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Postharvest conservation of three minimally processed cassava cultivars under cold storage

Conservación poscosecha de tres cultivares de yuca mínimamente procesada en cámaras frigoríficas

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Minimally processed cassava varieties.

Photo: A.L.S.L. Ragagnin

ABSTRACT

Once harvested and stripped of their bark, cassava roots have a short shelf life under ambient conditions. This is due to their high-water content, which makes them highly susceptible to attack by decaying fungi and the action of enzymes that darken the roots. After a few days of storage in ambient conditions, these roots become inedible. They develop mold and vascular discoloration. For family farmers, keeping food frozen is a challenge due to the high cost of freezing and especially due to the fact that the main means of selling their products is at street markets without any structure for installing freezers. This necessitates understanding how the food behaves in a refrigerated environment. The objective of this study was to evaluate physical changes in cassava roots stored in LDPE packaging and PVC-wrapped polystyrene trays for three cultivars.

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Two experiments were conducted: experiment 1 involved low-density polyethylene (LDPE) packages with three cassava cultivars (BRS 397, BRS 398 and IAC 576-70), while experiment 2 used expanded polystyrene trays wrapped in polyvinyl chloride (PVC) with the same cultivars. The trials were carried out at the Federal University of Jataí, Brazil. The experimental design was a completely randomized design with three replications and storage periods as treatments (0, 5, 10, and 15 days). After pre-processing, the roots were packaged and stored in a refrigerated environment at 5±1°C. Measurements taken during storage included fresh weight loss, color difference, hue angle, and chroma. Overall, both packaging methods helped reduce mass loss of cassava roots stored at 5±1°C. The BRS 397 cultivar showed the lowest color difference over the course of the storage days, followed by the BRS 398 cultivar, which exhibited the same behavior as the BRS 397 cultivar until around day 7 or 8, with an increase in color difference until the last day of storage.

Additional key words: *Manihot esculenta* Crantz; post-harvest deterioration; low density polyethylene; polyvinyl chloride; BRS 397; BRS 398; IAC 576-70.

RESUMEN

Una vez cosechadas y peladas, las raíces de yuca tienen una vida útil corta en condiciones ambientales. Esto se debe a su alto contenido de agua, que las hace muy susceptibles al ataque de hongos descomponedores y a la acción de enzimas que oscurecen las raíces. Después de unos días de almacenarse en condiciones ambientales, estas raíces se vuelven incomestibles, desarrollando moho y oscurecimiento vascular. Para los agricultores familiares, mantener los alimentos congelados es un desafío debido al alto costo de la refrigeración y especialmente debido a que el principal medio de venta de sus productos es en mercados callejeros sin ninguana estructura para instalar congeladores. Esto hace necesario comprender cómo se comportan los alimentos en un ambiente refrigerado. El objetivo de este estudio fue evaluar los cambios físicos en las raíces de yuca almacenadas en envases de polietileno de baja densidad (PEBD) y bandejas de poliestireno envueltas en PVC para tres cultivares. Se realizaron dos experimentos: el experimento 1 involucró envases de PEBD con tres cultivares de yuca (BRS 397, BRS 398 e IAC 576-70), mientras que en el experimento 2 se utilizaron bandejas de poliestireno expandido envueltas en policloruro de vinilo (PVC) con los mismos cultivares. Los ensayos se llevaron a cabo en la Universidad Federal de Jataí, Brasil. El diseño experimental fue completamente al azar con tres repeticiones y períodos de almacenamiento como tratamientos (0, 5, 10 y 15 días). Después del preprocesamiento, las raíces se envasaron y almacenaron en un ambiente refrigerado a 5±1°C. Las mediciones tomadas durante el almacenamiento incluyeron la pérdida de peso fresco, la diferencia de color, el ángulo de tonalidad y el croma. En general, ambos métodos de envasado ayudaron a reducir la pérdida de masa de las raíces de yuca almacenadas a 5±1°C. El cultivar BRS 397 mostró la menor diferencia de color a lo largo de los días de almacenamiento, seguido por el cultivar BRS 398, que exhibió el mismo comportamiento que el cultivar BRS 397 hasta alrededor del día 7 u 8 días, con un aumento en la diferencia de color hasta el último día de almacenamiento.

Palabras clave adicionales: *Manihot esculenta* Crantz; deterioro poscosecha; polietileno de baja densidad; cloruro de polivinilo; BRS 397; BRS 398; IAC 576-70.

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INTRODUCTION

Cassava (*Manihot esculenta* Crantz) is a perennial shrub belonging to the Euphorbiaceae family. The part used commercially is the root, which is rich in carbohydrates, making it an alternative food base, mainly in low-income regions, due to its reduced market value compared to other products (Jacob *et al*., 2023).

According to Viera *et al*. (2020), the Embrapa cultivars BRS 397, BRS 398 and BRS 400 are new materials that have been developed for cultivation in the Federal District region. To date, published data only exist on the minimal processing of the BRS 400 cultivar, which has been tested for different packaging and storage temperatures. There is no published research on the post-harvest handling of these minimally processed roots for the other cultivars. The BRS 397 variety has yellow flesh with a high beta-carotene content, while the BRS 398 variety has creamy flesh. Due to the early maturity of these varieties, they should be harvested 8 to 12 months after planting. The BRS 400 variety has pink flesh with a high lycopene content in the roots, a compound with significant antioxidant properties. Like BRS 397 and BRS 398, BRS 400 is precocious and has similar physical characteristics when cooked. However, its plant architecture features the first branch at a low height, requiring less dense planting, and its roots tend to grow vertically, making harvesting difficult. It is recommended to plant it on ridges (Viera *et al*., 2020). On the other hand, IAC 576-70 has yellow flesh due to the presence of beta-carotene in the roots. The roots should be harvested between 9 and 14 months after planting, after this period, the fiber content increases, and they can be used to produce yellow flour or animal feed (IAC, 2020).

Cassava roots undergo two main types of post-harvest deterioration. The first type is caused by physiological factors, resulting in a change in the internal coloration of the root. These reactions begin 24 to 72 h after harvest (Zainuddin *et al*., 2018). The second type of deterioration is pathological, in which microorganisms ferment the tissue, starting between 5 and 7 d after harvest (Zainuddin *et al*., 2018). According to Bonilla *et al*. (2013), the oxidation process primarily occurs through two reactions. The first occurs when the hydroxyl groups of starch are oxidized to carbonyl groups. The second involves the degradation of starch molecules, mainly by cleaving the α-1,4 bonds of amylose and amylopectin molecules. Recent transcriptome, proteome (Vanderschuren *et al*., 2014) and metabolome (Uarrota *et al*., 2014) studies have provided important new information about "post-harvest physiological deterioration" (PPD) triggers and symptoms, which were previously studied only at the phenotypic level. Comparative transcriptomics analysis has also revealed the role of melatonin in delaying PPD (Hu *et al*., 2016), combined with comparative proteomics between two PPD-contrasting genotypes (Qin *et al*., 2017). Both types of damage are primarily influenced by mechanical damage and injuries, which allow oxygen to penetrate the root's interior, accelerating enzymatic activity and facilitating the entry of microorganisms (Zainuddin *et al*., 2018).

Studies have shown that physiological changes begin to occur within 24 h of harvest, with blue-black discoloration commonly occurring in the root after 72 h stored at room temperature (Zidenga *et al*., 2012). Cassava roots are susceptible to cold injury, internal decay with increased water loss, decay, loss of edible quality, and lack of germination when stored at temperatures below 5-8°C, depending on cultivar and agroclimatic conditions (Uchechukwu-Agua *et al*., 2015).

The International Center for Tropical Agriculture (CIAT) in Palmira, Colombia, has developed some advanced methods for cassava storage (Osunde and Fadeyibi, 2012). These methods include refrigeration at lower temperatures in the range of 0-5°C, freeze-drying, and waxing with kerosene (Uchechukwu-Agua *et al*., 2015). These methods are used for export purposes, but maintaining the equipment used for this purpose is espensive, and in addition, their handling requires specialized personnel (Osunde and Fadeyibi, 2012). These methods can improve the storage of fresh cassava root for up to two weeks, but refrigeration is not the most commonly used method in developing countries (Uchechukwu-Agua *et al*., 2015).

Information on the postharvest handling, processing and storage of cassava roots and products is limited (Uchechukwu-Agua *et al*., 2015). The same authors emphasize that for successful large-scale production and utilization of cassava roots and products, the application of novel postharvest handling, processing, packaging and storage techniques is critical. The successful application of these postharvest technologies will contribute to the maintenance of the quality and safety of the products, as well as to the reduction of the incidence of postharvest losses, ultinately improving food safety (Opara and Mditshwa, 2013).

The quality and sustainability of the crop depends not only on pre-harvest factors, but also on post-harvest handling. This is especially true for a crop like cassava, which deteriorates rapidly (Iyer *et al*., 2010). The quality of fresh cassava roots can be improved by reducing postharvest losses. Some proven measures to prevent losses include the use of improved varieties with longer shelf life, the use of good agricultural practices during cultivation, proper handling during and after harvest, and the use of appropriate processing techniques (Uchechukwu-Agua *et al*., 2015).

Furthermore, packaging and storage are key factors in postharvest handling that ensure food safety and product integrity (Daramola *et al*., 2010). Packaging ensures the quality of the root by protecting it from bruising and injury. It also prevents excessive moisture loss.

The use of suitable packaging and storage temperatures can reduce the microbial load in food, improving quality maintenance and extending its shelf life (Jacob *et al*., 2023). Food packaging is designed to protect the product, provide essential information about it, facilitate its handling for distribution to the consumer. In the process of ensuring food quality, safety, and shelf life extension, packaging plays a key role (Vasile and Baican, 2021).

Family farming is responsible for 87% of total cassava production in Brazil, as reported by the latest census conducted by IBGE (2024). For family farmers, keeping food frozen is a challenge due to the high cost of freezing food and primarily because their main marketing channel is open-air markets.

Thus, the objective of this study was to evaluate the physical changes in three cassava root cultivars packaged in LDPE and PVC-wrapped polystyrene trays during a specified cold storage period.

MATERIALS AND METHODS

Plant material

The roots were harvested from an experimental field at the Núcleo de Pesquisas Agronômicas (NPA) of the Universidade Federal de Jataí, Campus Jatobá (-17°52’53” S, -51°42’52” W and altitude of 696 m), Brazil. The planting of the cultivars was carried out in January, and the harvest was carried out manually according to the time indicated for each cultivar, approximately 9 months after planting.

Three cassava cultivars were used: IAC 576-70 and BRS 397, both with yellow roots, and BRS 398, with cream-colored roots. The Embrapa cultivars (BRS 397 and BRS 398) are new materials developed for cultivation in the Federal District (Vieira *et al*., 2018). In recent years, the IAC 576-70 cultivar has been the most planted in the Federal District and neighboring areas, showing good acceptance among consumers as a minimally processed product (Rinaldi *et al*., 2017).

Root preparation

After harvesting, the roots were stored in plastic boxes and taken to the NPA laboratory, approximately 300 m from the experimental field, where the conditioning operations were carried out.

In the laboratory, the roots were selected based on their commercial characteristics. They were washed under running water to remove the soil adhered to them. Afterward, the roots were sanitized using a solution of 0.2 mL L^{-1} of active chlorine diluted in cold water for 15 min to reduce microbial activity. Then, the roots were cut transversely into pieces of approximately 6 cm in length, peeled, and divided in half with longitudinal cuts.

The roots were sanitized again, this time using a lower concentration, with a solution of 0.02 mL L^{-1} of active chlorine diluted in cold water for 2 min. Subsequently, the surface was drained of excess sanitizing solution.

Experiments and variables considered

The roots were weighed and packaged in low-density polyethylene (LDPE) bags (35×45 cm, 20 μm thick), which were manually tied for Experiment 1, and in expanded polystyrene trays (240×185×22 mm) wrapped in polyvinyl chloride (PVC) film (12 μm thick PVC) for Experiment 2. After packaging, the cassava roots were stored at 5±1°C.

For both experiments, 800 g of roots were used per package for each of the cultivars, and the variables were evaluated every 5 d during the storage period on days 0, 5, 10, and 15.

Cassava cannot be marketed without any type of coating, which in this case could simulate a control treatment, according to health surveillance regulations.

During the experimental period, the variables evaluated were fresh mass loss (g) and color difference based on hue angle (°) and chroma.

The mass loss of the roots was calculated using a digital scale and estimated by the difference between the initial and the final mass of the packages containing the cassava roots, while the color parameters L*, a*, b*, hue angle and chroma were determined with a colorimeter (Konica Minolta®, model CR-10) by taking three readings on each surface. The color difference was calculated using the formula proposed by Konica Minolta (2007).

Statistical analysis

A completely randomized design with three replications was used. For the analysis of the variable data, the normality of the errors and the homogeneity of the variances were tested. The means of the factors were subjected to regression analysis. The choice of equations was based on the significance of the regression coefficients by Student's *t*-test, the coefficient of determination (R^2), and their potential to explain the biological phenomenon. The statistical software used was SAS (2013). The graphical representations of the results were generated using Sigma Plot software, version 11.0 (Grafiti LLC, 2020).

RESULTS AND DISCUSSION

The fresh mass loss had a polynomial adjustment for the three cultivars under study in both types of packaging. Overall, there was little variation in fresh mass loss for the cultivars stored in LDPE packaging (±0.3%) during the experimental period, indicating that the packaging was able to maintain the mass throughout the storage period (Fig. 1A). However, for the roots stored in PVC packaging, the mass loss ranged from 2.0 to 4.0% during the evaluated days, with the greatest mass loss in cultivar BRS 398 (Fig. 1B).

Mass loss is a natural process during the storage of preserved vegetables, whether whole or minimally processed. According to Schudel *et al*. (2023), inefficiencies during storage, packaging, or transport can be identified by recognizing hygrothermal food loss drivers. Examples include: (1) adapting optimal storage temperature to prevent decay as well as chilling injuries; (2) improving packaging ventilation to ensure cooling efficiency and maintain appropriate humidity conditions around the products; or (3) product-related solutions, such as maintaining particular storage or packaging gas composition that act on the commodity's unique physiology to prolong its shelf life.

Andrade *et al*. (2014), working with minimally processed cassava cultivar Mossoró, packaged in polypropylene and refrigerated at 5±2°C in Serra Talhada, observed a mass loss of approximately 0.1% over 11 d of storage. This indicates that mass loss and permeability to water vapor could be related to the type of packaging used, as polypropylene has a low permeability (Jorge, 2013), similar to LDPE, with an average mass loss of 0.17%.

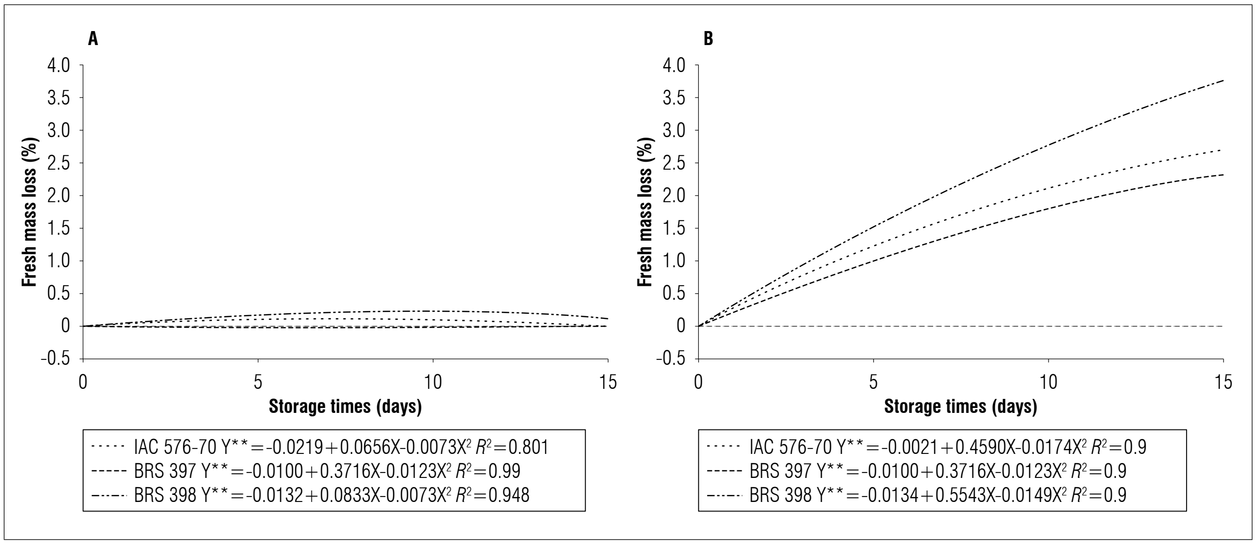

Figure 1. Fresh mass loss of three cassava cultivars stored in LDPE packages (A) and PVC packaging (B). **Significant at *P*≤0.05.

In addition, fresh mass can also vary depending on the plant species under study (Tao *et al*., 2024). Nainggolan *et al*. (2024), reported that for most vegetables, the fresh mass loss ranges between 5 and 10%, to avoid withering and drying. The same author concluded that the future post-harvest studies on cassava should focus on prioritizing sustainable drying processes for cassava products, considering both environmental consequences and societal advantages.

Alves *et al*. (2005), working with minimally processed cassava roots from local markets, packaged in expanded polystyrene trays wrapped in PVC and refrigerated at 5±0.5°C, reported a mass loss of approximately 2.5% over a 7-d storage period. This type of packaging resulted in the greatest loss of moisture compared to sealed and vacuum multilayer packaging. PVC is a material with medium permeability to water (Carbone *et al*., 2016), allowing water from the cassava roots to be partially lost to the environment.

For the color differences of the cassava roots stored in the LDPE packaging, the data showed a quadratic adjustment for the cultivars BRS 397 and BRS 398, and an exponential adjustment for IAC 576-70. The cultivar BRS 397 presented the smallest color difference over the storage period, followed by BRS 398, which showed almost the same behavior as the cultivar as BRS 397 until the 10^{th} d, after which the color difference increased until the last day of storage (Fig. 2A). The PVC-wrapped expanded polystyrene trays presented a quadratic fit in color difference for cultivars IAC 576-70, BRS 397 and BRS 398. Both BRS 397, and BRS 398 exhibited small color differences throughout the storage period, indicating low visual color changes across all the storage days (Fig. 2B).

Cassava roots are highly susceptible to post-harvest deterioration (Ayetigbo *et al*., 2021). Once cassava is harvested, physiological and microbial deterioration processes initiate, typically caused by oxidative changes of phenolic substances, the action of enzymes involved in the oxidation of these compounds, and microorganisms, resulting in color changes. Storing the roots in appropriate packaging can preserve them for extended periods and increase their shelf life (Salcedo *et al*., 2010; Vieites *et al*., 2012).

The cultivar IAC 576-70 showed the highest color difference during the storage period, presenting significantly higher values compared to the other two cultivars, demonstrating greater susceptibility to browning during storage compared to BRS 397 and BRS 398 (Fig. 3A). The cultivar IAC 576-70, stored in LDPE packaging, also showed large color differences compared to the other two cultivars packaged in PVC, confirming the greater susceptibility of this cultivar's roots to color change during refrigerated storage (Fig. 3B).

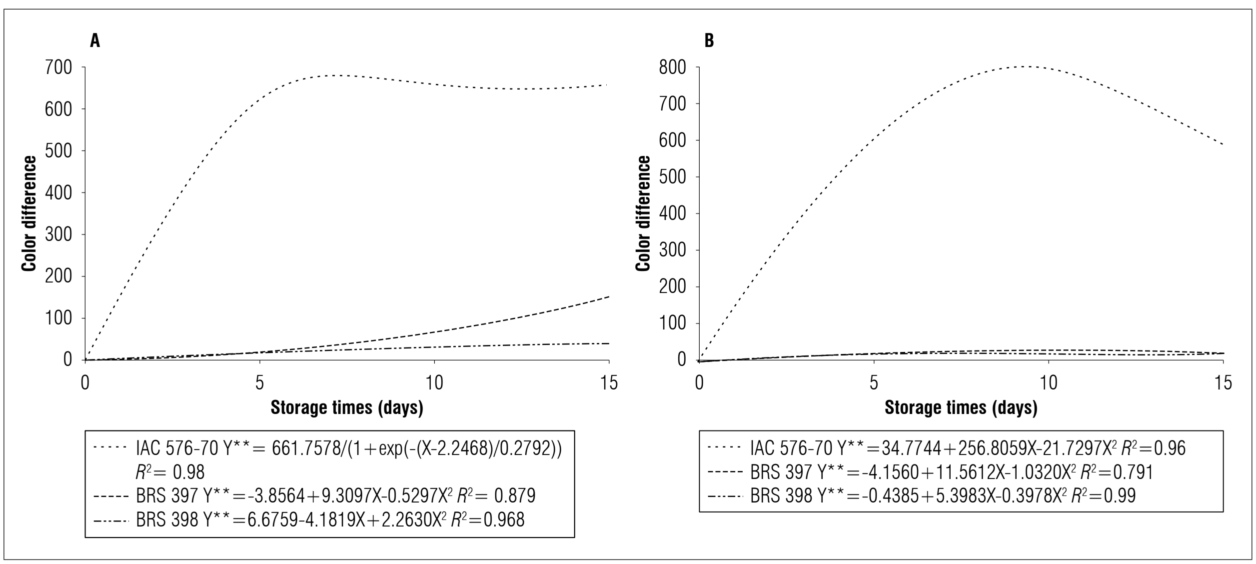

Figure 2. Color difference of three cassava cultivars stored in LDPE packages (A) and in PVC packaging (B). **Significant at $P\leq0.05$.

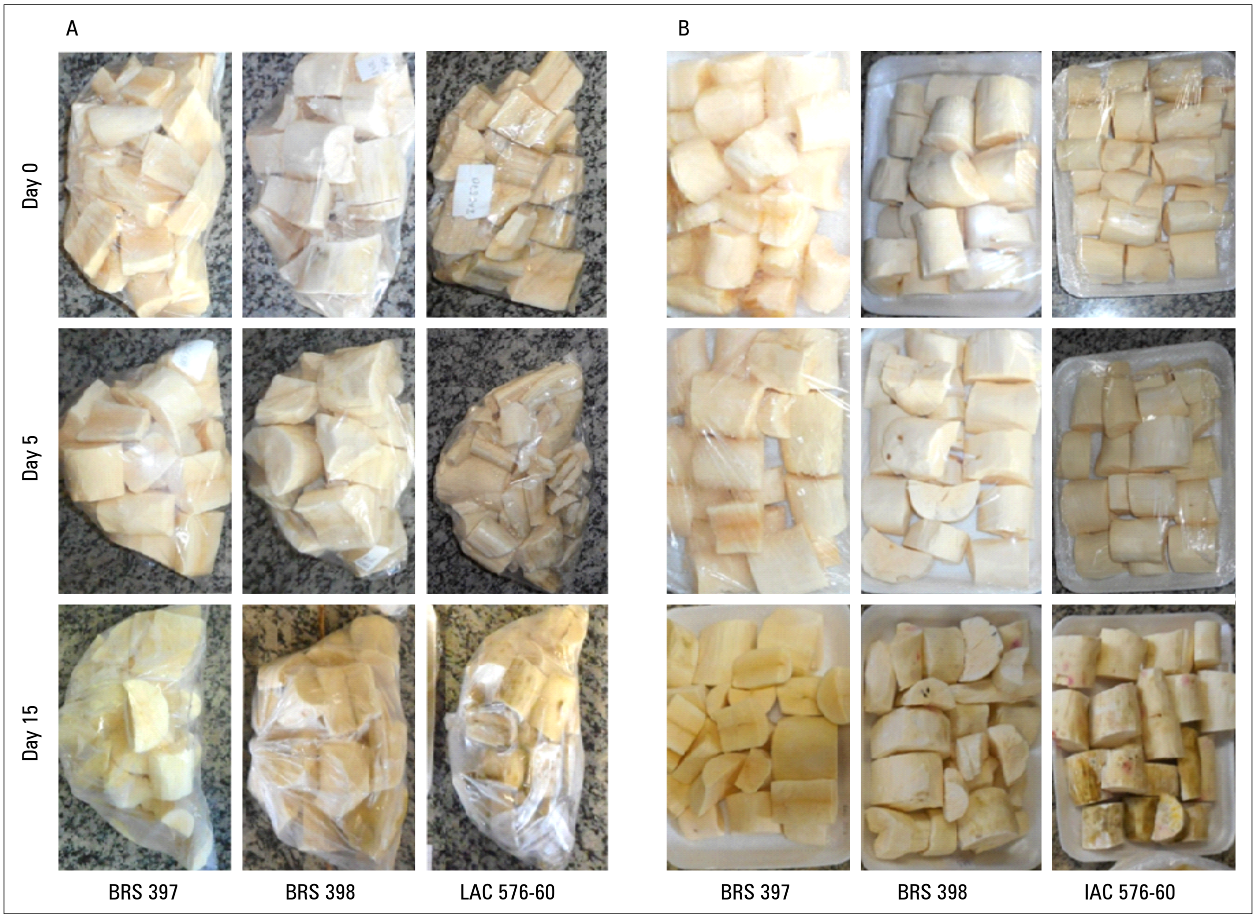

Figure 3. **Visual changings in the color of three cassava cultivars on the 0th, 5th, and 15th day of storage in LPDE packaging (A) and in polystyrene trays wrapped in PVC (B).**

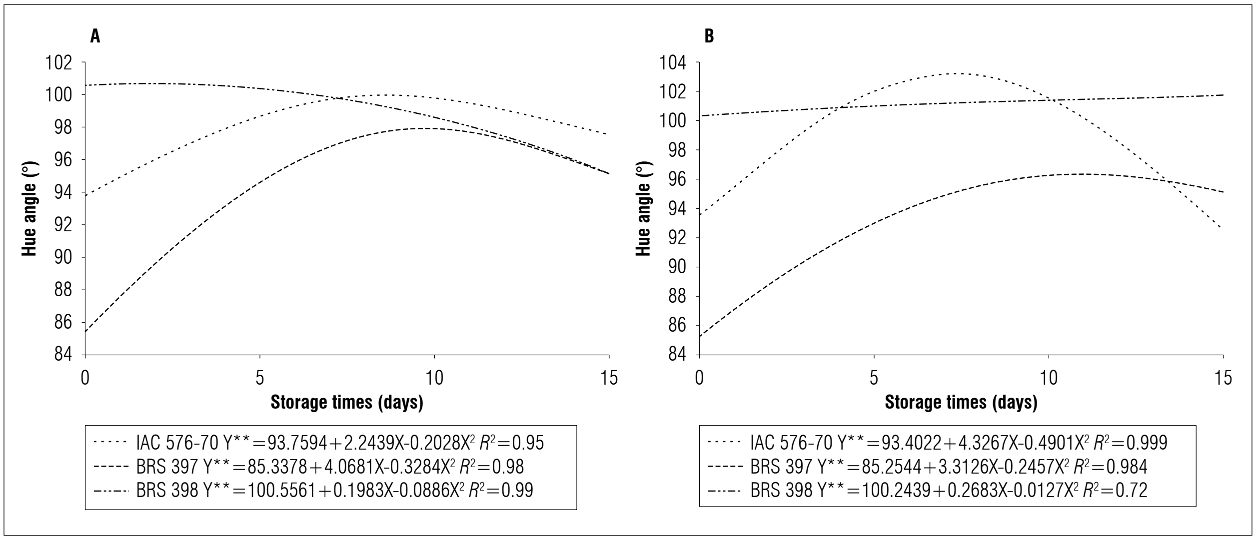

Figure 4. **Hue angle of three cassava cultivars stored in LDPE packages (A) and in PVC packaging (B). **Significant at $P \leq 0.05$.**

Conditioning practices such as cutting the roots promote an increase in respiration and ethylene production rates, which have a very short-term effect (Vieites *et al*., 2012). The roots acquire a brownish color, generally 48 h after harvest, and also undergo changes in smell and flavor, making them unsellable (Henrique *et al*., 2015). Roots stored in bags experience a slower deterioration process (Zainuddin *et al*., 2018).

The hue angle of the cultivars IAC 576-70, BRS 397 and BRS 398 showed a quadratic adjustment in both types of packages. The cultivars IAC 576-70, BRS 397 and BRS 398 in LDPE packaging did not show a significant variation in the hue angle at the end of the storage period (4.63%), remaining close to 90°, which corresponds to the yellow color (Fig. 4A). When stored in PVC, the cultivar BRS 398 showed the lowest variation during the 15-d storage period, while the hue angle of cultivars IAC 576-70 and BRS 397 varied during the storage period but also remained close to 90° at the end of the storage period (Fig. 4B).

The hue angle values close to 90° obtained by all the cultivars, except for BRS 398 in polystyrene trays wrapped in PVC, represent the yellow color. This is an important characteristic, as consumers tend to prefer yellow over cream-colored roots, associating these colors with the palatability of the roots (Vieira *et al*., 2011). Even though the cultivar IAC 576-70 did not show significant variation in hue during the storage period when stored in LDPE packaging, there was noticeable darkening of the roots (Fig. 3A), a characteristic that is crucial when consumers select roots.

Rinaldi *et al*. (2015), experimenting with the minimally processed cassava cultivar IAC 576-70 in LDPE packaging in Planaltina (Brazil), found mean hue angle values of 80.05° over 28 d of storage, with no significant changes in hue angle during this period. They also did not observe a significant difference in the hue angle during the storage period for the cultivar BRS 399, which has yellow flesh, similar to cultivars IAC 576-70 and BRS 397.

Rinaldi *et al*. (2017), conducting studies on the minimally processed cassava cultivar IAC 576-70 in Planaltina, reported hue angle values close to 90° over 35 d of storage, with no significant changes in hue angle during this period. This was also observed in the present study for cultivars with cream and yellow roots.

Chroma values in cassava roots packed in LDPE packaging and PVC-wrapped trays showed a quadratic adjustment for the three evaluated cassava cultivars. Similar chromaticity was observed in both packaging types. All cultivars demonstrated a decrease in saturation from day 0 to day 10, after which saturation increased again, stabilizing close to 24, confirming that the roots maintained a yellow color (Fig. 5A and B).

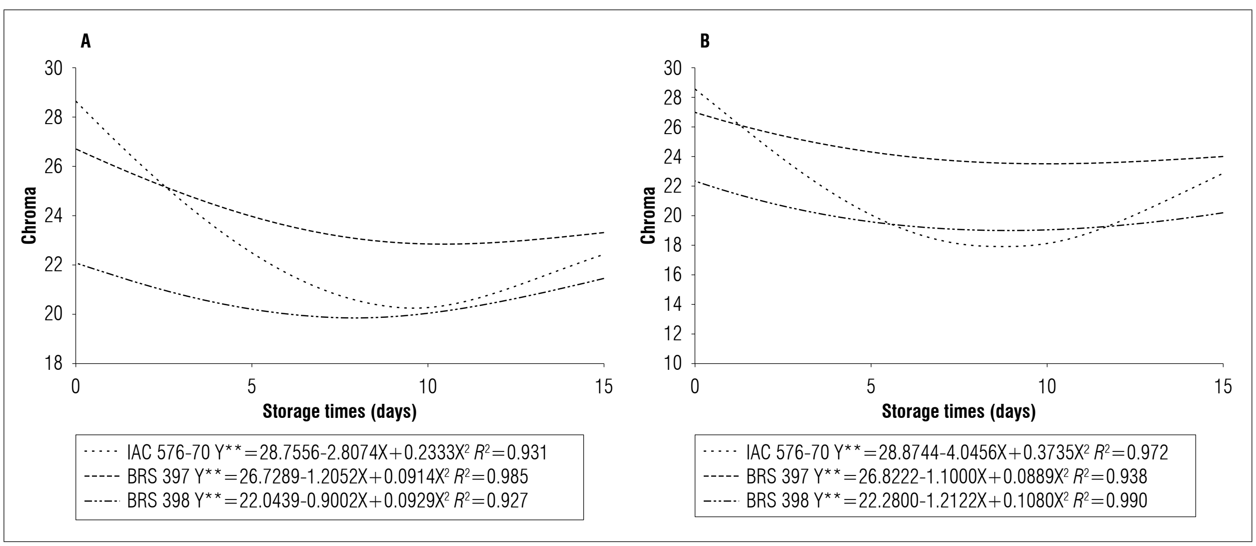

Figure 5. Chroma of three cassava cultivars stored in LDPE packages (A) and in PVC packaging (B). **Significant at $P\leq0.05$.

Rinaldi *et al*. (2017), did not observe any difference in chroma values during 35 d of storage while analyzing the cultivar IAC 576-70, stored at 3°C in Planaltina (Brazil), with values ranging between 20.74 and 23.74. The values observed in the present study for this same cultivar ranged from 20.77 to 29.31, indicating that the cassava roots grown in Jataí (Brazil) had a more intense yellow color.

CONCLUSION

The LDPE and PVC-wrapped packaging types minimized mass loss at 5±1°C. Cultivar BRS 397 exhibited the least color difference during storage, followed by cultivar BRS 398, which maintained similar behavior to cultivar BRS 397 until approximately days 7 or 8. From then onward, the color difference increased until the the final storage day (15). Cultivar IAC 576-70 exhibited the most pronounced color difference throunghout the storage period, with values significantly higher compared to the other cultivars. This indicates greater susceptibility to browning during storage.

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