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Postharvest conservation of coquinho-azedo fruits under modified atmosphere

Conservação pós-colheita de frutos de coquinho-azedo sob atmosfera modificada

Conservación poscosecha de frutos de coquinho-azedo bajo atmósfera modificada

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ABSTRACT
Coquinho-azedo (*Butia capitata*) fruits are highly valued for their rich content of fiber, minerals, vitamin C, and pro-vitamin A carotenoids. They are consumed in their natural state and used in various products, offering an alternative income source for rural communities. This study aimed to assess the postharvest characteristics of coquinho-azedo fruits stored under different modified atmosphere conditions. The fruits were stored at 13°C using PVC, PP, PET, and a Control group without packaging. Over 17 days, the fruits' physicochemical characteristics were evaluated. Packaging significantly improved senescence scores and reduced the loss of fresh mass, soluble solids, vitamin C, and firmness compared to the Control group. PVC packaging showed superior color and firmness performance, while PP packaging maintained consistent fruit color. PET packaging had the highest levels of soluble solids, vitamin C, and titratable acidity. Utilizing modified atmosphere packaging, particularly PVC, effectively preserved the quality of coquinho-azedo fruits during postharvest storage. These findings contribute to enhancing shelf life and marketability, benefiting both producers and consumers.

Keywords: *Butia capitata*, cerrado, packaging, shelf-life.

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RESUMO
Os frutos de coquinho-azedo (Butia capitata) são altamente valorizados por seu rico conteúdo de fibras, minerais, vitamina C e carotenoides pró-vitamina A. Eles são consumidos em seu estado natural e utilizados em vários produtos, oferecendo uma fonte alternativa de renda para as comunidades rurais. Este estudo teve como objetivo avaliar as características pós-colheita de frutos de coquinho-azedo armazenados sob diferentes condições de atmosfera modificada. Os frutos foram armazenados a 13°C utilizando PVC, PP, PET e um grupo controle sem embalagem. Durante 17 dias, foram avaliadas as características físico-químicas dos frutos. As embalagens melhoraram significativamente os escores de senescência e reduziram a perda de massa fresca, sólidos solúveis, vitamina C e firmeza em comparação com o grupo controle. A embalagem de PVC apresentou melhor desempenho em cor e firmeza, enquanto a embalagem de PP manteve a cor dos frutos de forma consistente. A embalagem de PET apresentou os maiores níveis de sólidos solúveis, vitamina C e acidez titulável. A utilização de embalagens com atmosfera modificada, particularmente de PVC, preservou de forma eficaz a qualidade dos frutos de coquinho-azedo durante o armazenamento pós-colheita. Estes resultados contribuem para o aumento da vida útil e da comercialização, beneficiando tanto produtores quanto consumidores.

Palavras-chave: *Butia capitata*, cerrado, embalagem, vida útil.

RESUMEN
Los frutos de coquinho-azedo (*Butia capitata*) son muy valorados por su alto contenido en fibra, minerales, vitamina C y carotenoides pro-vitamina A. Se consumen en su estado natural y se utilizan en varios productos, ofreciendo una fuente alternativa de ingresos para las comunidades rurales. Este estudio tuvo como objetivo evaluar las características poscosecha de frutos de coquinho-azedo almacenados bajo diferentes condiciones de atmósfera modificada. Los frutos se almacenaron a 13°C utilizando PVC, PP, PET y un grupo de control sin embalaje. Durante 17 días, se evaluaron las características fisicoquímicas de los frutos. Las embalajes mejoraron significativamente las puntuaciones de senescencia y redujeron la pérdida de masa fresca, sólidos solubles, vitamina C y firmeza en comparación con el grupo de control. El embalaje de PVC mostró un mejor rendimiento en color y firmeza, mientras que el embalaje de PP mantuvo de forma consistente el color de los frutos. El embalaje de PET tuvo los niveles más altos de sólidos solubles, vitamina C y acidez titulable. El uso de embalajes con atmósfera modificada, particularmente de PVC, preservó de manera efectiva la calidad de los frutos de coquinho-azedo durante el almacenamiento poscosecha. Estos hallazgos contribuyen a mejorar la vida útil y la comercialización, beneficiando tanto a productores como a consumidores.

Palabras clave: *Butia capitata*, cerrado, embalaje, vida útil.

1 INTRODUCTION

The Brazilian Cerrado is the largest and most threatened tropical savanna in the word, covering a vast expanse of land in central Brazil. This region is characterized by a unique combination of vegetation, with small trees, grasses and a wide variety of species adapted to

specific climatic conditions, such as seasonal drought and nutrient-poor soils (Colman et al., 2022). Among the emblematic species found in the Cerrado, the coquinho-azedo (*Butia capitata*) stands out.

The fruits of coquinho-azedo (*Butia capitata*) play a key role in regional food and economy. These fruits are widely consumed in the Cerrado region due to their nutritional value, being a rich source of fiber, minerals, vitamin C and pro-vitamin A carotenoids (Pereira et al., 2023). Also, are used in production of juices, ice cream, popsicles and oils, contributing as an alternative source of income for rural populations and cooperatives (Silva & Scariot, 2013).

However, the postharvest conservation of these fruits presents challenges, since they are highly perishable and sensitive to environmental factors. Rapid deterioration and loss of quality affect its marketability and availability, resulting in economic losses for producers and traders. This happens because the chemical reactions start even before harvesting and continue during storage, which brings an important conditioning factor to this step. In addition, storage under ideal conditions can facilitate the maintenance of specific characteristics of fruit and provide a longer shelf-life for the product (Pennazza et al., 2013). Therefore, effective conservation strategies are needed to extend the shelf-life of these fruits and preserve their nutritional and sensory characteristics.

In this context, the modified atmosphere has been shown to be a promising technology for fruit preservation. The modified atmosphere consists of controlling the gaseous composition that surrounds the fruits, delaying the maturation process and prolonging their shelf-life (Fante et al., 2014). The use of packages that reduce the oxygen content and increase the carbon dioxide content in the atmosphere around can inhibit respiratory activity, delay water loss and minimize the development of pathogens, resulting in more efficient conservation (Mendonça et al., 2015).

Considering the economic and nutritional importance of coquinho-azedo fruits, as well as the need for effective conservation strategies, the present study aimed to evaluate the postharvest characteristics of these fruits when subjected to different conditions of modified atmosphere. Through the investigation of these conditions, it is expected to obtain relevant information for the development of adequate storage and conservation practices for coquinho-azedo fruits, benefiting both producers and consumers.

2 MATERIAL AND METHODS

Coquinho-azedo fruits were harvested at the green-mature stage from an area with typical Cerrado formation in Mirabela, Minas Gerais, Brazil (16°17′20″S and 44°9′2″W). The fruits were carefully selected based on their degree of maturation, absence of mechanical damage, and overall sanity. Upon selection, the fruits underwent a sanitization process using a chlorinated solution (100 ppm/10 min.). Following sanitization, the fruits were drained at room temperature to remove excess moisture. To study the effects of different packaging conditions on post-harvest conservation, the fruits were divided into four treatment groups with specific packaging materials:

1) Control: expanded polystyrene packaging (15 x 15 x 2.5 cm), without a lid;
2) PVC: expanded polystyrene packaging (16 x 11 x 3.5 cm), manually coated with a polyvinyl chloride film;
3) PET: polyethylene packaging (15 x 13 x 5.5 cm), with a rigid lid made of the same polymer;
4) PP: polypropylene packaging (16 x 12 x 5 cm), with a rigid snap-on lid made of the same polymer.

Following packaging, the fruits were stored in a refrigerated incubator under controlled conditions at a temperature of 13 ± 1 ºC and 90% relative humidity. This temperature was selected based on laboratory testing to determine the optimal post-harvest storage temperature for preservation of coquinho-azedo fruits, comparing it to temperatures of 7 °C and 25 °C (room temperature). Additionally, the relative humidity of 90% was maintained to prevent excessive moisture loss and maintain the desired fruit texture and appearance. These conditions were maintained throughout the storage period to simulate ideal post-harvest preservation. During the storage period, the durability of the fruits was periodically assessed through various analyses, including to physical appearance, fresh mass loss, firmness, color changes, pH, titratable acidity, soluble solids and vitamin C.

The physical appearance of the coquinho-azedo fruits was visually evaluated, classifying them into grades from 1 to 5. Grade 1 represented fruits with no stains, injuries, or deterioration, while grade 5 indicated fruits that were completely deteriorated and unsuitable for consumption. The percentage of fresh mass loss was determined gravimetrically by calculating the ratio

between the initial mass of the fruit sample and the mass of the sample on evaluation day

Firmness was evaluated using the applanation method developed by Calbo & Nery (1995). Pressure was applied to the fruits, and the resulting flattened area was measured. The weight exerted by the equipment plate caused an ellipsoid-shaped area on the fruit surface. The relationship between the weight exerted and the flattened area was used to determine firmness, expressed in N/cm². Equation 1 was used for this calculation, considering the acceleration due to gravity on Earth (approximately 9.81 m/s²).

$$Firmness\ (N/cm^2) = \frac{Weight\ exerted}{Flattened\ area} \cdot 9{,}81 \quad (1)$$

Color analysis was conducted using a Konica Minolta colorimeter, model Chroma CR-400/410. The colorimeter expressed the results using the CIELab* system, providing values for luminosity (L*), intensity from green to red (a*), and intensity from blue to yellow (b*). The °Hue and Chroma color indices were calculated using Equations 2 and 3, respectively:

$$°Hue = tg^{-1}\ b^*/a^* \quad (2)$$

$$Chroma = \sqrt{(a^2 + b^2)} \quad (3)$$

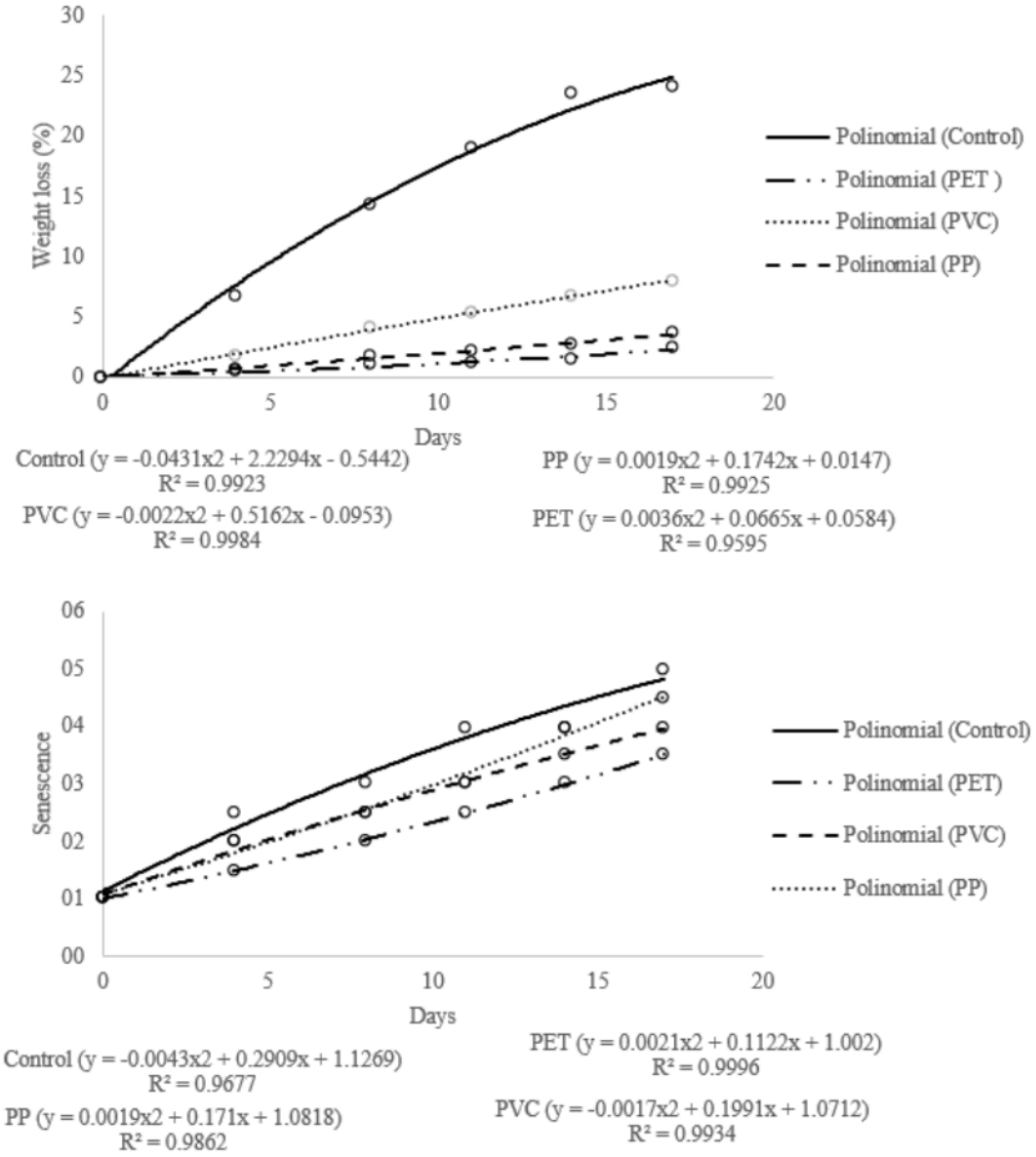
The pH of the fruit samples was determined using a digital pH meter (Hanna model PH21). Titratable acidity, soluble solids in a digital refractometer and vitamin C content were analyzed according to the methods of the Association of Official Analytical Chemists (AOAC, 2012).

The experiment was conducted in a completely randomized design. The treatments consisted of four packaging types (Control, PVC, PET and PP), and the fruits were evaluated at six different storage times (0, 4, 8, 11, 14, and 17 days). Each treatment combination was replicated three times, with each experimental unit consisting of 12 fruits. The data were subjected to analysis of variance (ANOVA), and means were compared using the Scott-Knott test at a significance level of 5%. The statistical analysis was performed using the AgroEstat software, version 1.1.0.711.

3 RESULTS AND DISCUSSION

The fresh mass loss of coquinho-azedo fruits exhibited a gradual pattern across all three treatments, with the control treatment showing the most significant loss, as shown in Figure 1. These findings are consistent with the observations of Zamorska & Rybchak (2021), who reported that the use of plastic packaging greatly reduces fresh mass loss. Among the tested packages, fruits stored in PVC demonstrated the highest mass loss, averaging approximately 2.5 g at each evaluation. It is important to note that storage temperature played a crucial role in minimizing mass loss. Lower temperatures lead to reduced respiratory rates in vegetable products, resulting in decreased transpiration and fresh mass loss (Rahmadhanni et al., 2020).

Figure 1. Polynomial regression for weight loss and senescence of coquinho-azedo fruits (*Butia capitata*) stored in different types of packages at a temperature of 13°C.



Source: Prepared by the authors.

The senescence process of coquinho-azedo fruits occurred gradually over time in all three treatments, with the control treatment exhibiting the most pronounced effects. The modification of the package's internal atmosphere can occur through various mechanisms, such as a decrease in oxygen consumption and spontaneous production of carbon dioxide within the package. These mechanisms can effectively delay fruit maturation (Mendonça et al., 2015).

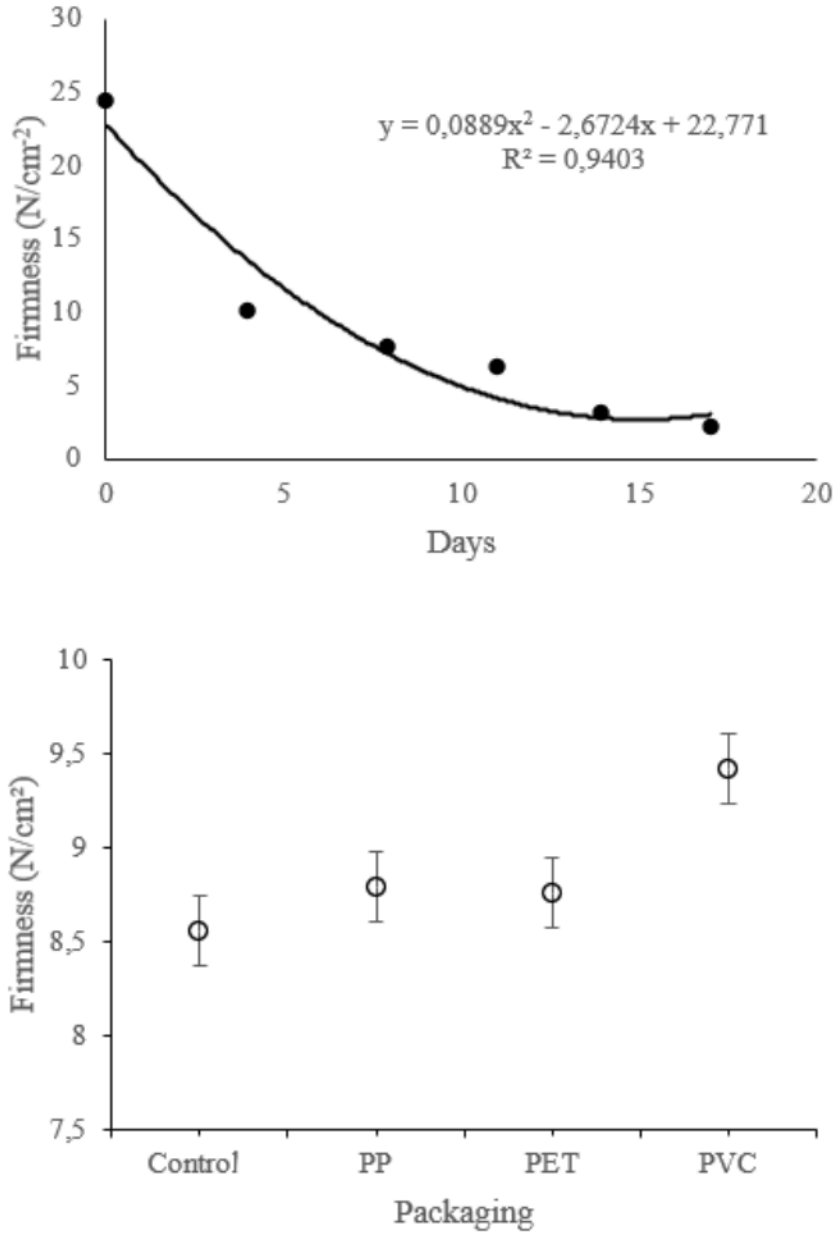
Figure 2 shown the progressive decrease in fruit firmness during the storage period. As the days passed, the resistance of the fruits decreased, and by the end of the experiment, the

firmness values fell below 5 N/cm². The mean firmness over time varied across the different packaging types, with fruits stored in PVC displaying the highest mean firmness. It is worth noting that all treatments exhibited higher average firmness values compared to the control without packaging. The variation observed may be attributed to differences in the harvesting stage or inherent variability between species. Fruit firmness is determined by pectic substances present in the cell walls, which solubilize as the fruit ripens, leading to pulp softening. Firmness is also closely associated with aroma, flavor, and the overall post-harvest shelf-life of fruits (Onias et al., 2018).

The luminosity values (L*) of the fruits exhibited fluctuations during the storage period, as presented in Table 1. These values serve as an indicator of browning, with higher values indicating less browning and a color closer to white (Mamede et al., 2015). Browning can have implications for the shelf-life of the product, as the darkening of fruits over time can be influenced by pigment formation and oxidative reactions associated with ripening (Jiang et al., 2016).

Chroma values showed more consistent results in the PP packaging treatment, maintaining values between 41.0 and 48.4 throughout the evaluation period. Statistical analysis revealed significant differences among all treatments, indicating variation in this characteristic. It is noteworthy that fruits with values close to 60 exhibit purer or more vibrant colors, while those tending towards zero display more neutral or less intense colors. Normally, fruits stored under ambient conditions undergo a faster color change, leading to a decrease in Chroma values. However, in the case of coquinho-azedo fruits subjected to the specific temperature and packaging conditions in this study, a significant decrease in Chroma values did not occur over time. It is important to highlight that all treatments were stored at a temperature of 13°C, which may have contributed to the limited variation observed for this characteristic (Mamede et al., 2015).

Figure 2. Polynomial regression for weight loss and senescence of coquinho-azedo fruits (*Butia capitata*) stored in different types of packages at a temperature of 13°C.



Source: Prepared by the authors.

The °Hue values of the fruits exhibited variation both between treatments and over the course of the evaluation period. Under the consistent temperature condition of 13°C maintained for all treatments, it was evident that unpackaged fruits experienced more pronounced changes in their color, highlighting the beneficial role of packaging in preserving fruit color. Consumers often utilize color as an important criterion to assess the degree of fruit ripeness (Barros et al., 2019).

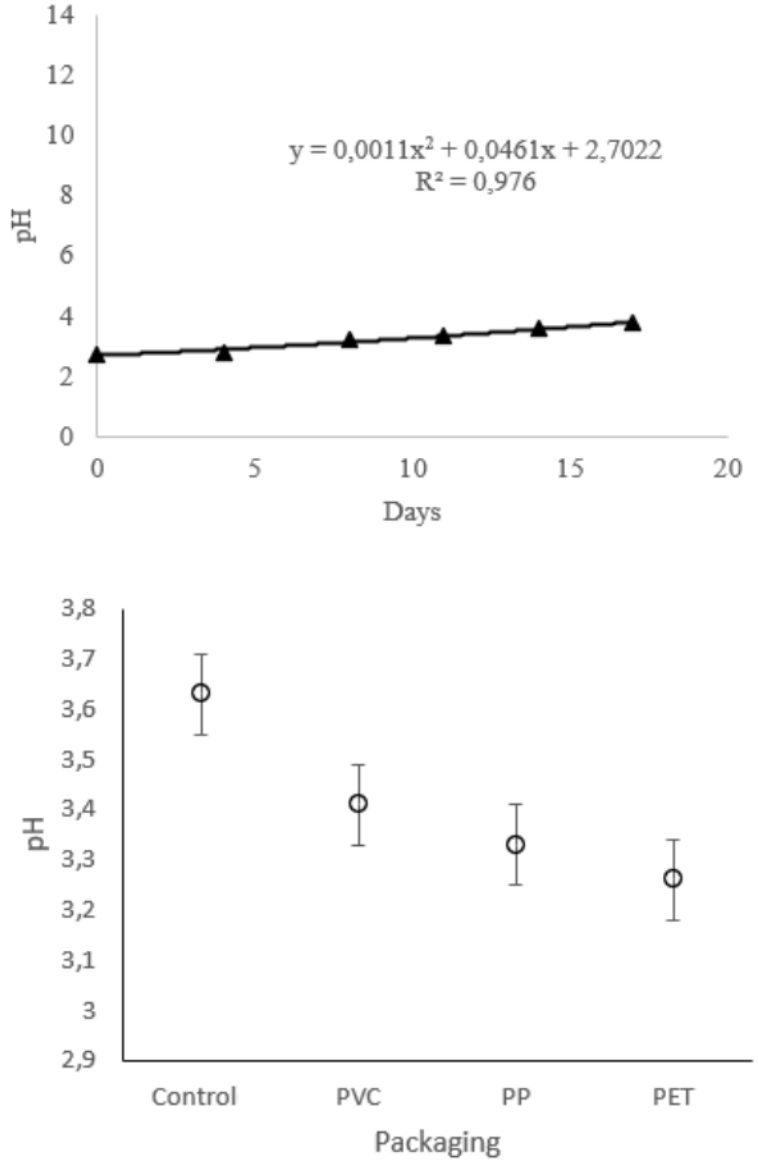
Table 1. Mean values of L*, a*, b*, Chroma and °Hue of coquinho-azedo fruits (Butia capitata) submitted to modified atmosphere.

Packaging	Days					
	0	4	8	11	14	17
			(L*)**			
Control	63,7 bA	67,1 aA	65,1 bB	61,5 cA	57,3 dB	54,7 eB
PET	63,7 bA	66,2 aA	62,7 bC	60,5 cA	58,4 dB	57,1 dA
PVC	63,7 bA	65,5 aA	66,9 aA	61,8 cA	60,1 dA	54,8 eB
PP	63,7 bA	66,1 aA	66,6 aA	58,9 cB	57,6 cB	57,0 dA
			(a*)^{NS}			
Control	-22,6	18,6	17,0	8,8	13,5	15,5
PET	-22,6	-17,8	6,1	39,3	55,4	12,9
PVC	-22,6	-3,6	5,9	38,9	29,9	59,4
PP	-22,6	-5,4	28,1	40,1	32,8	63,6
			(b*)^{NS}			
Control	39,5	46,8	47,1	188,8	43,5	106,9
PET	39,5	126,9	47,3	46,7	49,6	47,4
PVC	39,5	48,1	131,1	49,8	46,9	45,6
PP	39,5	113,1	47,8	46,4	45,7	43,5
			Chroma**			
Control	41,0 dA	47,2 aB	47,6 aB	45,9 bC	46,0 bC	44,2 cC
PET	41,0 dA	50,4 aA	47,4 cB	47,6 cB	50,7 aA	49,1 bA
PVC	41,0 cA	48,2 bB	51,6 aA	50,8 aA	48,5 bB	47,9 bA
PP	41,0 dA	44,9 cC	48,4 aB	47,6 aB	47,7 aB	46,2 bB
			°Hue**			
Control	104,4 aA	82,8 bC	80,9 bB	78,9 cA	72,8 dB	69,5 eC
PET	104,4 aA	93,9 bB	86,4 cA	79,1 dA	77,7 dA	74,7 eA
PVC	104,4 aA	94,3 bB	83,4 cB	78,4 dA	75,2 eA	72,1 fB
PP	104,4 aA	100,1 bA	81,2 cB	78,1 dA	73,3 eB	70,1 fB

Equal capital letters, in the same column, do not differ significantly at the 5% level in the Tukey test. Equal lowercase letters, on the same line, do not differ significantly at the 5% level in Tukey's test. NS: Not significant; **: significant at 1% probability; *: significant at 5% probability.
Source: Prepared by the authors.

The pH results shown in Figure 3 indicate that there was an interaction only for the packaging factor. The lower pH values observed in the figure favor food preservation by inhibiting the growth of microorganisms. In this context, pH serves as an indicator of fruit senescence, as stated by Alam et al. (2021), and the increase in pH throughout the storage period could be attributed to the reduction in acidity resulting from fruit ripening, which aligns with the findings of this experiment. The control treatment exhibited the highest pH values, possibly due to the absence of packaging.

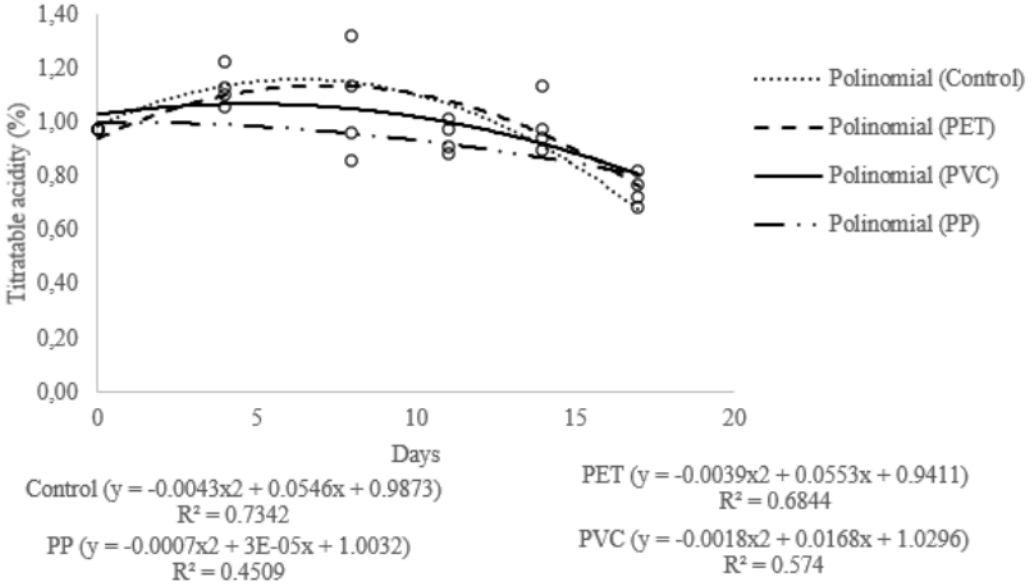
Figure 3. Average variation of pH values of coquinho-azedo fruits (*Butia capitata*) stored in different packages.

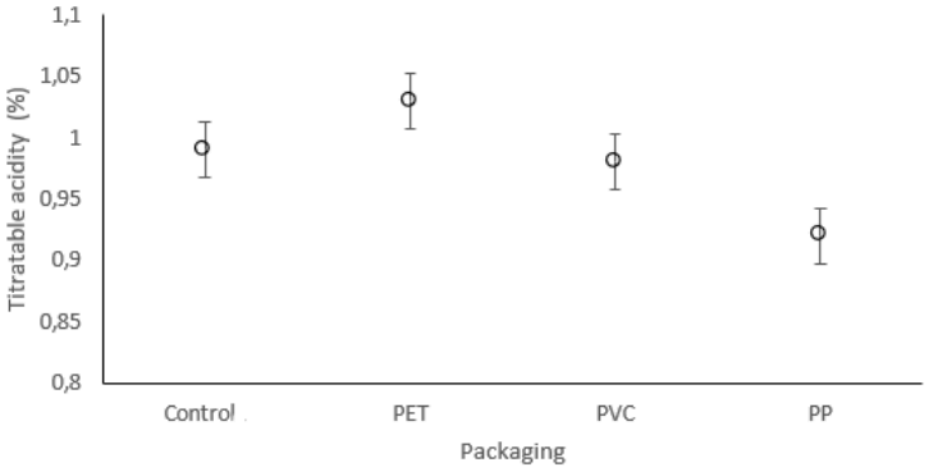


Source: Prepared by the authors.

Regarding titratable acidity, the results displayed in Figure 4 demonstrate an interaction with the packaging factor. Low acidity values, as depicted in the figure, contribute to food preservation by inhibiting microbial development. These findings differ from those reported by Aguiar et al. (2014), who observed average titratable acidity values of 3.92% and 2.71% in *B. capitata* fruits at 50% and 100% maturation, respectively, with a gradual reduction during storage. Various factors can influence these characteristics, including temperature, luminosity, ripeness stage, and the raw material used for analysis.

Figure 4. Polynomial regression and average variation for titratable acidity of coquinho-azedo fruits (*Butia capitata*) stored in different types of packaging at a temperature of 13°C.



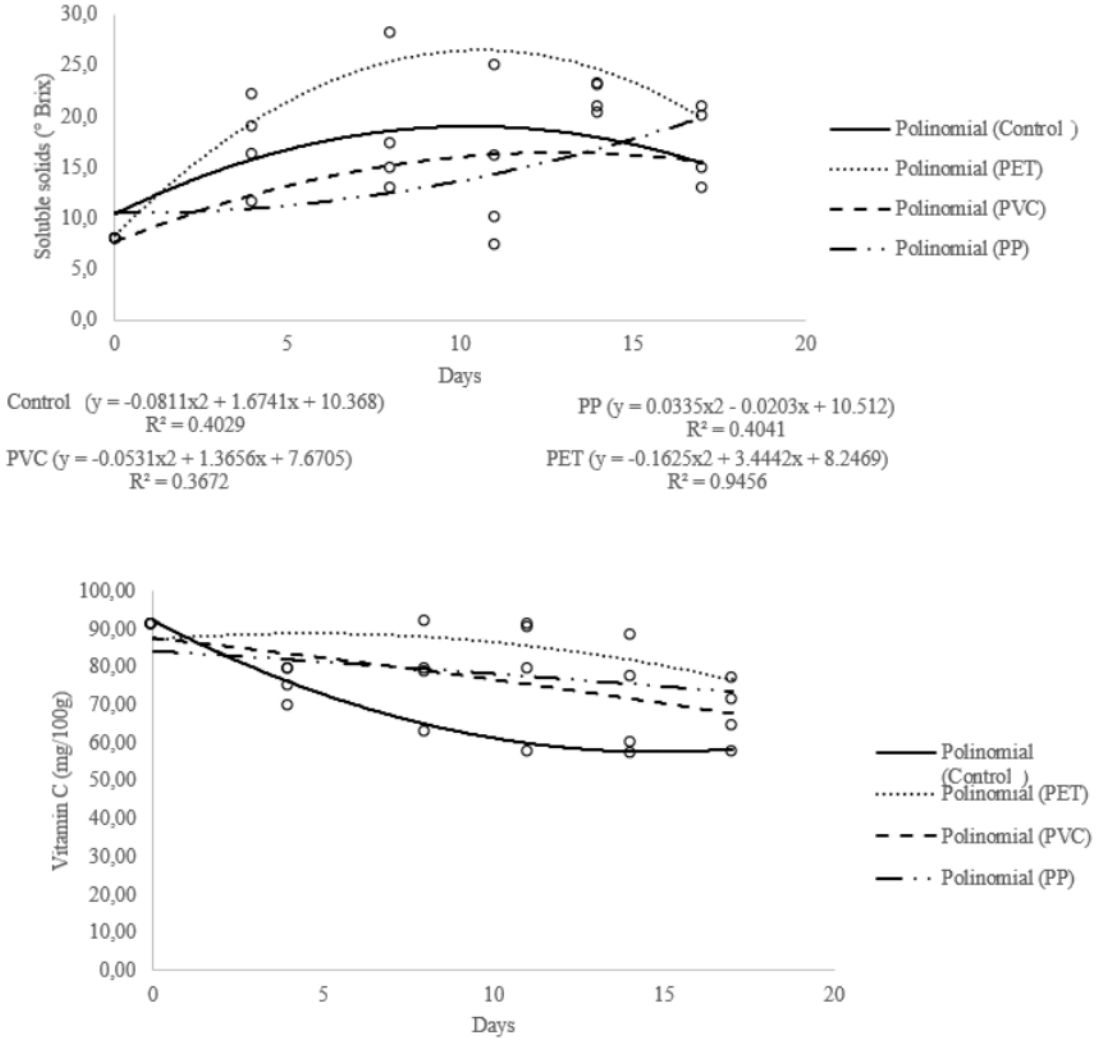


Source: Prepared by the authors.

Notably, the acidity values of coquinho-azedo fruit can impact the product's flavor and prolong the shelf-life of the pulp, as acidic products are less prone to microbial growth (Guan & Liu, 2019). The higher titratable acidity observed until the third day of evaluation indicates that coconut fruits stored under ambient atmosphere exhibited increased respiratory activity over time due to factors already present at the beginning of storage, including enhanced synthesis and accumulation of organic acids. Thus, the use of modified atmosphere was effective in maintaining respiration at lower initial levels during the entire evaluation period. Soluble solids provide an indication of the sugar content in coquinho-azedo and are closely related to fruit

respiration. Consequently, soluble solids can serve as standards for determining fruit ripeness (Silva et al., 2017).

Figure 5. Polynomial regression for soluble solids and vitamin C of coquinho-azedo fruits (B. *capitata*) stored in different types of packages at a temperature of 13°C.



Source: Prepared by the authors.

The soluble solids content of coquinho-azedo fruits gradually increased over time, as depicted in Fig. 5, with the PET packaging treatment yielding the highest values compared to other treatments. The soluble solids values obtained in this study align with those reported by Nunes et al. (2010) for Butia sp. species. A decline in vitamin C levels was observed after 17 days of storage. Fruits stored with packaging exhibited higher vitamin C retention compared to the control, with PET packaging demonstrating the least decay. These results are consistent with

those reported by Bertin et al. (2016), who also observed a decrease in vitamin C content during the storage of fruits such as acerola and caju-do-cerrado. The vitamin C findings agree with previous studies investigating the amount of vitamin C in Butia capitata conducted by Jachna et al. (2016). The quantity and stability of vitamins can be influenced by factors such as pH, oxygen presence, light exposure, presence of metals, and enzymatic activity, among others. Vitamin C is easily oxidized under such conditions, although stability increases with decreasing temperatures. However, oxidation losses can occur in fully frozen foods at extremely low temperatures (Rahmadhanni et al., 2020). In the present study, the combination of packaging and storage at a temperature of 13°C likely contributed to better fruit preservation throughout the storage period.

4 CONCLUSIONS

The present study demonstrated the effectiveness of different types of packaging for the post-harvest conservation of Butia capitata fruits. The results revealed that modified atmosphere packaging, particularly PET and PP, significantly reduced fresh mass loss, maintained fruit firmness, and minimized changes in color. Furthermore, these treatments helped preserve important physicochemical properties such as pH, titratable acidity, and soluble solids. This indicates that the use of appropriate packaging, combined with low temperatures, can effectively extend the shelf life of Butia capitata fruits, maintaining their quality and reducing losses during storage. These findings have significant implications for extending the post-harvest conservation of the fruits, with a potential increase in shelf-life for up to 17 days. Future research could further explore optimization strategies for packaging and temperature management to maximize the preservation of coquinho-azedo fruits and meet consumer demands for high-quality, extended shelf-life products.

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