Effect of temperature and storage on açaí (*Euterpe oleracea*) fruit water uptake: simulation of fruit transportation and pre-processing

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Abstract — Introduction. Açaí is a common palm in the Amazon River basin, from which a much-appreciated drink is prepared in the North of Brazil. Despite the strong increase in the drink market, some basic questions about the fruit postharvest physiology have not been properly studied. Our paper presents results about the fruit water absorption at different temperatures and times of storage, which may help the development of more efficient procedures for fruit transport and processing. **Materials and methods**. The experiments began approximately 3 h after harvest of fruits collected early in the morning. In a first experiment, to evaluate the effect of temperature on water absorption, fruits were submitted to five treatments: 0 °C, 6 °C, 12 °C, 26 °C and 39 °C. Each treatment was applied to 50 fruits, with four repetitions. Fruits from each lot were put into a beaker with water at the temperature of the selected treatment. Lots were weighed before immersion and every 10 min up to 60 min. The fruit relative increase in mass ($dMasse_{rel}$) was calculated according to experiment time. In a second experiment, to evaluate the effect of storage, fruits collected at the same spot were immediately stored in the lab at 10 °C under relative air humidity of 81% to 87%. After (5, 6 and 7) days of storage, the $dMasse_{rel}$ curves were determined. **Results and discussion**. Between 0 °C and 26 °C, the absorption reaches an asymptote after 30 min, and at 39 °C, the absorption continues to increase for a longer period. The maximum ($dMasse_{rel}$) regarding the temperature was fitted by a parabole, with a minimum at 13 °C. Fruits stored at 10 °C presented an increase in the absorption rate after the fifth day. **Conclusion**. Our data suggest that: (i) water absorption is minimum at 13 °C; (ii) the imbibition rate is temperature-related, and (iii) fruit stored at 10 °C, and relative humidity 81% to 87%, increases its water absorption rate at the end of the shelf-life time (5th day).

Brazil / Amazon river / *Euterpe oleracea* / fruits / fruit pulps / beverages / storage

Effet de la température et du stockage sur l'absorption d'eau par le fruit d'*Euterpe oleracea* : simulation de transport et de prétraitement du fruit.

Résumé — Introduction. Le « palmier pinot » est un palmier commun dans le bassin amazonien ; son fruit est à la base d'une boisson très appréciée au nord du Brésil. Malgré une forte progression de ce marché, certaines questions fondamentales sur la physiologie après-récolte du fruit n'ont pas encore été correctement étudiées. Notre document présente des résultats sur l'absorption d'eau par le fruit à des températures et des durées de stockage différentes ; ils pourraient aider à développer des procédures plus efficaces pour le transport et le traitement de ces fruits. **Matériel et méthodes**. Les essais ont commencé 3 h après la récolte des fruits effectuée tôt le matin. Tout d'abord, pour évaluer l'effet de la température sur l'absorption en eau, des fruits ont été soumis à cinq traitements : 0 °C, 6 °C, 12 °C, 26 °C et 39 °C appliqués chacun à 50 fruits, avec quatre répétitions. Les fruits de chaque lot ont été immergés dans un bécher à la température du traitement concerné. Les lots ont été pesés avant immersion et tous les 10 min jusqu'à 60 min. L'augmentation relative de la masse des fruits ($dMasse_{rel}$) a été calculée à chaque pesée. Ensuite, pour évaluer l'effet du stockage, des fruits de même origine ont été stockés en laboratoire à 10 °C (hygrométrie 81% à 87%). Les courbes de ($dMasse_{rel}$) ont été tracées après (5, 6 et 7) jours de stockage. **Résultats et discussion**. Entre 0 °C et 26 °C, l'absorption a atteint une asymptote après 30 min ; à 39 °C, elle a continué à augmenter. La représentation des maxima de ($dMasse_{rel}$) pour chaque température a suivi une parabole ; le point le plus bas a été observé pour les fruits stockés à 13 °C. Le taux d'absorption des fruits stockés à 10 ° C a augmenté après le cinquième jour. **Conclusion**. Selon nos données : l'absorption de l'eau par le fruit est minimale à 13 °C ; le taux d'imbibition est lié à la température ; le fruit stocké à 10 °C et hygrométrie de 81 % à 87 % augmente son taux d'absorption d'eau à la fin du temps de conservation (5^e jour).

Brésil / Amazone / *Euterpe oleracea* / fruits / pulpe de fruits / boisson / stockage

1. Introduction

At least three important species of the genus *Euterpe* can be found in Brazil: *E. edulis*, *E. precatoria* and *E. oleracea*.

There was an extensive population of *E. edulis*, a mono-stemmed palm, in the Atlantic forest, and for a long time, this species was explored for heart-palm extraction. The overwhelming reduction of this forest to 7% of its initial area and the unsustainable exploration of this natural resource reduced its population drastically.

E. precatoria is also a mono-stemmed palm; it is found primarily in the medium Solimões basin, an important tributary of the Amazon River.

Big populations of *E. oleracea* can be found along the river margins, in areas periodically flooded by the Amazon River basin, and close to the mouth of the river. This species is multi-stemmed and, for some years, it was inordinately explored for heart-palm extraction. Luckily, its fruit is an important nutrition item of the traditional human populations of this region [1]. Because of this fact, much effort has been made to discover sustainable management alternatives for native açaí populations [2–4].

Most of the production is made up of a smooth and very purple, almost black fruit, weighing (2.6 to 3) g [5]. The açaí fruit is almost round, with a diameter of about (1 to 2) cm. It contains a large core that occupies almost all its volume, and a pericarp only 1-mm thick. Between the seed and the pericarp, there is a well-packaged fiber layer, partially detachable during processing.

The nutritional attributes of açaí have been subjected to study since at least 1936 [6]. Since then, some authors have repeated the measurements using more modern techniques and samples from different spots, most of them from the "ecotype" used here and described by Paula [5]. The fruits studied here have a mean mass of 1.46 g and the fresh core, 1.09 g. The difference, 0.37 g, is the mean mass of the pulp, which corresponds to ~ 25% of the fruit.

Açaí drink is an effective functional food because of its high quantity of polyphenols. It has (247 to 265) $\text{kcal}\cdot 100\ \text{g}^{-1}$ of pulp, (20.7 to 22.5)% of lipids (dry matter base, DM), assimilable sugars from (20.7 to 36.4)% DM, proteins around 18.2% DM, and vitamins A, B, C and E [7, 8]. It also contains polyphenols, raw fibers [(32.3–34.0) $\text{g}\cdot 100\ \text{g}^{-1}$ DM] and elements (in $\text{mg}\cdot 100\ \text{g}^{-1}$ dry matter): Ca (133–286), Cu (1.7–2.0), Fe (1.5–26.0), K (499–932), Mg (121–174), Na (16.0–56.4), P (99–124), S (147) and Zn (2–7) [9]. However, the benefits of açaí for human health become evident when the populations that regularly consume it are observed [1].

In recent years, açaí beverages have secured other markets in Brazil and abroad, owing to their energetic and antioxidant properties and novel research that points to applications in food, medical and dental care [10–13].

Açaí is the most important fruit produced in the northeast of Pará (Brazil). In 2002, it represented 66% of all fruits produced, increasing to 76% the following year[1]. That represented 59% of the profit of the region in fruit commercialization in 2002, rising to 69% the following year. Most of that açai is consumed regionally, where the market is very robust with a tendency for growth. The secretary of agriculture of the State of Pará estimates that the fruit production in 2004 reached 350 000 t of fruit, which is 35% more than it was in 2003. Particularly in the city of Belém, the consumption must be between 120,000 L and 180,000 L daily.

Moreover, another market is being created which is based on exportation. According to the survey, it is estimated that it was around US$ 2.12 M in 2003, and at least US$ 5.49 M in 2005, corresponding to about 2.000 t to 3.000 t of drink [14].

Until recently, approximately 70% of açaí fruit production came from the extraction by small farmers along river borders of the Amazon River basin, and on Marajó Island [15]. When the processing industry is close to the harvesting spot, fruits are transported

[1] According to www.redesist.ie.ufrj.br, march 2006: Costa F.A., Andrade W.D.C. de, Silva F.C.F da, O processamento de frutas no nordeste paraense e região metropolitana de Belém – um arranjo produtivo emergente, IE-UFRJ, Rio de Janeiro, Brasil.

in small boats by the producers, who package the fruit in vegetal fiber baskets at ambient temperature (around 26 °C). For greater distances, the transport is done by ships, transporting around 10 t, anchoring as closely as possible to the producer. Frequently, fruits are received in small lots and only after large amounts of fruits reach the ship, the basement is opened. Ice is then spread in the basement, and fiber or plastic baskets are piled and covered with plastic, over which more ice is spread.

The inefficient air flux from the ice layers to the baskets cause big gradients of temperature that reduce the shelf-life time of the fruits. Another source of gradients is the sandwich-like disposition of ice and baskets, which cools only the outer layers during a 12-h journey. Additionally, the water from the melted ice is absorbed by the fruits not sheltered by the plastic, like those in the bottom of the piles, which alters the initial condition for processing.

Commonly-known information states that the ice-layer technique allows a maximum shelf-life time of 5 days. This limitation has social and economic consequences: small producers that live far from the processing industry (usually close to a city) do not get a reasonable price for their production since the fruits are of low quality at their arrival. The industry also does not have a regular supply throughout the year because there is no adapted storage methodology to attend to the slack season demands.

For the most part, açaí drinks are obtained by employing the traditional processing system. The fruits are sanitized and immersed in water for some time to reduce the binding forces between the pulp and the core. Then the fruits are inserted into a vertical cylinder, inside which six rods rotate at 360 rpm, with a sieve at the bottom. After a few seconds, the operator initiates a controlled water insertion in the superior opening of the cylinder. Initially an emulsion is formed, and then it flows through the sieve. Therefore, the physicochemical characteristics of the drink depend on the total water volume and the rhythm of its addition. Drinks with dry matter above approximately 19% present a disgusting taste, probably caused by the tannins extracted from the core [16, 17].

In our study, water absorption curves of açaí fruits were determined as a function of the temperature and storage time, which is relevant for at least three steps of the açaí business:

– transport: in high-capacity ships, açaí is cooled by crushed ice that after melting bestows water for undesirable fruit absorption;

– processing: an important step in fruit processing is its immersion in water to reduce the bonding force between the pericarp and the core;

– storage: the high ratio [surface:volume] of the pericarp makes the fruit very sensitive to the available water (liquid or vapor) in the storage chamber.

2. Materials and methods

The experiments took place at the *Laboratório de Agroindústria* of the *Embrapa Amazônia Oriental* (Belém, Pará, Brazil). Fruits were collected early in the morning on the Murutucu island (1° 39' 29.23" S, 48° 27' 17.64" W) off the coast of Belém, and immediately transported to the lab in a 1-L plastic bag with openings, and at ambient temperature (~ 26 °C). The experiments began approximately 3 h after harvest.

In a first experiment, the effect of temperature on the fruit absorption rate was evaluated. The temperatures were chosen from the range of temperatures found in the açaí chain: 0 °C, 6 °C and 12 °C (transportation), 26 °C (storage), and 39 °C (processing). Each treatment was applied to 50 fruits, with four repetitions. These fruits were chosen from those with no apparent damage. Fruits from each lot were put into a beaker with deionized water at the temperature of the selected treatment and the beaker was partially submerged in water at the same temperature. Lots were weighed before immersion and every 10 min up to 60 min (dMasse). Before each weighing, the fruit surface was quickly dried with tissue. A semi-analytical balance was used for weighings.

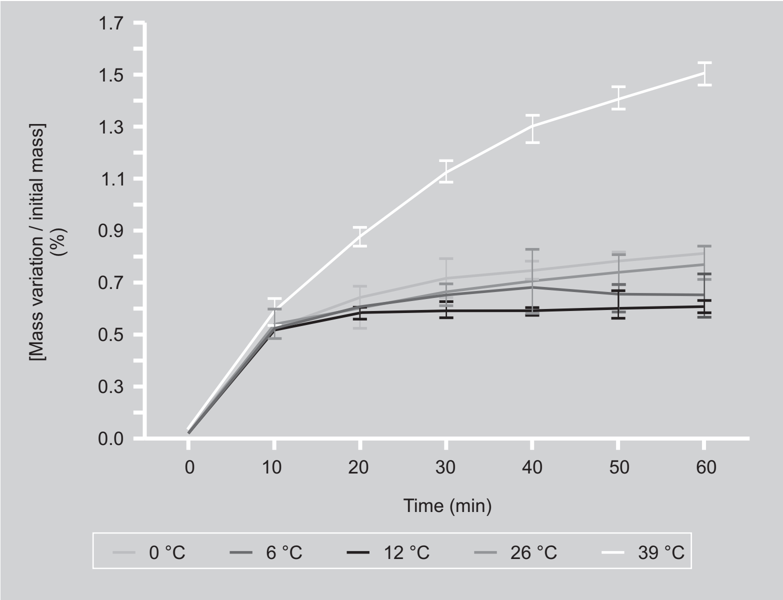

Figure 1.
Relative water mass variation of açaí (*Euterpe oleracea*) fruit immersed in water according to five bath temperatures.

These weight values were used to calculate the fruit relative increase in mass ($dMasse_{rel}$) ($dMasse_{rel}$ = dMasse / $Masse_{ini}$), according to experiment time; dMasse is the fruit mass variation and $Masse_{ini}$ is the fruit initial mass.

In a second experiment, to evaluate the effect of storage, fruits were collected at the same spot and transported in 15-L baskets. In the lab, they were immediately stored in a refrigerated chamber at 10 °C, chosen arbitrarily, under relative air humidity of about 81% to 87%. After (5, 6 and 7) days of storage, the $dMasse_{rel}$ curves were determined for each storage period, as for the first experiment.

Throughout our paper, to explain which part of the acaí is concerned by the metabolism, we use the nomenclature of Paula [5], who describes the fruit as: pericarp (epidermis, external parenchyma, esclerenchyma, internal parenchyma and endocarp), tegument and seed. To avoid misunderstanding, the [endocarp + seed] is called the "core". The core is a subproduct of the fruit processing and, when dried, their parts are easily separated. The endocarp is part of the internal parenchyma which contains the vascular tissue. The pulp, which is the part of the fruit removed during processing, is composed of the epidermis, external parenchyma, esclerenchyma and part of the internal parenchyma (not the endocarp).

3. Results and discussion

The fruit relative increase in mass ($dMasse_{rel}$) according to the experiment time reached its maximum value after 60 min of experimentation, whatever the temperature of immersion. Nevertheless, the curve profiles and the maximum values of ($dMasse_{rel}$) were different depending on the bath temperatures (*figure 1*).

Relative water mass variation ($dMasse_{rel}$) in time is a common way to present the seed water absorption [18]. For fruits, the interpretation of $dMasse_{rel}$ must consider the inward seed, whose absorption rate is different from the pericarp rate. However, palms are notorious for slow seed germination, and soaking the seed in water from (1 to 7) days is suggested in order to improve germination. For açaí seeds, water absorption should be similar and the seed absorption during the 60 min of the reported experiments must be negligible. Therefore, the absorbed water in the present experiments is retained by the pericarp.

A precise description of the anatomy that supports the water absorption with respect to the temperature is beyond the scope of this paper, but some comments can be made. In the fruit, the seed is covered by the vascular tissue (the layer of fibers) in the internal parenchyma, forming a matrix potential. The fibers are connected to the peduncle, forming a preferential path between that and the internal parenchyma for water uptake. In the fiber layer, water may reach a chemical and structural storage support. A reasonable model for that includes pectin or other hydrophylic chemicals involving the fibrous structure. This arrangement is a source of matrix potential, which could quickly suction water to the fiber interspaces, and trap it with the help of hydrophylic chemicals (first part of the graphic in *figure 1*) [19]. Following the water absorption, the matrix potential approaches zero and $dMasse_{rel}$ tends to an asymptote (second part of the graphic in *figure 1*).

A similar behavior was proposed for growing plant cells, whose walls have cellulose fibers interconnected by xyloglucans, thus forming a web encrusted in the pectin matrix. Both webs, linked by calcium bridges, present a matrix potential that increases the water absorption rate necessary for the inelastic volume increase in the cell [20, 21]. Nevertheless, not all the absorbed water through the insertion point goes straight to the fiber layer. Part of that is absorbed by mesocarp cells, in a slower and longer process that extends from time zero to the asymptote of $dMasse_{rel}$ curves. Both water absorption processes reduce the connecting area of neighboring cells between them and the fiber layer, which reduces the connecting strength. At the extreme of absorption and shape changes, the fruit surface cracks [22]. During the experiments, although the first crack was observed after 20 min (at 39 °C), only after 60 min did the cracking rate increase considerably.

Another water path is through the hydrophobic coating on the fruit surface. When submerged into water, fruit releases an oily substance from its epidermis, and observation suggests that the liberated amount is temperature-related. After the wax detachment, the water could migrate more quickly through the cracks of the epidermis. No paper containing a description of the wax from the surface of the fruit exists, to our knowledge; however, it is possible that the wax constitutes some fatty acids found in the fruit. Lubrano *et al.* [7] determined the oil composition of six palm species, including *E. oleracea*. The fatty acids were extracted from the depulped açaí with hexane and analyzed by gas chromatography. These authors reported 22% of pulp in the fresh fruit and 8.8% of oil in the pulp, whose main constituent was oleic acid. During the experiments reported here, after 50 min at 39 °C, the wax detached from the fruits was easily observed.

Water absorption at low temperatures occurs, for example, during fruit transportation for long distances, usually done by ships with a capacity of around 10 t of fruit. The ship anchors as closely as possible to the producers who yield the fruits and deliver it in small quantities. They are maintained on the deck of the ship until all shipments have been delivered. Afterwards, the basement is opened and the baskets are piled up over crushed ice, and then covered with a plastic layer, over which more ice is spread. During a typical trip lasting 20 h, the temperature of most of the fruit in the ship's basement is from about 0 °C to 26 °C.

Fruits at the bottom, close to the ice, absorb water at a temperature of around 0 °C, and, after 20 min the $dMasse_{rel}$ reaches up to 0.5% (*figure 1*). Upper baskets, especially those not on the side border of the pile, are not wet and the fruit's water content depends on the local microclimate.

It is expected that a proportion of the fruits, for at least part of the trip, is at the ambient temperature (26 °C). For temperatures up to that limit and after 60 min, the $dMasse_{rel}$ of a fruit is at around 0.5% to 0.7% (*figure 1*). After that, the epidermis of most fruits crack, and the cell contents leak, reducing the concentration of important chemical constituents of the drink.

In the processing plants, the fruits are intentionally immersed into water for a few minutes for mesocarp adhesion reduction and depulping optimization. In the small processing plants that service the local market with fresh pulp, the temperature is the same as the environment (~25 °C), but, in mid- and large-sized plants, the use of tepid water is more usual. At 39 °C, the wax detachment improves the water absorption before the first crack (after 20 min) and the fruits do not reach an asymptote (*figure 1*). After 60 min, the relative mass variation is 1.5%, considerably higher than for lower temperatures.

Those cracks (at 39 °C, they begin after 20 min; at 26 °C, after 60 min; for lower temperatures, no cracks were observed during the experiments) explain the outstanding maximum values of $dMasse_{rel}$ at higher temperatures; temperatures close to 0 °C may change mechanical characteristics of the wax film, making it mechanically rigid and breakable, and facilitating the appearance of small fractures through which the water could enter. The minimum of maximum values of the $dMasse_{rel}$ curve was observed at

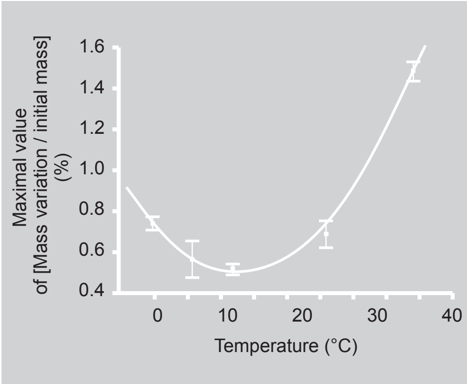

Figure 2.
Parabola showing the different maximum water mass variation of açaí (*Euterpe oleracea*) fruit immersed in water, obtained after 60 min of experimentation, *vs*. the temperature (T) of the water. The experimental data was fitted by the parabola [max $dMass_{rel} = 0.7446 - (0.03718 \times T) + 0.00143 \times T^2$]; the lower value is at 13 °C.

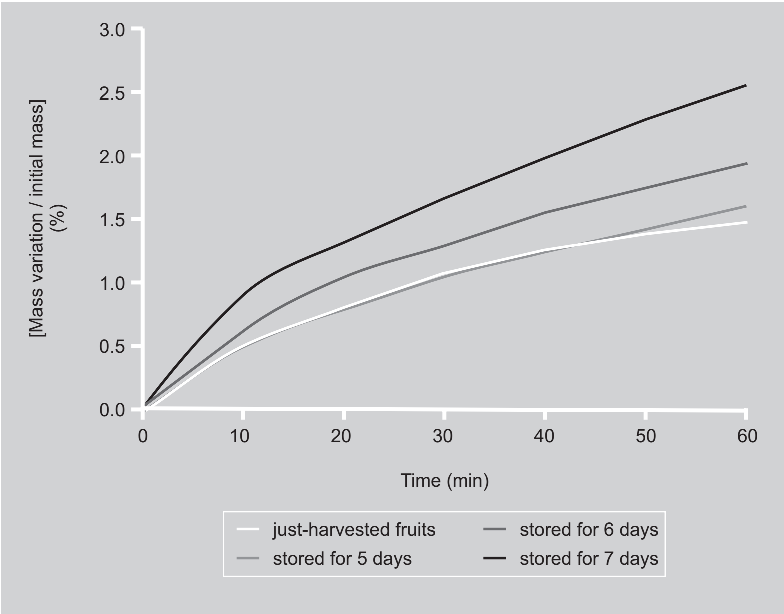

Figure 3.
Relative mass variation of açaí (*Euterpe oleracea*) fruit immersed in water at 39 °C according to time of immersion and for different durations of fruit shelf life at 10 °C. After the fifth day, when the curves tend to higher values, fruits furnish an unpleasant drink.

13 °C (*figure 2*); it is unexpected behavior whose cause may be the preservation of the wax barrier at this temperature.

Storage at 13 °C preserves the fruit structure but reduces its shelf life because of the big slope of Q10 close to the freezing point [23]. Unfortunately, the available literature does not include references to cold injury, freezing point and other aspects of açaí postharvest that would support a discussion about the most convenient temperature for fruit storage.

According to our results, fruits stored for 5 days at 10 °C (relative humidity from 81% to 87%) did not present a significant difference compared with the fruits just harvested (*figure 3*). After that, the absorption rate increased gradually after the end of the shelf-life time, but a further study is necessary to evaluate if this observation can become a test of quality of the fruit.

4. Conclusions

According to our results:

– water absorption would be minimum at 13 °C;

– the imbibition rate is temperature-related, but its usefulness in fruit processing is constrained by the epidermis disruption that leaks the cell contents;

– a storage temperature of 10 °C, and relative humidity of 81%–87%, would increase the fruit water absorption rate at the end of the shelf-life time.

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Efecto de la temperatura y del almacenamiento sobre la absorción de agua por parte del fruto *Euterpe oleracea*: simulación de transporte y de pretratamiento del fruto.

Resumen — introducción. La «Palma murrapo» es una palmera común en la cuenca amazónica; su fruto es la base de una bebida muy apreciada en el norte de Brasil. A pesar de una progresión fuerte de este mercado, algunas cuestiones fundamentales sobre la fisiología poscultivo del fruto no se han estudiado aún correctamente. Nuestro documento presenta resultados sobre la absorción de agua por parte del fruto a diferentes temperaturas y duraciones de almacenamiento; y podría contribuir a desarrollar unos procedimientos más eficaces tanto para el transporte como para el tratamiento de estos frutos. **Material y métodos**. Los experimentos comenzaron 3 h después de la cosecha de frutos, efectuada tempranamente por la mañana. Antes de todo, con el fin de evaluar el efecto de la temperatura en la absorción en agua, los frutos se sometieron a cinco tratamientos: 0 °C, 6 °C, 12 °C, 26 °C y 39 °C cada uno aplicados a 50 frutos, con cuatro repeticiones. Los frutos de cada lote fueron sumergidos en un vaso de precipitados a la misma temperatura del tratamiento en cuestión. Se pesaron los lotes antes de la inmersión y repetidamente entre cada 10 min a 60 min. El aumento relativo a la masa de los frutos ($dMasa_{rel}$) se calculó en cada toma de peso. Después, para evaluar el efecto del almacenamiento, se almacenaron en laboratorio frutos del mismo origen a 10 °C (higrometría 81% a 87%). Las curvas de ($dMasa_{rel}$) se trazaron tras (5, 6 y 7) días de almacenamiento. **Resultados y discusión**. Entre 0 °C y 26 °C, la absorción alcanzó una asíntota después de 30 min; a 39 °C, continuó aumentando. La representación de las máximas de ($dMasa_{rel}$) para cada temperatura siguió una parábola; el punto más bajo se observó para los frutos almacenados a 13 °C. El índice de absorción de los frutos almacenados a 10 °C aumentó después del quinto día. **Conclusión**. De acuerdo con nuestros datos: la absorción del agua por parte del fruto es mínima a 13 °C; el índice de imbibición está relacionado a la temperatura; el fruto almacenado a 10 °C y con higrometría de entre un 81 % a un 87 %, aumenta su índice de absorción del agua al final del tiempo de conservación (5° día).

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