremely), to evaluate the color, flavor, consistency and overall impression of the jams. The sensory evaluation was performed by 105 tasters (jam consumers of both sexes and in different age groups). Saltines were offered as a tasting vehicle, and drinking water was provided to cleanse the palate between samples.

The texture profile was determined in a Stable Micro System texture analyzer, model TATX2i, equipped with an HDP/90 platform and a P/6N needle probe with a 6-mm diameter and with a measurement speed of 5 mm s^{-1}, penetration depth of 10 mm and time of five seconds. Three replications were performed, and the following variables were collected: hardness, adhesiveness, elasticity, cohesiveness, gumminess, chewiness and resilience.

In the Laboratory of Microbiology, the most probable number (MPN g^{-1}) of coliforms per gram of sample at 35 °C and 45 °C was determined, and the presence or absence of Salmonella and the number of colony forming units (CFU) of molds and yeasts were determined according to methodologies proposed by the ICMSF (2009) and Silva *et al*. (2001).

Statistical design

The experimental design was a completely randomized design (CRD) with four replicates. Each experimental unit consisted of a 100-mL package. Four pitaya jam formulations with different proportions of pulp replaced with mesocarp (0, 20, 40 and 60%) were evaluated. The results were evaluated by analysis of variance. To evaluate the data, the means were analyzed using Tukey’s test with 5% probability using SISVAR software (Ferreira, 2011).

Results and discussion

Physicochemical analyses

A significant difference in pH was observed among the treatments (Table 2). The treatment without peel had the lowest pH value (4.79), while the treatment with 60% peel had the highest pH value (5.02). Conversely, the treatments with 20 and 40% peel showed intermediate values, corresponding to 4.88 and 4.93, respectively; they did not differ significantly from one another. Thus, the replacement of pulp with pitaya peel promoted an increase in the pH of the jam, with the highest pH observed in the formulation with the highest proportion of peel. According to Lopes (2007), the optimal pH for gel formation is 3.0 to 3.2. At values above 3.4, gelation may not occur.

In the present study, higher pH values were found, but they did not compromise the gel structure. Similarly, Carneiro *et al*. (2015), when formulating physalis jam, noted that even with high pH values (4.35), the product had a texture and color characteristic of jam. Oliveira *et al*. (2017a), when comparing the physicochemical variables of jams made with pitaya mesocarp with those of jams made from the pulp of other red fruits (raspberries, grapes and blackberries), observed pH values of 5.42 for pitaya jams, which presented a higher value and tended towards an alkaline pH. Oliveira *et al.* (2017b), evaluating sweet pastes of pitaya, guava, strawberry and grape, also found higher pH values (4.88) for sweet pitaya paste. In fresh fruits, Lima *et al*. (2013) found pH values ranging from 4.83 to 5.67 in commercial pitayas acquired from markets in the region of Brasília, Federal District (DF), where these fruits are classified as low-acidity fruits. According to Franco and Landgraf (2008), foods with pH values above 4.5 are classified as having low acidity, which is the case for pitaya jams.

The soluble solids, titratable acidity and soluble solids/titratable acidity ratio did not differ significantly among treatments, with means of 64.6%, 1.05% malic acid and 61.67, respectively. The soluble solids content mainly represents the concentration of sugars and organic acids present in fruits and fruit products such as jam (Cecchi, 2007), and the content obtained was within the standards required by Brazilian legislation, which recommends levels of approximately 65 ° Brix (Brasil, 1978). Titratable acidity, in general, serves to measure the acidic taste of fruits and is represented by the amount of organic acids in the sample, which, in this case, included a predominance of malic acid

(Hamacek *et al*., 2011). Dessimoni-Pinto *et al*. (2011), when studying jams with 80% and 50% jaboticaba peel replacing pulp, obtained values of 1.98 and 1.67 g of citric acid/100 mL^{-1}, while Garcia *et al*. (2017) studied buriti jam and found 0.60 g 100 g^{-1} of titratable acidity. In turn, Heiffig *et al*. (2006) and Iensen et al. (2013), in their study of kiwi jams, reported means of 1.35 g 100 g^{-1} and 0.65 g 100 g^{-1} citric acid, respectively. The titratable acidity observed for pitaya jam was within the range reported by the cited authors.

The soluble solids/titratable acidity ratio, however, is one of the best ways to evaluate fruit flavor due to the significance of the balance of acids and sugars in taste perception. The lower the acidity and the higher the ratio value are, the greater the perception of sweetness by the consumer (Oliveira *et al*., 2014). For the consumer market of fresh and/or processed fruits, a high ratio is desirable because it translates into sweetness, generating a more pleasant flavor. The mean ratio observed in the present study is similar to that reported by Oliveira *et al*. (2017a) in jams formulated using pitaya mesocarp (68). Thus, the high ratio value observed indicates that the jams had a satisfactory flavor.

The jams formulated with and without peel exhibited a red color characteristic of the fruit, although there were small variations in tones and appearance due to differences in the concentrations of pulp/peel and seeds (Figure 1).

According to the color analysis, the variables L*, b* and h did not differ significantly, with means of 16.83, -0.76 and 356.22, respectively, while the variables a* and C* were significantly influenced by the differences in treatment (Table 2).

Jams with 20, 40 and 60% of pulp replaced with peel did not differ significantly from the jams without substitution. However, the jam with 20% substitution had higher mean a* and C* compared to the jam with 60% substitution. Positive values of a* are associated with red color, with higher values indicating more intense color, while the coordinate C* represents the saturation or purity of the color, and the higher its value is, the more “pure” the color will be. Thus, these results indicate that the formulation with 20% of the pulp replaced with peel had redder, purer color.

The characteristic color of pitaya is determined by betalains (Li-chen *et al*., 2006). Betalains are a class of natural water-soluble nitrogen-containing pigments that confer attractive colors to groups of fruits and flowers (Mello *et al*., 2015). They consist of two subgroups, red-violet betacyanins and yellow-orange betaxanthins (Mobhammer et al., 2005; Herbach *et al*., 2006). According to Abreu *et al.* (2012), pitaya pulp has more betalains than pitaya peel. Thus, it was expected that the replacement of pulp with peel would reduce the a* value of the jams. However, the pulp contains numerous dark seeds that may negatively impact the visualization of the red color typical of the pitaya pulp. Since the peel has no seeds, it is believed that the replacement of 20% of the pulp with peel reduced the impact of the seeds on the red color of the jams, leading to a higher a* value. As the level of substitution increased, the impact of the reduction in seeds was surpassed by the lower intensity of the red color of the peel compared to the pulp and did not result in significant differences. The higher mean C*, which was also observed in the jam with 20% substitution, suggests a product with a more striking red color, since higher C* values result in brighter colors that are more attractive to the consumer (Kirca *et al*., 2007).

Sensory analysis

The jams were subjected to sensory evaluation by 105 consumers of both sexes and different age groups. The color of the jams was not significantly affected by the replacement of pulp with peel, according to the sensory analysis. Therefore, the difference in the reddish color detected in the instrumental colorimetric evaluation was not noticeable to the tasters. These results are positive and important from the point of view of quality, as they suggest that the replacement of pulp with peel, regardless of the proportion replaced, can take place without interfering with consumer acceptance in terms of the color of the jam. In addition, the overall mean was 8 points, indicating that the tasters liked the jam very much, regardless of the substitutions.

The flavor, consistency and overall impression of the jams were influenced by the replacement of pitaya pulp with peel (Table 3). The substitution level of 20% generated the highest means for consistency and overall impression compared with the other formulations. The mean consistency and overall impression observed for the jam with 20% substitution were 7.56 and 7.73, respectively, demonstrating that the tasters liked this jam moderately to a lot. Thus, the addition of the peel increased potential consumers' approval of the jams.

Regarding flavor, the only difference detected was between the jams with 20% and 60% substitution. The first presented the highest mean (7.46), which fell between the categories "liked moderately" and "liked a lot". The second had a mean of 6.87, which fell between "liked slightly" and "liked moderately".

The tasters' preference for the treatment with 20% peel in place of pulp was evident in the sensory analysis. The tasters' observations on the sensory analysis forms indicated some factors that may have influenced this preference. Some tasters reported that the seeds lent a pleasant sensation of crunchiness to the jams but that the formulation that contained only pulp had a "sticky" consistency that made it difficult to transfer the jam from the spoon to the saltine used for tasting. For the formulations with 40 and 60% substitution, the tasters reported a small reduction in crunchiness due to the reduction in the amount of seeds. In addition, some tasters reported a slight loss in flavor intensity in the formulations with 60% substitution, which had a higher proportion of peel. The formulation with 20% substitution had the best combination of crunchiness, color intensity and consistency according to some tasters. It should be noted that the tasters' observations were based on the codes of the samples because the analyses were performed blindly; that is, the testers were not aware of the differences in the composition of the formulations provided to reduce possible interference with the scores.

Mango, jaboticaba and June plum jams made with the peel and pulp of these fruits were more sensorially accepted than those prepared only with pulp, with sensory scores greater than 7.0 (Lago-Valnzela *et al*., 2011; Dessimoni Pinto *et al*., 2011; Damiami *et al*., 2008). These authors report that, according to tasters, the preference for jams with peel was due to the more intense characteristic flavor and aroma of the fruits, in addition to a palatability similar to that of conventional gelatin. In addition to the greater sensory appeal, the authors emphasize that the use of peel adds nutritional value to the jams, since peels are usually more nutritional than pulp, and that the use of the peels helps to reduce production cost and promotes environmental sustainability. Thus, the results obtained in the present study corroborate those of the cited authors.

It is noteworthy that pitaya jam is still unfamiliar to many consumers. Nonetheless, the overall means for color, flavor, consistency and overall impression ranged from 7 to 8 on a 9-point hedonic scale, corresponding to "liked moderately" and "liked a lot". These results indicate that these jams have high potential for production and commercialization.

Texture profile analysis (TPA)

Textural variables are important components in the perception of food quality and acceptability; they reflect the chemical composition of the food and its structure (Dias *et al*., 2011; Chen and Opara, 2013).

According to the results (TPA), there were significant differences in hardness, adhesiveness, cohesiveness, gumminess and resilience among the treatments (Table 4).

The formation of the gel and its final characteristics are directly related to the soluble solids, pectin, acid and pulp content (Godoy *et al*., 2009). However, as there were no significant differences in soluble solids, and the acidity and amount of pectin added to the jams was standardized, the observed texture variations are assumed to be mainly linked to variations in the amount of pulp, peel and seeds and to heterogeneous seed distribution in the samples.

The replacement of pulp with peel reduced the hardness, gumminess and resilience of the jams. A reduction in these variables was observed with the replacement of pulp with peel at levels up to 40%, although the jam with 60% substitution had higher mean values of these variables than the jams with 20 and 40% substitution, which was contrary to the observed trend but was always lower than the values of the control. The adhesiveness and cohesiveness of the jams increased according to the percentage of pulp that was replaced with peel. The adhesiveness was higher with higher substitution ratios; the more negative the adhesiveness values are, the greater the adhesiveness is. Cohesiveness was positively affected by the substitutions, most prominently in the 20 and 40% formulations, which did not differ from one another.

Hardness represents the force required to break the material, cohesiveness is the extent to which a material can be deformed before breaking, and gumminess is determined by multiplying these two variables and refers to the energy required to disintegrate a semisolid food to the point that it is ready to swallow (Szczesniak, 2002). Adhesiveness is the energy required to overcome the attractive forces between the surface of the food and the surface of other materials with which the food is in contact, and resilience is the ability of a body to return to its original size after being compressed in a manner that simulates the action of the molars.

Fruit pulp is usually tender because it consists predominantly of parenchymal tissue that are rich in water. Conversely, the peel consists of dermal tissue, which is drier, although it may also include parenchymal tissue. However, pitaya pulp, although it is tender due to the presence of parenchymal tissue, is full of minuscule seeds, and these seeds are notoriously harder than the peel. Thus, it is believed that the reduction in the number of seeds due to the partial replacement of pulp with peel led to a decrease in the hardness of the jams. A similar effect on gumminess was also observed, since the reduction of the number of seeds reduces the energy needed to transform the jam into a product that is ready for swallowing. The reduction in the number of seeds also similarly affected the resilience of the jams, since the reduction of these miniscule solid bodies in jam, a semisolid food, reduces its ability to recover its original size after a bite. However, the jams with 60% substitution of peel for pulp showed greater hardness, gumminess and resilience than the jams with 20 and 40% substitution, probably due to the greater hardness and elasticity of the peel, which have an effect on these textural variables that exceeds the effect of the reduction in the number of seeds starting at 60% substitution. In fact, the peels of red pitaya have approximately twice as much dietary fiber as the pulp (Abreu *et al*., 2012). In addition, there is a greater amount of insoluble fiber than soluble fiber in pitayas, and insoluble fibers are present in greater amounts in the peel than in the pulp (De Mello, 2014), which increases the peel's resistance to heat treatment due to the formation of strong gels that can be used as texture-enhancing agents in foods. Furthermore, pitaya peel has more pectin than pitaya pulp. Iensen *et al*. (2013), when evaluating 18 kiwi jams with variations in the proportions of pectin, pulp and sugars, observed that the influence of pectin on the texture of the gels occurred starting at 1.5 g 100 g^{-1}; below this value, Brix did not significantly affect the compressive strength of the jam. Pectin forms chemical bonds with the soluble solids and water in a product, facilitating the formation of a firmer gel with these components. In summary, the effect of the pulp seeds on the hardness, gumminess and resilience of the jams surpassed the effects of the peel, although this effect was visibly diluted in formulations 60% substitution of peel for pulp.

The increase in adhesiveness due to the increase in the substitution ratio may be associated with the lower water content of the peel. Water has a lubricating effect, and its reduction makes foods stickier and therefore leads to greater adhesiveness. Conversely, the increase in cohesiveness caused by the substitutions may be associated with a reduction in the number of seeds, so that the more dispersed and less abundant the seeds are, the more cohesive the jam is. Seeds occupy space in jams, reducing the tendency of the molecules to remain together and thus decreasing cohesiveness. Reducing the number of seeds by partially replacing pulp with peel increases cohesiveness.

Microbiological analysis

Resolution RDC no. 12 of Anvisa (Brazil, 2001) stipulates the following microbiological limits for fruit jams: a maximum of 104 CFU g^{-1} for molds and yeasts, the absence of Salmonella in 25 g of sample and a maximum of 102 MPN g^{-1} for coliforms at 45°C. The microbiological results obtained in the present study indicate the absence of microorganisms in the jams, which proves that the product was contamination-free and, therefore, safe according to the current legislation. The low pH and high soluble solids content observed in the jams help limit microbial growth, particularly that of food-spoiling and/or foodborne pathogenic bacteria, which are sensitive to these variables (ICMSF, 2009). Furthermore, the results suggest that good manufacturing practices were successfully adopted.

Conclusions

Pitaya jams have high sensory acceptability and good quality. The jam with 20% peel had better acceptance by the tasters. Peel has potential for use and can contribute to minimizing production losses, adding value to the product and reducing the impact of waste on the environment.

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Table 1. Mass (g) of the ingredients for the formulation of pitaya jams with different proportions of peel in place of pulp.

Percentage pulp replaced with peel (%)	Ingredients(g)				
	Peel	Pulp	Water	Sugar	Pectin
0	0	420	280	465.5	11.65
20	84	336	280	465.5	11.65
40	168	252	280	465.5	11.65
60	252	168	280	465.5	11.65

Table 2. Mean values and coefficient of variation of pH and color (a* and chroma) for the treatments with different proportions of pulp replaced with peel.

Proportion of pulp replaced with peel, %	pH		a*		Chroma	
0	4.79	C	19.70	ab	19.76	ab
20	4.88	B	24.52	a	24.56	a
40	4.93	A	18.86	ab	18.94	ab
60	5.02	A	15.86	a	15.91	b
CV (%)	0.80		18.14		17.96	
Mean	4.90		19.74		19.79	

* Means followed by the same letter in the column do not differ at the 5% probability level according to Tukey's test.

Table 3. Mean values, overall mean and coefficient of variation in the acceptability test (flavor, consistency and overall impression) for jams formulated with different percentages of peel.

Proportion of pulp replaced with peel (%)	Scores (means)		
	Flavor	Consistency	Overall impression
0	7.04 ab	6.80 b	7.21 b
20	7.46 a	7.56 a	7.73 a
40	7.19 ab	6.99 b	7.28 b
60	6.87 b	6.66 b	7.05 b
CV (%)	20.19	21.98	16.97
Mean	7.14	7.00	7.32

*Means followed by the same letter in the column do not differ at the 5% probability level according to Tukey's test.

Table 4. Mean values, overall mean and coefficient of variation for the texture profile (TPA) of the treatments formulated with different percentages of peel.

Percentage of pulp replaced with peel (%)	Hardness (g)	Adhesiveness (g.s)	Cohesiveness	Gumminess	Resilience
0	556.19 a	-111.37 a	0.50 c	281.70 a	0.18 a
20	192.16 c	-203.76 b	0.72 a	135.90 c	0.17 a
40	108.78 d	-221.72 c	0.77 a	83.34 d	0.10 c
60	408.64 b	-299.15 d	0.58 b	237.44 b	0.15 b
CV (%)	8.47	1.96	3.74	5.03	6.96
Mean	316.44	-209.00	0.64	184.59	0.15

*Means followed by the same letter in the column do not differ at the 5% probability level according to Tukey's test.

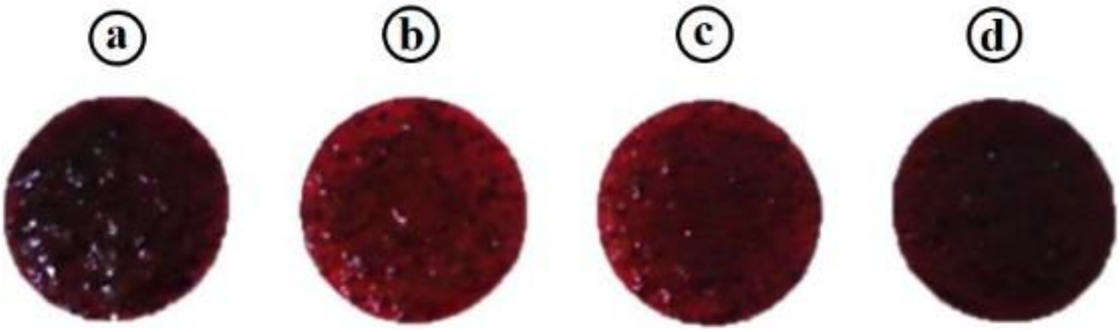

Figure 1. Appearance of red pitaya jams formulated with different levels of peel used in place of pulp. From left to right: a) 0; b) 20; c) 40; and d) 60% peel.