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Physical and chemical properties of pitaya fruits during storage using different packages

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Abstract

The pitaya is a fruit that gaining popularity. In the past, the plant and its flower were only used as decoration. Like all fruits, it has storage requirements, making its shelf life time longer, however, as it is a fruit with relatively recent commercialization, there are still no studies that demonstrate the best way to store it, increasing its viability for a longer period. Therefore, the objective of the present work was to evaluate the influence of the packaging material and storage time on the physical and chemical properties of the pitaya. A Completely Randomized Design (CRD) was used in a 3 x 6 factorial arrangement, with three replications. The treatments consisted of three types of packaging; Low Density Polyethylene (LDPE), cardboard box, and Expanded Polystyrene tray (EPS) + Polyvinyl Chloride (PVC); testing five different storage periods (0, 2, 4, 7, 9, and 11 days). The following characteristics were analyzed during storage: fruit mass, pulp/peel ratio, diameter, length and thickness of the fruits, water content of the fruits, pH, and soluble solids content. After performing the analyses, the cardboard box showed the best performance regarding the pitaya fruit's shelf life throughout storage. The findings herein indicate that pitaya fruits can be stored for up to 9 days in cardboard boxes without having their physical or chemical characteristics altered under uncontrolled ambient temperature and relative humidity conditions.

Keywords: *Hylocereus polyrhizus;* Fruit quality; Low Density Polyethylene (LDPE); Cardboard box; Expanded Polystyrene tray (EPS); Polyvinyl Chloride (PVC).

Highlights

- The cardboard box demonstrated the best performance for pitaya fruit storage
- Pitaya fruits can be stored for up to 9 days in cardboard boxes
- The physical and chemical properties are preserved for up to 9 days

1 Introduction

Brazil has an enormous diversity of soils and an ideal climatic condition to produce several fruit varieties of various species, among them is the pitaya (*Hylocereus polyrhizus*). This is a fruit originally from the Americas and, despite being one of the little known tropical fruits, it has a high potential for domestic and foreign markets due to its exotic appearance, sweet/smooth flavor, firm pulp as well as its nutritional and functional properties (Cheok et al., 2017 Faleiro & Junqueira, 2021 Lee, 2021; Ramos et al., 2018).

The pitaya is considered an exotic fruit that was relatively unknown up until recently, nevertheless, it is currently exhibiting a high market growth, both in terms of the fruit and its production. Moreover, it is a fruit that stands out not only for being exotic but also for its desirable sensory characteristics (Verona-Ruiz et al., 2020).

In addition to its beauty, the pitaya has attractive characteristics, such as a high content of phenolic compounds coupled with substances with antioxidant activity, namely ascorbic acid, carotenoids, and polyphenols, as well as containing betalains, which leads to a beneficial effect on people's health (Santa et al., 2020). This fruit can be consumed in the form of the fresh fruit itself, as a juice, only the pulp, as an ice cream or a mousse, or even as a coloring agent for sweet goods (Utpott et al., 2020).

It is known that the pitaya, when stored in ambient conditions, undergoes a rapid loss of quality, and deteriorates quickly, accelerating the occurrence of undesirable alterations (García-Cruz et al., 2016), which results in a short post-harvest shelf life, in general, 6 to 8 days without refrigeration, approximately (Nerd & Mizrahi, 1999). These losses are mainly caused by the poor handling of harvesters, or by using technologies that are inadequate for a given food, both in the planting and storage stages (Castro, 2014).

The packaging in which the fruit is to be stored can influence its physical and chemical properties since it can lead to undesirable processes during the storage phase. The fruits, as organic products, are subject to certain types of fungal infections and specific diseases that can rot them, thus, it is essential to take greater care with its packaging (Jalgaonkar et al., 2020).

The pitaya is highly perishable, containing a large amount of water to obtain a prolonged lifetime and to avoid fruit loss, because of this, particular attention should be paid to how this produce will be stored, both regarding the storage facility and the type of packaging that will be used. Fruits with a higher amount of water and easily degraded compounds during ripening can be damaged when not handled properly (Jalgaonkar et al., 2020; Utpott et al., 2020).

According to Lisboa et al. (2022), packaging plays an important role in distribution, storage, transport, and commercialization, as it protects the product from having its content violated. The author also states that it is necessary to investigate whether the existing packaging ensures that the produce is in a good state of conservation, allowing it a good presentation as well as consumption, guaranteeing quality, avoiding losses, and, consequently, providing greater sustainability to the production process.

Economically, unavoidable food losses can have a direct and negative impact on the income of producers along with the consumers, and many farmers who live on the margins of food insecurity could have an immediate impact on their means of income (Food and Agriculture Organization of the United Nations, 2011).

The pitaya is a fruit whose demand has grown in recent years and, associated with this, the demand for studies related to the post-harvest of such fruits has likewise increased, especially related to shelf life, better packaging for maintaining the produce quality, and avoiding the chemical alterations that occur during storage.

This work aims to evaluate the influence of the packaging material and storage time on the physical and chemical attributes of the pitaya, in order to identify the best packaging for storage to extend the shelf life of these fruits in the mesoregion of Northeast Pará.

2 Material and methods

For this experiment, pitaya fruits of the species *Hylocereus costaricensis* with purple pulp were used. The fruits were harvested from four-year-old plants planted in Sítio das Pitayas do Pará, municipality of Tomé-

Açu, in Pará - Brazil. The criterion used for harvesting was developed, ripe fruits with some red spots on the pulp, characterizing the market demands for this fruit (Figure 1).

Figure 1. Visual characteristics of the freshly picked fruits (standard market demand). Source: Own work.

After harvesting, the fruits were taken to the Agronomic Engineering Laboratory of the Universidade Federal Rural da Amazônia/Campus Tomé-Açu, where the post-harvest analyses were performed.

A Completely Randomized Design (CRD) was used in a 3 x 6 factorial arrangement, with three replications. The treatments consisted of three packaging materials; Low Density Polyethylene (LDPE), cardboard box, and Expanded Polystyrene Tray (EPS) + Polyvinyl Chloride (PVC); and five storage periods (0, 2, 4, 7, 9, and 11 days). The experiment consisted of 54 plots.

From the sample of fruits freshly picked in the field bearing the features required by the market, three fruits were randomly selected to carry out the characterization of the average values pertaining to these fruits' physical and chemical properties at the beginning of storage, using the following analyses:

a. For the fruits' mass, diameter, and length: The whole fruits were weighed on a precision scale (Kw Waagen, model KNL) with a maximum weighing capacity of 1.6 kg. Then, the intact fruits had their diameter, width, and thickness measured with the aid of a digital caliper (Kala) with a capacity of 152.4 mm and 6".

b. For the mass of the fruits' peels and pulp: Ensuing the analyses described in item "a", the intact fruits were cut in half and the pulp was removed completely. After this process, the masses of the pulp and peel were weighed separately on the same precision scale (Figure 2).

c. For the pulp/peel ratio: With the total pulp mass and the total peel mass obtained in item "b", the pulp/peel ratio was calculated using Equation 1:

$$\frac{Pulp}{Peel} = \frac{pulp\ mass}{pell\ mass} \quad (1)$$

Where:

$\frac{Pulp}{Peel}$ = pulp/peel ration, dimensionless;

Pulp mass: Total pulp mass, in grams; and

Pell mass: Total peel mass, in grams.

d. For the water content: After removing the fruit pulp as described in item "b", the pulp sections were mixed in a tray and, with the aid of tweezers, pieces of pulp were randomly collected so that each crucible had 30 g of fresh fruit. The crucibles containing the pulp pieces were taken to the dry oven (Lucadema, model 80/81) for 24 hours at 25 ºC, after which the water content was determined on a wet basis according to Equation 2 (Brasil, 2009).

$$Wc_{wb} = \left(\frac{tm-ds}{tm}\right) * 100 \quad (2)$$

Where:

Wc_{wb} = Water content, in percentage;

tm = Total pulp mass, in grams; and

ds = Dry pulp mass, in grams.

e. For the pH: The pulp pieces obtained in item “b” were crushed with the aid of a mixer (Mallory, model Robot 250). Part of the pulp processed by the mixer was taken to the benchtop pH meter (MS Tecnopon, model mPA-210) and the pH of the samples was assessed.

f. For the soluble solids content (Degree Brix): Part of the pulp processed in item "e" was used to determine the sample’s brix value with the aid of a refractometer (RBR brand, model RM-T90).

Figure 2. Separation of pulp and peel. Source: Own work.

After performing the initial characterization of the fruits, the rest of the sample was collected, and the freshly picked specimens were taken to storage.

Two ripe fruits, free of defects and with a similar degree of maturation, were chosen to compose each plot. In the laboratory, the fruits were randomly assorted into their respective packages. The Expanded Polystyrene (EPS) packaging was wrapped with Polyvinyl Chloride (PVC) and was not perforated, while the cardboard box was closed with adhesive tape, as was the Low Density Polyethylene (LDPE) packaging. The fruits were then stored in a laboratory environment for 11 days (Figure 3).

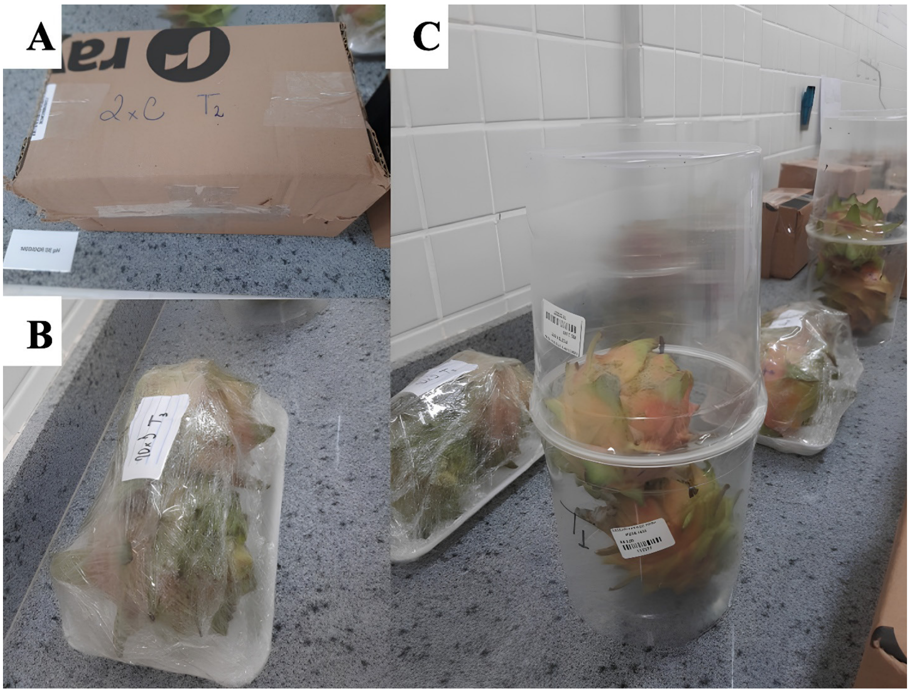

Figure 3. Fruits in their respective packages. Cardboard box - (A); Expanded Polystyrene tray (EPS) + Polyvinyl Chloride (PVC) - (B); Low Density Polyethylene (LDPE) - (C). Source: Own work.

After the onset of the storage, the fruits assorted in different packages were submitted to the analyses described in items “a”, “b”, “c”, “d”, “e” and “f” at 2, 4, 7, 9 and 11 days of storage.

During the storage period, both the temperature and the relative humidity conditions of the storage environment (laboratory) were monitored by a thermo-hygrometer data logger (BSide, model BTH01), programmed to register readings every 5 minutes. The averages can be observed in Figure 4.

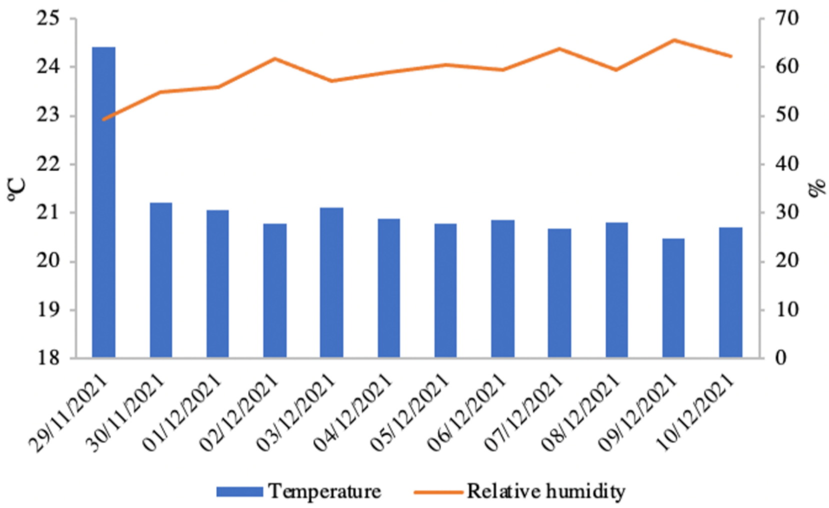

Figure 4. Temperature and relative humidity conditions in the laboratory during the pitaya’s storage period.

The data obtained was submitted to analysis of variance by the F-test at a 5% probability and, when relevant, the qualitative factors were assessed by the Tukey test at a 5% probability, with the quantitative factors analyzed by the regression test. For the statistical analysis, the SISVAR 5.6 software was used (Ferreira, 2019).

3 Results and discussions

Until the fourth day of storage, all fruits of all treatments appeared to be normal and presented characteristics suitable for consumption. From the seventh day onwards, it was possible to observe changes in the physical and chemical properties, when the fruits stored in LDPE and EPS+PVC packages began to have their pulp quality compromised, even becoming completely rotten. The cardboard box treatments were the only methods with no fruit loss.

This may be explained by the low rate of permeability to gases of Low Density Polyethylene (LDPE) and Expanded Polystyrene (EPS) + Polyvinyl Chloride (PVC) packaging to water vapor, CO_2, and O_2, which are the gases involved in the respiratory process of the produce. The exocarp (Lisboa et al, 2022), by being enclosed along with the fruits inside the packaging, may have caused the acceleration of the produce deterioration, which was not observed in the cardboard box, for example.

It was observed through the analysis of variance that the mass, diameter, length, average peel thickness and mass, as well as the amount of soluble solids of the studied fruits, showed a significant difference related to both the packaging factor and the time factor in isolation, with the interaction (P*T) of the packaging factor significantly influencing the pulp/peel ratio during storage (Table 1).

Table 1. Analysis of variance results for the following evaluated characteristics: mass (in g), diameter (in mm), length (in mm), average (in mm), Average Peel Thickness (APT) (in g), Pulp Mass (PM) (in g), Peel Mass (PLM) (in g), Pulp/Peel Ratio (P/PR) (in g/g), Water Content (WC) (in %), pH and Soluble Solids Content (SSC) (in °Brix).

Source of variation	DF	Ms									
		Mass	Diameter	Length	APT	PM	PLM	P/PR	WC	pH	SSC
Packaging (P)	2	64873.35^{*}	3015.85^{*}	2865.91^{*}	9.05^{**}	45338.23^{**}	5581.75^{*}	5.39^{***}	6108.66^{*}	7.75^{*}	57.70^{*}
Time (T)	5	50346.25^{*}	1526.36^{*}	2155.12^{*}	16.85^{***}	8974.81^{ns}	12739.21^{***}	0.16^{ns}	1340.21^{ns}	0.43^{ns}	37.21^{*}
P*T	10	19415.63^{ns}	873.13^{ns}	822.17^{ns}	1.56^{ns}	11012.66^{ns}	1523.33^{ns}	1.23^{**}	825.10^{ns}	1.97^{ns}	15.33^{ns}
Error	36	14397.71	597.89	679.06	1.15	7073.07	1459.50	0.42	616.49	1.75	11.10
Total	53	-	-	-	-	-	-	-	-	-	-
CV	-	31.40	30.66	30.77	28.58	33.98	29.79	36.02	31.06	36.50	30.19

Ms: mean square. *Significant at 0.05. **significant at 0.01. ***significant at 0.001. ns: not significant. Degree of Freedom (DF) and Coefficient of Variation (CV). Averages derived from three repetitions.

Regarding the coefficients of variation, it was observed that, except for the characteristics of Average Peel Thickness (APT) and Peel Mass (PLM), all presented coefficients of variation greater than 30%, which is considered high, according to the criteria described by Pimentel-Gomes (1985). This may have happened due to the fact that the pitaya culture has undergone a few studies on genetic improvement and the cultivar studied in the present research still presents variations in both physical and chemical characteristics of its fruits.

The cardboard box had the best results for the physical and chemical characteristics in most of the analyzed characteristics, not differing from the Low Density Polyethylene packaging. It is noteworthy that the cardboard box showed a considerable significant difference in the Average Peel Thickness as well as in the Pulp/Peel Ratio in relation to the other packages (Table 2).

The Expanded Polystyrene packaging (EPS) + Polyvinyl Chloride (PVC) was the material with the worst results, with no significance in any of the characteristics. This probably occurred because the packaging method promoted a modified atmosphere, prompting the fruits to increase their respiratory rate, raising the CO_2 concentration and decreasing the O_2 concentration, losing water to the environment and promoting faster deterioration. Both the excessive reduction of O_2 and the increase of CO_2 can trigger fermentative metabolism processes, resulting in the development of an alcoholic flavor/aroma along with pulp deterioration (Both et al., 2017).

Table 2. Packaging material analysis of the (EPS+PVC, the cardboard box, and the LDPE for the variance of mass, diameter, length, Average Peel Thickness (APT), Pulp Mass (PM), Peel Mass (PLM), Pulp/Peel Ratio (P/PR), Water Content (WC), pH and Soluble Solids Content (SSC).

Variable	Packaging		
	EPS+PVC	Polyethylene	Cardboard box
Mass (g)	322.69 b	380.89 ab	442.74 a
Diameter (mm)	65.64 b	82.54 ab	91.07 a
Length (mm)	70.54 b	88.76 ab	94.77 a
APT (mm)	3.06 b	4.47 a	3.71 ab
PM (g)	206.73 b	232.32 b	303.58 a
PLM (g)	108.70 b	142.85 a	133.23 ab
P/PR (g/g)	1.40 b	1.58 b	2.43 a
WC (%)	65.12 b	85.11 ab	89.59 a
pH	2.92 b	3.74 ab	4.22 a
SSC (°Brix)	9.00 b	11.75 a	12.36 a

The same letters in the column do not differ statistically from each other using the Tukey test at 5% probability. Averages derived from three repetitions.

Regarding the storage time, alterations were observed throughout the period for most of the characteristics, from the 9th day of storage onwards.

In the case of the fruit mass, it began to decline from the 7th day of storage, however, the significant variance was first observed on the 9th day, continuing until the last day of storage (Figure 5).

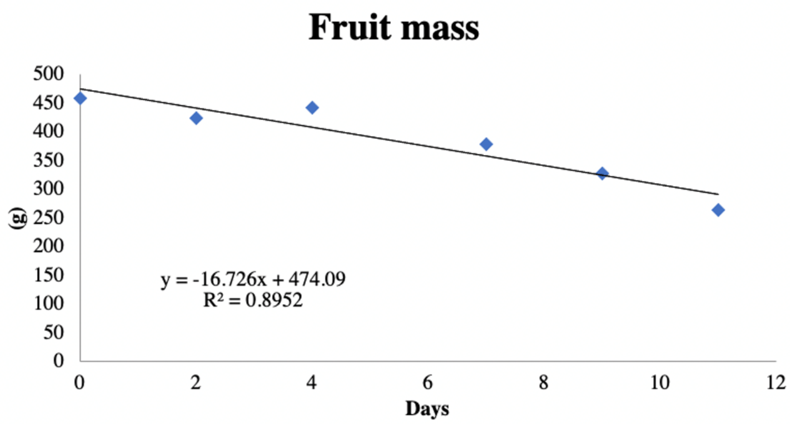

Figure 5. Behavior of the pitaya's mass (g) over storage time (days).

At the 9th day of storage (Figura 5), a 382.10 g average fruit mass was registered, which is a higher value than the findings described by Sibut et al. (2023), According to the authors, while working with the productive capacity of different pitaya genotypes, it was observed an average fruit mass value of 212.73 g in the 2020/21 harvest for the purple cultivar BRS GC in the Brazilian Midwest, demonstrating the superiority of the purple cultivar from Pará, that maintained higher values of fruit mass during storage.

As for the mass loss during storage, this behavior may be related to the respiratory activity leading to the loss of water to the environment, due to the fruits' transpiration (Lufu et al., 2019).

The fruits' length and diameter were significant on the 9th day of storage. The average length and diameter were around 84.7 and 79.8 mm, respectively (Figure 6), which is close to the values found by Morais et al. (2021), in a study using red-fleshed pitaya that registered mean values of 91.29 mm in length and 94.82 mm in diameter.

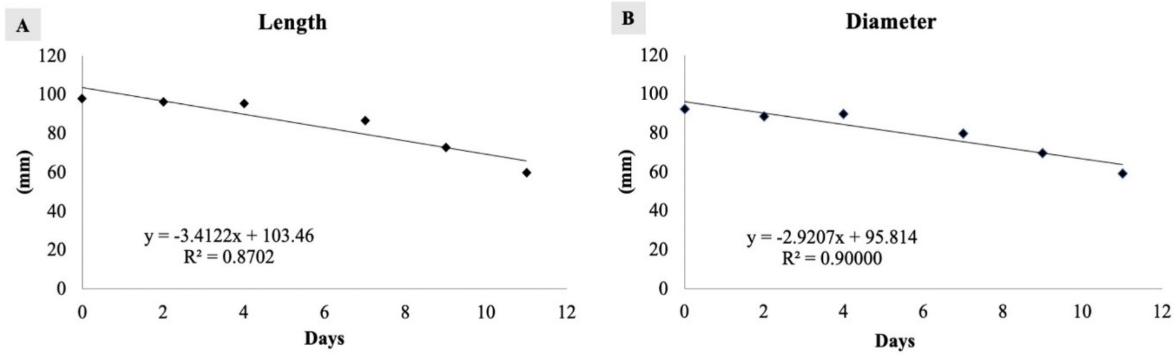

Figure 6. Length (A) and Diameter (B) of the pitaya's mass over storage time (days).

The fruits lost peel thickness and reached a point of significant difference after the 4th day of storage (Figure 6). As previously stated by Magalhães (2017), the fruit peel is an important factor from the post-harvest point of view, as it protects the produce against water loss as well as from mechanical, chemical, and biological damage. A thinner epidermis may result in fruits more susceptible to harm. On the other hand, when the peels are thicker, they tend to reduce pulp yield, as it is a relationship variable (Oliveira et al., 2021).

The fruits showed an increase in the pulp mass and a decrease in the peel mass, reinforcing what was proven in the analysis of the peel thickness, occurring significantly after the 9th day of storage. The pulp average was 247.54 g and the peel average was 128.26 g, slightly different from the values found by Oliveira et al. (2021), who analyzed a "golden" pitaya and obtained a pulp mass of 264.04 g, along with 95.63 g of peel mass (Figure 7).

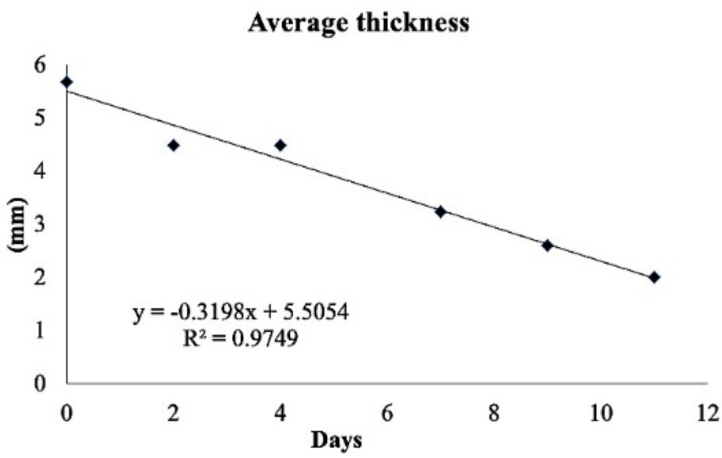

Figure 7. Average thickness of the pitaya's peels over storage time (days).

Another important attribute to be observed in the post-harvest period is acidity. The fruits' acidity is a result of the presence of organic acids, and their accumulation promotes an increase in the acidic or sour flavor, as this process is related to fermentation and, in this case, the fruit may already be at the beginning of senescence, increasing its acidity (Damodaran et al., 2010). On that note, the fruits of the present study's sample had a uniform pH behavior throughout the storage period, not presenting any statistical difference in relation to time, with an average of 3.63 pH.

Moisture content is crucial information on food composition, being one of the parameters frequently determined in routine assessments, and can serve as an indicator of product quality, since it has a direct influence on storage (Luu, et al., 2021; Perween et al., 2018). In the current study, the fruits' water content remained stable until the 4th day of storage began to decrease after the 7th day, and the significance was verified on the 9th day (Figure 8).

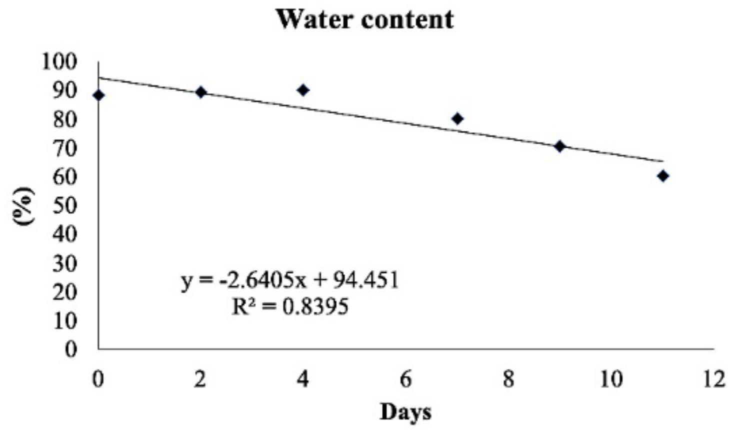

Figure 8. Water content of pitaya's fruits over storage time (days).

The Soluble Solids Content values in this study ranged from 7.83 to 13 °Brix and showed a significant difference from the 9th day onwards (Figure 9). These values are consistent with Sobral et al. (2019) findings using pitaya pulps, with a 7 to 11 °Brix variance. Fruits in general, when ripe, have average values of Soluble Solids Content between 8 and 14% (Chitarra & Chitarra 2005).

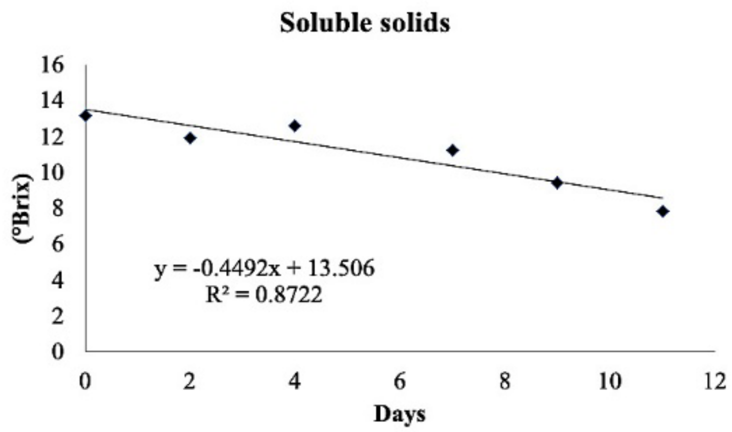

Figure 9. Soluble Solids Content values of pitaya fruits over storage time (days).

Concerning the Pulp/Peel interaction, it can be seen in Table 3 that, when analyzing the storage time, only the cardboard box showed a significant difference during the assessed period. At 11 days of storage, when the produce started to show a difference from the storage period onset, the highest average observed was related to the Pulp/Peel Ratio (P/PR). Still on the P/PR (Table 3), a significant alteration of this characteristic was registered at 9 and 11 days of storage, with the cardboard box presenting the highest average values for this feature.

The increase of the Pulp/Peel Ratio during storage observed in the cardboard box packaging treatment (Table 3) may have occurred because the thickness and mass of the peel reduced during storage. This reduction led to an increase in the pulp/peel ratio, which may have been more significant for the cardboard box, as this packaging material leaves the fruits exposed to conditions that allow gas exchanges with the environment, while the EPS + PVC and Polyethlene packaging present a barrier to gas exchange.

Table 3. Average values of the Pulp/Peel Ratio for pitaya fruits in different packages over storage time (days).

Storage time (days)	Packages		
	Polyethylene	EPS+PVC	Cardboard box
0	**1.7 aA**	**1.7 aA**	**1.7 aA**
2	1.4 aA	1.7 aA	1.7 aA
4	1.4 aA	2.1 aA	2.1 aAB
7	1.4 aA	1.3 aA	2.4 aAB
9	2.0 abA	0.8 bA	3.0 aAB
11	1.4 bA	0.9 bA	3.6 aB
Average	1.6	1.4	2.4

Averages followed by the same uppercase letter in the line and lowercase in the column do not differ from each other by the Tukey Test at 5% probability.

Concerning the behavior of the Pulp/Peel Ratio during storage, it can be seen in Figure 10 that the EPS + PVC and the Polyethlene packages exhibited a constant behavior throughout the storage period, while the cardboard box showed a linear behavior, indicating that the Pulp/Peel Ratio increases during storage.

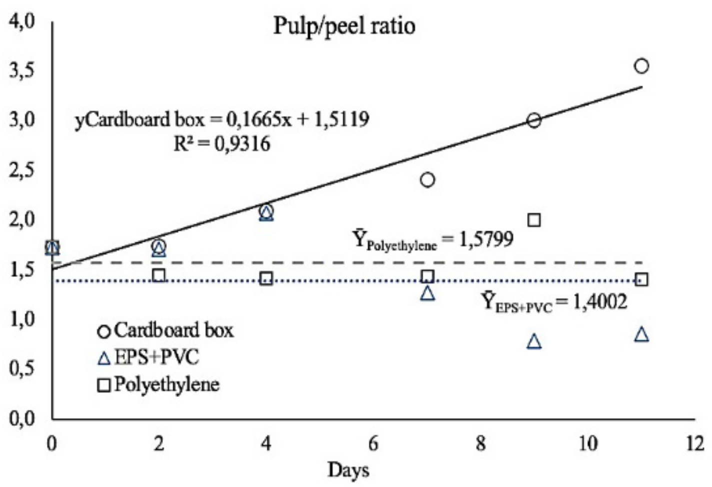

Figure 10. Mean values for the Pulp/Peel Ratio of the pitaya fruits over storage time (days).

The increasing linear behavior of the Pulp/Peel Ratio (Figure 10) during storage may be explained by the fact that there was no barrier to the gas exchange between the fruits and the environment. The EPS +PVC and the Polyethlene packages kept the Pulp/Peel Ratio constant. Despite the constant behavior of the Pulp/Peel Ratio for the EPS +PVC and the Polyethlene packages, when considering the other characteristics studied in repetition (Table 1), it was possible to observe that these packages maintained better average values only for this characteristic, and for fruit mass. For the other assessed characteristics, the cardboard box showed superior performance in maintaining the chemical and physical characteristics of pitaya fruits stored under uncontrolled laboratory conditions.

4 Conclusions

In the present study, three types of packaging materials; Low Density Polyethylene (LDPE), cardboard box, and Expanded Polystyrene tray (EPS) + Polyvinyl Chloride (PVC); and five storage periods (0, 2, 4, 7, 9, and 11 days) were used to evaluate the best conditions for pitaya storage. According to the results obtained herein, the cardboard box achieved the best performance regarding the fruits' shelf life throughout storage.

To conclude, pitaya fruits can be stored for up to 9 days in cardboard boxes without having their physical and chemical characteristics altered under uncontrolled temperature and relative humidity conditions.

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