PAB
Pesquisa Agropecuária Brasileira

ISSN 1678-3921

Journal homepage: www.embrapa.br/pab

For manuscript submission and journal contents, access: www.scielo.br/pab

Storage/ Original Article

Enhancing star fruit shelf life using edible coatings from babassu starch and oil with plasticizers

Rodrigo Anacleto Pinto[(1)],
Romerson Ambrósio da Silva[(1)],
Gislane Romano Mendonça[(1)],
Virginia Kelly Gonçalves Abreu[(1)],
Tatiana de Oliveira Lemos[(1)],
Djany Souza Silva[(1)],
Daniela Souza Ferreira[(1)] and
Ana Lúcia Fernandes Pereira[(1 ✉)]

[(1)] Universidade Federal do Maranhão, Centro de Ciências de Imperatriz, Avenida da Universidade, s/nº, Residencial Dom Afonso Felipe Gregory, Campus Bom Jesus, CEP 65915-060 Imperatriz, MA, Brazil.
E-mail: rodrigo.ap@discente.ufma.br, romerson.ambrosio@hotmail.com, gr.mendonca@discente.ufma.br, virginia.abreu@ufma.br, tatiana.lemos@ufma.br, ds.silva@ufma.br, daniela.sf@ufma.br, ana.fernandes@ufma.br

✉ Corresponding author

Received
October 23, 2023

Accepted
June 20, 2024

How to cite
PINTO, R.A.; SILVA, R.A. da; MENDONÇA, G.R.; ABREU, V.K.G.; LEMOS, T. de O.; SILVA, D.S.; FERREIRA, D.S.; PEREIRA, A.L.F. Enhancing star fruit shelf life using edible coatings from babassu starch and oil with plasticizers. **Pesquisa Agropecuária Brasileira**, v.59, e03567, 2024. DOI: https://doi.org/10.1590/S1678-3921.pab2024.v59.03567.

Abstract – The objective of this work was to determine the effect of edible coatings made with babassu (*Orbignya phalerata*) starch and oil, combined with different plasticizers, on the shelf life of star fruit (*Averrhoa carambola*). The experimental design was completely randomized, in a 5x6 factorial arrangement, with five treatments and six storage periods, with ten replicates per treatment in each storage period. The fruits were stored for 20 days at 10°C and a relative humidity of 65–70%. Five treatments were evaluated: four coated ones (with starch+glycerol, starch+mannitol, starch+oil+glycerol, and starch+oil+mannitol) and one uncoated (control). The studied variables were: mass loss, pH, titratable acidity, soluble solids, ascorbic acid, and color. Mass loss, pH, soluble solids, redness, and yellowness increased linearly during storage, whereas titratable acidity, ascorbic acid, and luminosity decreased linearly. The starch+mannitol treatment stood out, presenting the highest luminosity and the best interaction with babassu oil, which reduced fruit yellowness. However, this interaction caused a lower adherence of the plasticizer to the peel of the fruit, not slowing its ripening down. The use of the starch+mannitol coating reduced mass loss and polysaccharide conversion into soluble sugars. Therefore, this treatment is a promising eco-friendly technique for an improved postharvest storage of star fruit.

Index terms: *Averrhoa carambola*, Amazon raw materials, color, glycerol, mannitol, storage.

Aumento da estabilidade de carambolas com uso de coberturas de amido e óleo de babaçu com plastificantes

Resumo – O objetivo deste trabalho foi avaliar o efeito de revestimentos comestíveis feitos de amido e óleo de babaçu (*Orbignya phalerata*), combinados com diferentes plastificantes, no tempo de prateleira de carambolas (*Averrhoa carambola*). O delineamento experimental foi inteiramente casualizado, em arranjo fatorial 5x6, com cinco tratamentos e seis períodos de armazenamento, com dez repetições por tratamento, em cada período de armazenamento. Os frutos foram armazenados durante 20 dias a 10°C e em umidade relativa de 65–70%. Foram avaliados cinco tratamentos: quatro revestidos (com amido+glicerol, amido+manitol, amido+óleo+glicerol e amido+óleo+manitol) e um não revestido (controle). As variáveis estudadas foram: perda de massa, pH, acidez titulável, sólidos solúveis, ácido ascórbico e cor. Perda de massa, pH, sólidos solúveis, e intensidade de vermelho e de amarelo aumentaram linearmente durante o armazenamento, enquanto acidez titulável, ácido ascórbico e luminosidade diminuíram linearmente. O tratamento com amido+manitol se destacou, tendo apresentado a maior luminosidade e a melhor interação com o óleo de babaçu, o que proporcionou menor amarelecimento da fruta. No entanto, esta interação causou menor aderência do plastificante à superfície da fruta, não tendo retardado o seu amadurecimento. O uso do revestimento de amido+manitol reduziu a perda de massa e a conversão dos polissacarídeos em açúcares solúveis. Portanto, este tratamento é uma técnica *eco-friendly* promissora para melhor conservação pós-colheita de carambolas.

Termos para indexação: *Averrhoa carambola*, matérias-primas da Amazônia, cor, glicerol, manitol, armazenamento.

Introduction

Star fruit (*Averrhoa carambola* L.), belonging to the Oxalidaceae family, is popular due to its exotic appearance, delicate flavor, potassium content, and presence of antioxidants such as carotenoids and ascorbic acid (Singh et al., 2014). Studies have shown that the fruit has several medicinal properties (Baraiya et al., 2014; Costa et al., 2022), as the prophylactic effect of its extract observed on hepatocellular carcinoma in mice (Singh et al., 2014).

Given its high water content, star fruit is subject to chemical and microbial deterioration when stored, which causes extensive postharvest losses (Gol et al., 2015). During storage, this fruit usually undergoes changes in color, texture, and flavor due to transpiration, ethylene biosynthesis, and other metabolic processes (Brizzolara et al., 2020). This shows the importance of developing processes for an improved preservation of star fruit.

An alternative to protect these fruits is the application of edible coatings, typically made of polymers such as polysaccharides, which are proper water and oxygen barriers due to their tightly packed and ordered hydrogen-bonded network structure (Thakur et al., 2019). In addition, to improve the efficiency and functionality of edible and biodegradable coatings, composite or bilayer coatings have been developed, as those integrating proteins, polysaccharides, and lipids (Baraiya et al., 2014; Mendonça et al., 2024).

A possible composite edible coating includes starch from the mesocarp and oil obtained from different sources, such as babassu (*Orbignya phalerata* Mart.), a palm tree native of Amazonia (Nobre et al., 2018), whose extractivism occurs mainly in the Brazilian states of Maranhão, Tocantins, and Piauí (Nobre et al., 2018). In this species, more than 60% of the almonds in the endocarp are made up of oil rich in lauric acid, and the flour from the mesocarp is a by-product of oil extraction (Cazado & Pinho, 2016). However, despite being rich in starch, babassu has only been explored as animal food and biomass (Cazado & Pinho 2016; Maniglia et al., 2017, 2019).

Considering that polysaccharide-based coatings are relatively hydrophilic and rigid, polyol plasticizers, such as glycerol and mannitol, have been used to improve the mechanical properties of these coatings. According to Molavi et al. (2015) and to Thakur et al. (2019), plasticizers act on starch chains, increasing molecular mobility and, consequently, the flexibility of the used material.

Although the use of edible coatings to preserve star fruits has been evaluated (Baraiya et al., 2014; Gol et al., 2015; Oliveira et al., 2015; Sanches et al., 2017), there are no known studies using babassu as a source of starch and oil for coatings with different plasticizers.

The objective of this work was to determine the effect of edible coatings made with babassu starch and oil, combined with different plasticizers, on the shelf life of star fruit.

Materials and Methods

The star fruit used in the study were acquired in the west of the state of Maranhão, Brazil. In the laboratory, the fruits were selected to obtain five batches of 50 fruits each, homogeneous in color and size, without physical injuries or visual defects. All fruits were washed thoroughly with water, disinfected using sodium hypochlorite solution (200 mg L^{-1}) for 15 min, and air-dried.

The experiment followed a completely randomized design, in a 5x6 factorial arrangement, with five coating treatments and six storage periods, with ten replicates per treatment in each storage period. The treatments were: control, uncoated fruits; starch+glycerol, coating using babassu mesocarp starch and a layer of glycerol; starch+mannitol, coating with babassu mesocarp starch and a layer of mannitol; starch+oil+glycerol, coating using babassu mesocarp starch, babassu oil, and a layer of glycerol; and starch+oil+mannitol, coating with babassu mesocarp starch, babassu oil, and a layer of mannitol. The experimental unit was composed of one star fruit weighing approximately 170 g. The star fruit were stored for 20 days at 10°C and 65–70% relative humidity. The studied variables were: mass loss, pH, titratable acidity, soluble solids, ascorbic acid, and color. The measurements were performed at 0, 4, 8, 12, 16, and 20 days of storage.

The evaluated edible coatings were prepared using babassu mesocarp starch (5% w/v), babassu oil (5% w/v), plasticizers (30% w/v glycerol or mannitol), and distilled water. For this, the starch was extracted from the babassu mesocarp according to Maniglia & Tapia-Blácido (2016), with modifications. To obtain the starch, babassu mesocarp flour was homogenized with sodium hydroxide solution (NaOH) at 0.25% w/v, filtered in an 80 mesh sieve, and bleached with hydrogen peroxide at 35% v/v. Afterwards, successive washes were carried out with distilled water until the maximum separation of the starch. The obtained starch was then dried, at 40ºC, in the SL-102/360 forced-air circulation oven (Solab: Equipamentos para Laboratórios, Piracicaba, SP, Brazil).

The oil and plasticizer contents were calculated concerning the percentage of babassu mesocarp starch. The obtained solution was gelatinized on the NT-338 hot plate (Novatecnica: Equipamentos para Laboratório, Piracicaba, SP, Brazil) by stirring with the 713D mechanical stirrer (Fisatom, São Paulo, SP, Brazil) up to 86ºC, followed by cooling down until 30ºC.

For the application of the coatings, the fruits were dipped in the respective edible coating treatment for 5 min. Then, the fruits were stored in the TE-371 incubator (Tecnal Equipamentos Científicos, Piracicaba, SP, Brazil) at 10ºC and 65–70% relative humidity.

Mass loss (expressed in percentage) was calculated as the difference between the initial and final masses of the fruit, divided by the initial mass. To obtain the initial and final masses, the star fruit were weighed at the beginning of the experiment just after coating and air-drying and, then, every 4 days during the storage period.

To measure pH, the mPA-210 bench pH meter (MS Tecnopon Equipamentos Especiais Ltda., Piracicaba, SP, Brazil) was used in a solution of 10 g of fruits dissolved in 100 mL of distilled water, as described by Instituto Adolfo Lutz (2008). To determine titratable acidity, 10 g of fruits were dissolved in 100 mL of distilled water and titrated with NaOH solution (0.1 mol L^{-1}); the results were expressed in grams of acid per 100 g of the sample (Zenebon et al., 2008).

Soluble solids were directly determined using the HI96801 digital refractometer (Hanna Instruments Brasil, Barueri, SP, Brazil), with results expressed in °Brix (Zenebon et al., 2008).

Vitamin C content (ascorbic acid) was determined using 2.6-dichlorophenolindophenol reagent by titration by AOAC 43.064 official method (Latimer Jr., 2012), with results expressed in milligrams of ascorbic acid per 100 g.

The color of the star fruit was determined using the CM-2300D spectrophotometer (Konica Minolta Sensing, Ramsey, NJ, USA), operating in the CIE L*a*b* system. The apparatus was calibrated with a white ceramic plate, using the D65 illuminant.

The statistical analyses were performed using the XLSTAT software (Addinsoft, Paris, France), at 5% probability. Initially, the data were subjected to a three-factor analysis of variance, which included the effects of treatments, storage periods, and the interaction between treatment and storage period. The results of the treatments were compared by Tukey's test. When a significant interaction was verified, unfolding was used to evaluate the effect of each factor in relation to the other.

Shapiro-Wilk's, Durbin-Watson's, and Levene's tests were used to check for normality assumptions, independence of errors, and homogeneity of variances, respectively. Linearity was verified through residual graphs. All assumptions were met.

A regression analysis was performed to describe the effect of storage period. The goodness of fit of each model was determined using: degrees of freedom; ratio between the sum of variation explained by the model and the actual variation in the response variable (R_2); adjusted R_2, which is the ratio between the sum of explained variation and the actual one, but taking into account only the number of significant explanatory variables; mean squared error; root mean squared error; mean absolute percentage error; Durbin-Watson's test; Akaike's information criterion; and Amemiya's prediction criterion.

Results and Discussion

For the evaluated variables, there was no significant interaction ($p>0.05$) between treatments and storage (Tables 1, 2, 3, and 4).

Mass loss during postharvest, which corresponds to water loss through metabolic processes and product degradation (Sapper & Chiralt 2018; Ferreira et al., 2020), increased linearly over time according to the regression analysis. These losses were reduced with the starch+mannitol treatment, which even presented lower values (p<0.05) than the control (Table 1). Therefore, the starch and this plasticizer show a desirable interaction, forming a coating with a lower permeability to water vapor, which prevents mass losses. Franco et al. (2017) concluded that different plasticizers interact differently with starch, changing some film properties. When evaluating the application of films made of starch mixed with gelatin and plasticizers (sorbitol, glycerol, and mannitol) to strawberry [*Fragaria* × *ananassa* (Weston) Duchesne ex Rozier] fruits, the authors found that solubility was lower in the film with mannitol and significantly influenced by acetylated starch, with consequent effects on fruit mass losses.

Throughout the storage period, pH and titratable acidity changed (p<0.05). According to the regression analysis, pH increased from 10 to 22% as titratable acidity decreased during storge time (Table 2). In general, the evaluated treatments did not prevent the increase in pH or the reduction in titratable acidity. According to Gol et al. (2015), a reduction in acidity and an increase in pH is expected in fruits with a high respiration rate, such as star fruit. Similarly, Ferreira et al. (2020) found that pH and titratable acidity did not differ significantly between fruits of the Brazilian Cerrado when uncoated or coated with cassava (*Manihot esculenta* Crantz) starch and babassu flour.

Regarding the increase in pH, that of the star fruit evaluated in the present study was low compared with the values reported in the literature for other fruit species. Vyas et al. (2014), for example, found increases from 50.80 to 77.27% in papaya (*Carica papaya* L.) fruit covered with two carbohydrate-based coating materials and stored for 21 days. Ebrahimi & Rastegar (2020) verified an increase of 41.67% in mango (*Mangifera indica* L.) fruits protected with guar-based edible coatings enriched with *Spirulina platensis* and aloe vera extract, also stored for 21 days. However, for different cultivars of star fruit for fresh-cut production, Ogassavara et al. (2009) also observed slight changes in pH during 8 days of storage, which is an indicative that this is a characteristic of star fruit.

Soluble solids presented a linear increase during storage according to the regression analysis, in alignment with the results reported by Baraiya et al. (2014) for star fruit protected with edible coating containing sodium alginate, olive oil, and green tea extract. The means test showed that the lowest values (p<0.05) were obtained in the treatment with starch+mannitol (Table 3). The observed increase in soluble solids can be attributed to the accumulation of hexose sugar during fruit ripening due to the conversion of polysaccharides into soluble sugars through the action of various hydrolyzing enzymes (Ren et al.,

Table 1. Mass loss of star fruit (*Averrhoa carambola*) stored for 20 days, at 10ºC (n = 5), with and without coatings made with babassu (*Orbignya phalerata*) oil and mesocarp using different plasticizers[(1)].

Storage period (days)	Coating treatment					Mean[(2)]
	Uncoated	Starch + glycerol	Starch + mannitol	Starch + oil + glycerol	Starch + oil + mannitol	
0	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00
4	7.44±1.50	6.82±2.31	4.44±2.74	6.68±2.56	5.62±1.67	6.20±1.18
8	14.33±5.80	14.68±5.94	9.96±8.00	15.52±5.10	13.15±6.65	13.53±2.17
12	20.99±6.70	21.69±7.18	15.07±9.76	23.61±5.72	20.32±7.79	20.34±3.19
16	24.48±5.01	25.09±5.94	17.45±8.59	27.55±4.71	23.73±6.94	23.66±3.76
20	29.65±3.33	30.00±5.07	20.95±6.98	32.46±5.46	28.79±6.45	28.37±4.37
Mean	19.38±8.69a	16.38±11.42ab	11.31±8.02b	17.64±12.06ab	15.27±11.85ab	
ANOVA effects			p-value			
Treatment			0.022			
Storage			<0.0001			
Treatment x storage			1.000			

[(1)]Means followed by different letters, in the rows, differ by Tukey's test, at p<0.05. [(2)]Linear effect: $y = 0.30 + 1.37x$; $R^2 = 0.79$, where y is mass loss, and x is storage period. ANOVA, analysis of variance.

2020; Krishna et al., 2012). According to Nurul Hanani et al. (2012), to control ripening, it is essential to decrease the amount of carbon dioxide escaping from the internal tissues of star fruit during storage, which is possible through coating. Considering this finding and the results obtained in the present study, the edible coating with starch+mannitol probably slowed down the rise in carbon dioxide.

Regarding ascorbic acid, there was no significant interaction (p=1.00) between treatments and storage. Ascorbic acid only changed negatively ($p<0.05$) with storage period ($y = 11.53 - 0.09x$; $R^2 = 0.80$, where y is ascorbic acid, and x is storage time). Ding et al. (2007) also observed a reduction in the ascorbic acid of star fruit stored for 5 days, which could be explained by the autoxidation of vitamin C by ascorbate oxidase.

In the present study, reductions in vitamin C content ranged from 12.12 to 22.77%, which indicates that this bioactive compound was well maintained. These values are lower than the reductions from 55.45 to 63.13% found by Baraiya et al. (2014) when applying edible coating containing sodium alginate, olive oil, and green tea extract to star fruit.

As to color components, there was a linear reduction during storage in color component L* (luminosity) according to the regression analysis. In addition, the highest values ($p<0.05$) by the means test were observed in the starch+mannitol treatment (Table 4). Color component a* (redness) changed ($p<0.05$) only with storage time, showing the following linear reduction according to the regression analysis: $y = 1.26 + 0.15x$; $R^2 = 0.20$, where y is color component a*, and x is storage period. For color component b* (yellowness), there was an increase over time according to the regression analysis. Moreover, the means test showed that the highest values were found in the starch+mannitol treatment. Regardless of the used plasticizer, the treatments containing starch and babassu oil presented the lowest values.

Table 2. pH and titratable acidity of star fruit (*Averrhoa carambola*) stored for 20 days, at 10ºC (n = 5), with and without coatings made from babassu (*Orbignya phalerata*) oil and mesocarp using different plasticizers[(1)].

Storage period (days)	Coating treatment					
	Uncoated	Starch + glycerol	Starch + mannitol	Starch + oil + glycerol	Starch + oil + mannitol	Mean
			Titratable acidity (g acid per 100 g)			
0	0.38±0.17	0.38±0.17	0.38±0.17	0.38±0.17	0.38±0.17	0.38±0.00[(2)]
4	0.32±0.05	0.34±0.07	0.36±0.03	0.37±0.01	0.34±0.10	0.35±0.02
8	0.22±0.04	0.25±0.01	0.33±0.03	0.32±0.21	0.25±0.08	0.27±0.05
12	0.21±0.04	0.20±0.01	0.24±0.03	0.26±0.05	0.22±0.04	0.23±0.02
16	0.16±0.01	0.18±0.01	0.21±0.01	0.24±0.04	0.19±0.04	0.20±0.03
20	0.15±0.01	0.17±0.71	0.19±0.01	0.19±0.03	0.16±0.04	0.17±0.02
Mean	0.21±0.07a	0.25±0.09a	0.29±0.08a	0.29±0.08a	0.26±0.09a	
ANOVA effects				p-value		
Treatment				0.882		
Storage				0.053		
Treatment x storage interaction				1.000		
			pH			
0	2.44±0.53	2.44±0.53	2.44±0.53	2.44±0.53	2.44±0.53	2.44±0.00[(3)]
4	2.49±0.37	2.46±0.38	2.61±0.13	2.46±0.16	2.48±0.16	2.50±0.06
8	2.61±0.99	2.52±0.28	2.65±0.30	2.67±0.71	2.51±0.30	2.62±0.06
12	2.84±0.56	2.74±0.04	2.78±0.73	2.70±0.07	2.62±0.13	2.75±0.06
16	2.77±0.43	2.77±0.04	2.84±0.92	2.76±0.15	2.66±0.11	2.78±0.03
20	3.00±0.79	2.87±0.79	2.89±0.67	2.83±1.22	2.71±0.10	2.88±0.07
Mean	2.74±0.20a	2.63±0.18a	2.70±0.17a	2.64±0.16a	2.65±0.16a	
ANOVA effects				p-value		
Treatment				0.882		
Storage				0.053		
Treatment x storage interaction				1.000		

[(1)]Means followed by different letters, in the rows, differ by Tukey's test, at $p<0.05$. [(2)]Linear effect: $y = 0.37 - 0.01x$; $R^2 = 0.42$, where y is titratable acidity, and x is storage period. [(3)]Linear effect: $y = 2.44 + 0.02x$; $R^2 = 0.80$, where y is pH, and x is storage period. ANOVA, analysis of variance.

DOI: 10.1590/S1678-3921.pab2024.v59.03567

Table 3. Total soluble solids (°Brix) of star fruit (*Averrhoa carambola*) stored for 20 days, at 10ºC (n = 5), with and without coatings made from babassu (*Orbignya phalerata*) oil and mesocarp using different plasticizers[(1)].

Storage period (days)	Coating treatment					
	Uncoated	Starch + glycerol	Starch + mannitol	Starch + oil + glycerol	Starch + oil + mannitol	Mean[(2)]
	Total soluble solids (°Brix)					
0	6.78±0.15	6.78±0.15	6.78±0.15	6.78±0.15	6.78±0.15	6.78±0.00
4	7.20±0.12	7.14±0.19	6.88±0.08	7.06±0.93	7.12±0.15	7.08±0.12
8	7.30±0.47	7.18±0.11	6.96±0.11	7.28±0.79	7.44±0.53	7.23±0.18
12	7.86±0.61	7.56±0.14	7.05±0.04	7.34±1.15	7.62±0.27	7.49±0.31
16	8.40±2.03	7.60±0.12	7.09±0.07	7.56±0.21	7.90±0.74	7.71±0.48
20	8.68±1.04	7.76±0.11	7.12±0.75	7.92±1.13	8.64±0.40	8.02±0.65
Mean	7.89±0.35a	7.34±0.17a	6.98±0.10b	7.32±0.39a	7.58±0.65a	
ANOVA effects	p-value					
Treatment	0.009					
Storage	<0.0001					
Treatment x storage interaction	0.963					

[(1)]Means followed by different letters, in the rows, differ by Tukey's test, at $p<0.05$. [(2)]Linear effect: $y = 6.77 + 0.06x$; $R^2 = 0.21$, where y are total soluble solids, and x is storage period. ANOVA, analysis of variance.

Table 4. Color components L*, a*, and b* of star fruit (*Averrhoa carambola*) stored for 20 days, at 10ºC (n = 5), with and without coatings made from babassu (*Orbignya phalerata*) oil and mesocarp using different plasticizers[(1)].

Storage period (days)	Coating treatment					
	Uncoated	Starch + glycerol	Starch + mannitol	Starch + oil + glycerol	Starch + oil + mannitol	Mean
	Color component L*					
0	45.73±2.28	44.88±1.68	50.14±3.59	44.78±3.78	45.58±5.52	46.22±2.23[(2)]
4	44.34±2.07	44.62±1.71	49.53±5.16	43.90±3.43	45.24±2.76	45.53±2.29
8	43.71±2.90	43.25±1.62	48.87±1.59	43.10±2.21	44.01±3.16	44.59±2.42
12	42.82±3.00	43.14±0.62	47.38±2.32	42.95±2.13	43.03±2.97	43.86±1.97
16	42.02±5.25	41.74±1.02	47.11±5.69	41.82±1.40	41.50±3.91	42.84±2.40
20	40.97±4.24	41.41±3.36	46.08±6.25	41.57±5.72	40.90±3.38	42.19±2.20
Mean	42.77±1.34b	43.13±1.43b	48.19±1.57a	43.02±1.22b	43.38±1.92b	
ANOVA effects	p-value					
Treatment (L*)	<0.0001					
Storage (L*)	0.000					
Treatment x storage interaction (L*)	1.000					
Treatment (a*)	0.123					
Storage (a*)	0.001					
Treatment x storage interaction (a*)	1.000					
	Color component b*					
0	23.99±1.03	23.18±2.55	24.50±1.07	20.25±1.76	20.13±2.00	22.41±2.08[(3)]
4	24.23±0.38	23.88±3.76	26.47±2.87	21.48±3.90	20.37±3.83	23.29±2.41
8	26.38±3.04	24.23±1.93	27.79±1.15	22.23±5.92	20.48±8.42	24.22±2.97
12	26.92±1.58	25.24±3.31	29.52±1.70	23.92±5.34	24.51±8.41	26.02±2.26
16	27.53±1.13	28.44±1.35	30.99±2.11	24.25±0.79	24.60±6.58	27.16±2.80
20	28.22±3.27	28.68±1.04	32.85±0.70	26.33±1.81	25.51±2.12	28.32±2.85
Mean	26.66±1.52b	25.61±2.38b	28.69±3.05a	23.08±2.19c	22.60±2.52c	
ANOVA effects	p-value					
Treatment	<0.0001					
Time	<0.0001					
Treatment x time interaction	1.000					

[(1)]Means followed by different letters, in the rows, differ by Tukey's test, at $p<0.05$. [(2)]Linear effect: $y = 46.27 - 0.21x$; $R^2 = 0.80$, where y is color component L*, and x is storage period. [(3)]Linear effect: $y = 22.17 + 0.31x$; $R^2 = 0.22$, where y is color component b*, and x is storage period. Linear effect: $y = 1.26 + 0.15x$; $R^2 = 0.20$, where y is color component a* value not shown in the table, and x is storage period. ANOVA, analysis of variance.

A reduction in luminosity is an indicator of darkening, which can be caused by an increase in the concentration of pigments, such as carotenoids (Gol et al., 2015). The reduction in luminosity, possibly related to the increase in redness, may explain the considerable browning observed during storage. When evaluating the application of films with natural and modified starches to strawberry fruits, Franco et al. (2017) found that coated fruits showed a lighter color. Consumers tend to associate luminosity and color to a better food quality, preferring brighter-colored foods (Andrade-Pizarro et al., 2015). In the present study, the starch+mannitol treatment resulted in the brightest star fruit.

According to Chen et al. (2017), consumers prefer star fruit with a yellow peel and no brown spots. Using coating with chitosan, Sanches et al. (2017) found an increase in the yellow color of star fruit stored for 16 days, a process related to ripening. In the present work, the low yellowness values observed in the treatments containing babassu oil may be related to the color of the oil. Mattei et al. (2013), for example, when evaluating films with acetylated starch, gelatin, plasticizer, and oils of *Tetradenia riparia* (Hochst.) Codd and *Rosmarinus officinalis* L., concluded that the chemicals present in the oils significantly interfered with the film properties: *R. officinalis* made the films opaque and yellower, whereas *T. riparia* decreased opacity. In the present study, babassu oil may have had a better interaction with the coating, reducing yellowing, but caused a lower adherence of the coating to the peel of the fruit, whose ripening was not slowed down.

During fruit storage, there was no incidence of rot. In addition to the protective barrier provided by the used coating, refrigeration helped to preserve the fruits, especially in the control treatment.

Conclusions

1. The starch+mannitol coating treatment is effective to preserve star fruit (*Averrhoa carambola*) stored for 20 days.
2. Babassu (*Orbignya phalerata*) oil seems to interact with the edible coating but does not slow down star fruit ripening.
3. The starch+mannitol treatment is a promising eco-friendly postharvest technique to enhance the shelf life of star fruit.

Acknowledgments

To Coordenação de Aperfeiçoamento de Pessoal de Nível Superior (CAPES), for financing, in part, this study (Finance Code 001); to Conselho Nacional de Desenvolvimento Científico e Tecnológico (CNPq), for support (process number 486745/2013-9); and to Fundação de Amparo à Pesquisa e ao Desenvolvimento Científico e Tecnológico do Maranhão (FAPEMA), for funding (process number 885/15).

References

ANDRADE-PIZARRO, R.D.; SKURTYS, O.; OSORIO-LIRA, F. Effect of cellulose nanofibers concentration on mechanical, optical, and barrier properties of gelatin-based edible films. **DYNA**, v.82, p.219-226, 2015. DOI: https:// doi.org/10.15446/dyna.v82n191.45296.

BARAIYA, N.S.; RAO, T.V.R.; THAKKAR, V.R. Enhancement of storability and quality maintenance of carambola (*Averrhoa carambola* L.) fruit by using composite edible coating. **Fruits**, v.69, p.195-205, 2014. DOI: https://doi.org/10.1051/fruits/2014010.

BRIZZOLARA, S.; MANGANARIS, G.A.; FOTOPOULOS, V.; WATKINS, C.B.; TONUTTI, P. Primary metabolism in fresh fruits during storage. **Frontiers in Plant Science**, v.11, art.80, 2020. DOI: https://doi.org/10.3389/fpls.2020.00080.

CAZADO, C.P.S.; PINHO, S.C. de. Effect of different stress conditions on the stability of quercetin-loaded lipid microparticles produced with babacu (*Orbignya speciosa*) oil: evaluation of their potential use in food applications. **Food Science and Technology**, v.36, p.9-17, 2016. DOI: https://doi.org/10.1590/1678-457X.6769.

CHEN, S.-W.; HSU, M.-C.; FANG, H.-H.; TSAI, S.-H.; LIANG, Y.-S. Effect of harvest season, maturity and storage temperature on storability of carambola 'Honglong' fruit. **Scientia Horticulturae**, v.220, p.42-51, 2017. DOI: https://doi.org/10.1016/j.scienta.2017.03.047.

COSTA, E.M.A.; FIGUEIRA, M.B. de A.; CARRÃO, D.B.; HABENSCHUS, M.D.; OLIVEIRA, A.R.M. de; ACHO, L.D.R.; LIMA, E.S.; MAGALHÃES, I.R. dos S. Phenolic and flavonoid content and in vitro inhibitory effect of some Amazonian fruit juices on CYP3A4 activity. **Acta Amazonica**, v.52, p.172-178, 2022. DOI: https://doi.org/10.1590/1809-4392202103642.

DING, P.; AHMAD, S.H.; GHAZALI, H.M. Changes in selected quality characteristics of minimally processed carambola (*Averrhoa carambola* L.) when treated with ascorbic acid. **Journal of the Science and Food Agriculture**, v.87, p.702-709, 2007. DOI: https://doi.org/10.1002/jsfa.2772.

EBRAHIMI, F.; RASTEGAR, S. Preservation of mango fruit with guar-based edible coatings enriched with *Spirulina platensis* and *Aloe vera* extract during storage at ambient temperature. **Scientia Horticulturae**, v.265, art.109258, 2020. DOI: https://doi.org/10.1016/j.scienta.2020.109258.

FERREIRA, D.C.M.; MOLINA, G.; PELISSARI, F.M. Effect of edible coating from cassava starch and babassu flour

(*Orbignya phalerata*) on Brazilian Cerrado fruits quality. **Food and Bioprocess Technology**, v.13, p.172-179, 2020. DOI: https://doi.org/10.1007/s11947-019-02366-z.

FRANCO, M.J.; MARTIN, A.A.; BONFIM JR., L.F.; CAETANO, J.; LINDE, G.A.; DRAGUNSKI, D.C. Effect of plasticizer and modified starch on biodegradable films for strawberry protection. **Journal of Food Processing and Preservation**, v.41, e13063, 2017. DOI: https://doi.org/10.1111/jfpp.13063.

GOL, N.B.; CHAUDHARI, M.L.; RAO, T.V.R. Effect of edible coatings on quality and shelf life of carambola (*Averrhoa carambola* L.) fruit during storage. **Journal of Food Science and Technology**, v.52, p.78-91, 2015. DOI: https://doi.org/10.1007/s13197-013-0988-9.

KRISHNA, H.; DAS, B.; ATTRI, B.L.; KUMAR, A.; AHMED, N. Interaction between different pre- and postharvest treatments on shelf life extension of 'Oregon Spur' apple. **Fruits**, v.67, p.31-40, 2012. DOI: https://doi.org/10.1051/fruits/2011064.

LATIMER JR., G.W. (Ed.). **Official Methods of Analysis of AOAC International**. 19th ed. Gaithersburg: AOAC International, 2012. 96p. Official Method 43.064.

MANIGLIA, B.C.; TAPIA-BLÁCIDO, D.R. Isolation and characterization of starch from babassu mesocarp. **Food Hydrocolloids**, v.55, p.47-55, 2016. DOI: https://doi.org/10.1016/j.foodhyd.2015.11.001.

MANIGLIA, B.C.; TESSARO, L.; LUCAS, A.A.; TAPIA-BLÁCIDO, D.R. Bioactive films based on babassu mesocarp flour and starch. **Food Hydrocolloids**, v.70, p.383-391, 2017. DOI: https://doi.org/10.1016/j.foodhyd.2017.04.022.

MANIGLIA, B.C.; TESSARO, L.; RAMOS, A.P.; TAPIA-BLÁCIDO, D.R. Which plasticizer is suitable for films based on babassu starch isolated by different methods? **Food Hydrocolloids**, v.89, p.143-152, 2019. DOI: https://doi.org/10.1016/j.foodhyd.2018.10.038.

MATTEI, D.; GUIMARÃES, L.F.; FERREIRA, F.B.P.; SANTOS, S.R. da S.R. dos; MARTIN, A.A.; GAZIM, Z.C.; DRAGUSKI, D.C. Análises das propriedades físicas e antimicrobianas de filmes a base de amido contendo óleo essencial de *Tetradenia riparia* (Hochst.) Codd e *Rosmarinus officinalis* L. – Lamiaceae. **Arquivos de Ciências Veterinárias e Zoologia**, v.16, p.129-136, 2013.

MENDONÇA, G.R.; CAMPOS, R. de S.; SILVA, R.A. da; SILVA, D.S.; PEREIRA, A.F.; ABREU, V.K.G.; FREITAS, E.R.; PEREIRA, A.L.F. Effectiveness of babassu starch and oil coating with plasticizers to improve shelf life of eggs. **Journal of Coatings Technology and Research**, v.21, p.255-266, 2024. DOI: https://doi.org/10.1007/s11998-023-00815-1.

MOLAVI, H.; BEHFAR, S.; SHARIATI, M.A.; KAVIANI, M.; ATAROD, S. A review on biodegradable starch-based film. **Journal of Microbiology, Biotechnology and Food Sciences**, v.4, p.456-461, 2015. DOI: https://doi.org/10.15414/jmbfs.2015.4.5.456-461.

NOBRE, C.P.; COSTA, M.G. da; GOTO, B.T.; GEHRING, C. Arbuscular mycorrhizal fungi associated with the babassu palm (*Attalea speciosa*) in the eastern periphery of Amazonia, Brazil. **Acta Amazonica**, v.48, p.321-329, 2018. DOI: https://doi.org/10.1590/1809-4392201800092.

NURUL HANANI, M.Z.; HALIMAHTON ZAHRAH, M.S.; ZAIBUNNISA, A.H. Effect of chitosan-palm stearin edible coating on the post harvest life of star fruits (*Averrhoa carambola* L.) stored at room temperature. **International Food Research Journal**, v.19, p.1433-1438, 2012.

OGASSAVARA, F.O.; DURIGAN, J.F.; TEIXEIRA, G.H. de A.; CUNHA JÚNIOR, L.C. Comparação entre cultivares de carambola para produção de produtos minimamente processados. **Revista Brasileira de Fruticultura**, v.31, p.544-551, 2009. DOI: https://doi.org/10.1590/S0100-29452009000200032.

OLIVEIRA, T.A. de; AROUCHA, E.M.M.; LEITE, R.H. de L.; FERREIRA, R.M. de A.; SANTOS, F.K.G. dos. Conservação pós-colheita de carambola sob refrigeração com recobrimento de biofilme de gelatina e PVC. **Revista Verde de Agroecologia e Desenvolvimento Sustentável**, v.10, p.59-66, 2015. DOI: https://doi.org/10.18378/rvads.v10i4.3653.

REN, Y.-Y.; SUN, P.-P.; WANG, X.-X.; ZHU, Z.-Y. Degradation of cell wall polysaccharides and change of related enzyme activities with fruit softening in *Annona squamosa* during storage. **Postharvest Biology and Technology**, v.166, art.111203, 2020. DOI: https://doi.org/10.1016/j.postharvbio.2020.111203.

SANCHES, A.G.; SILVA, M.B. da; SANTOS, E.X. dos; TRIPOLONI, F.M.; CORDEIRO, C.A.M. Preservação da qualidade pós-colheita de carambola com solução filmogênica de quitosana. **Acta Iguazu**, v.6, p.98-111, 2017.

SAPPER, M.; CHIRALT, A. Starch-based coatings for preservation of fruits and vegetables. **Coatings**, v.8, art.152, 2018. DOI: https://doi.org/10.3390/coatings8050152.

SINGH, R.; SHARMA, J.; GOYAL, P.K. Prophylactic role of *Averrhoa carambola* (star fruit) extract against chemically induced hepatocellular carcinoma in Swiss albino mice. **Advances in Pharmacological and Pharmaceutical Sciences**, v.2014, art.158936, 2014. DOI: https://doi.org/10.1155/2014/158936.

THAKUR, R.; PRISTIJONO, P.; SCARLETT, C.J.; BOWYER, M.; SINGH, S.P.; VUONG, Q.V. Starch-based films: major factors affecting their properties. **International Journal of Biological Macromolecules**, v.132, p.1079-1089, 2019. DOI: https://doi.org/10.1016/j.ijbiomac.2019.03.190.

VYAS, P.B.; GOL, N.B.; RAO, T.V.R. Postharvest quality maintenance of papaya fruit using polysaccharide-based edible coatings. **International Journal of Fruit Science**, v.14, p.81-94, 2014. DOI: https://doi.org/10.1080/15538362.2013.801753.

ZENEBON, O.; PASCUET, N.S.; TIGLEA, P. (Coord.). **Métodos físico-químicos para análise de alimentos**. 4.ed., 1.ed. digital. São Paulo: Instituto Adolfo Lutz, 2008. 1020p. Versão eletrônica. Available at: <https://wp.ufpel.edu.br/nutricaobromatologia/files/2013/07/NormasADOLFOLUTZ.pdf>. Accessed on: Aug. 21 2024.