Postharvest quality of papaya fruit wrapped with polyvinyl chloride film added with silver

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Abstract

The main goal of this research was to evaluate the postharvest quality during storage of papaya wrapped with polyvinyl chloride containing silver. Fourier Transform Infrared Spectroscopy, scanning electron microscopy and atomic absorption spectroscopy were employed for the film characterization. For the postharvest experiments, unwrapped fruits were compared to individually wrapped ones in both conventional polyvinyl chloride film and polyvinyl chloride film containing silver and stored under two conditions (10 days at 15°C, and 2 days at 22°C to simulate market conditions). The physicochemical analyzes, including soluble solids, titratable acidity, ratio, pH, ascorbic acid, weight loss, firmness and color were performed every two days of storage, while microbiological analyzes were performed on the 1st and 10th day of storage. Sensory analysis was carried on the last day of storage. Physicochemical analyses showed that fruits wrapped with polyvinyl chloride films presented a lower weight loss compared to than unwrapped fruits. These results were in accordance with sensory analysis. More importantly, papaya wrapped with polyvinyl chloride film containing silver kept papaya peel green for longer time causing a delay in ripening, indicating its potential to extend postharvest shelf-life of papaya and reduce postharvest losses.

Keywords: PVC, microorganism, color, ripening, smart packing, *Carica papaya*

INTRODUCTION

Papaya is a climacteric fruit, highly perishable, presenting a soft pulp with low resistance to damages and decays. Diseases and losses during storage and marketing are major problems found on papaya conservation (Bautista-Baños et al., 2013). The papaya postharvest losses of papaya are considered very high, and can achieve levels over 75% (Paull et al., 1997). Accordingly, the fruit may not reach its consumers as a result of postharvest losses. Film packaging can be an alternative to keep and extend fruits shelf-life. The most common plastic materials used for fruit packaging are the low-density polyethylene (LDPE) and polyvinyl chloride (PVC) (Marconcini, 2017). These films present distinct features depending on the film composition and processing variables (Sandhya, 2010) and have been used for postharvest application (Becaro et al., 2016; Dias et al., 2011; Donglu et al., 2016). More recently, nanotechnology based-approaches have gained prominence for post-harvest application. For instance, to improve film characteristics, nanoparticles and other materials have been employed to improve film characteristics, such as permeability, antimicrobial properties, etc. (Becaro et al., 2015; De Moura et al., 2012; Duncan, 2011; Guo et al., 2013). Silver has been studied as an important polymeric film addictive, mainly as for antimicrobial use (Becaro et al., 2015; Anh et al., 2016). However, silver has been pointed to be an inhibitor of ethylene action (Vinod et al., 2009).

Therefore, the main goal of this research was to evaluate the postharvest quality during storage of papaya fruits wrapped with PVC containing silver and compare them with unwrapped fruits and fruits wrapped with PVC without silver.

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MATERIAL AND METHODS

Film characterization

1. Infrared spectroscopy (FT-IR).

The PVC films were analyzed by Fourier transform infrared spectroscopy (FT-IR) using a Paragon 1000 Perkin-Elmer Spectrophotometer. Spectra of each sample were collected in the range from 4000 to 400 cm^{-1} using 64 scans with a resolution of 4 cm^{-1}.

2. Scanning electron microscopy (SEM).

Morphological features of each film were analyzed using Scanning Electron Microscopy (SEM) technique with field emission gun (FEG). Several Images of the films surface were obtained in backscattering mode, using a FEI microscope, Inspect S50 model and 25 kV. Energy dispersive X-ray spectroscopy (EDX) measurements were carried out to analyze chemical composition of PVC film samples.

3. Atomic absorption spectroscopy.

The samples were prepared by calcining four PVC film samples of 10 g each in a muffle oven at 900°C for 1 h. After that, the samples were left in a desiccator with silica gel for cooling. At room temperature, the ashes were weighed, added to 10 mL of nitric acid P.A. and placed in digester block at 150°C for 4 h. Next, 3 mL of hydrogen peroxide P.A. was added, leaving the sample under heating for 2 h. With the complete digestion, the material was transferred to 50 mL volumetric flasks, and volume was completed using deionized water. Atomic absorption spectroscopy was employed to evaluate the presence of silver in the samples using a PinnAAcle 900T Spectrometer Atomic Absorption, Perkin Elmer. The atomization mode used was by graphite furnace, using synthetic air and argon gas. The calibration curve was obtained by diluting a standard silver reference (1 g L^{-1}).

Experimental design

Papayas, solo group, cultivar Golden, were carefully transported overnight to Embrapa laboratory, São Carlos, SP, from a commercial production farm (Bahia, Brazil). Fruits were at stage 1 of maturation, having less than 15% of skin surface covered by a yellow color (Santamaría Basulto et al., 2009) and were selected based on size, color and absence of defects for standardization.

Stretchable and transparent PVC commercial films with and without the addition of silver (Alpfilm®) were used to wrap individually (using a single layer) papaya fruits. Three treatments were used: T1 – control unwrapped fruits; T2 – fruits wrapped with conventional PVC film; and T3 – fruits wrapped with AgPs PVC film. Fruits were stored for 10 days at 15°C, and then kept for 2 days at 22°C to simulate market conditions.

Microbiological fruit analysis

Each fruit was washed in 0,1% peptone water (for nearly 2 min) at a concentration of 1 g mL^{-1} to a sterile container, being the initial dilution of each treatment. Serial dilutions were made until 10^{-3} g mL^{-1}. 100 μL of each dilution was spread on to potato dextrose agar (PDA) medium and incubated at 28°C for five days for fungal colonies counting. The final counting was the arithmetic mean of triplicates multiplied by the dilution value. The result was expressed in CFU mL^{-1} (Downes and Ito, 2001).

Fungal severity disease

The assessment of fungal diseases severity was evaluated after 12 days following the visual scale developed by Navarro and Arauz (1999). The severity was expressed as a percentage of affected area.

Physicochemical analyses

Each of the parameters below (soluble solids (SS), titratable acidity (TA), ratio (SS/TA), ascorbic acid (AA), weight loss, firmness measurement, color measurement) were evaluated using 3 repetitions, and each repetition was composed by 3 different fruits. At each time, nine fruits per treatment were evaluated. The physicochemical analyzes were performed at every two days of storage and microbiological analyzes were performed on the 1st and 10th day of fruit storage.

1. Soluble solids (SS).

The concentration of soluble solids (SS) was determined in homogenized pulp samples using a digital refractometer Atago RX-5000cx bench. The results were expressed as °Brix (IAL, 2008).

2. Titratable acidity (TA).

TA was determined by potentiometric titration solution. 0.1 M NaOH was added until a pH of 8.1 was reached. Values were expressed in g 100 g^{-1} of citric acid in pulp (IAL, 2008).

3. Ratio (SS/TA).

The ratio rate was determined by the relation SS/TA.

4. pH.

The pH values were determined using a benchtop potentiometer (Quimis Q400A) from the pulp obtained from 50 g of papaya (IAL, 2008).

5. Ascorbic acid (AA).

Ascorbic acid was determined by using the high-performance liquid chromatography (HPLC) technique. The equipment employed was an Agilent Varian C18 column (2.5×2.5 mm, 5 μm), with UV-visible detector set at 254 nm reading of the L-ascorbic acid and phosphate buffer pH 2.5 as mobile phase. The mobile phase flow rate was 1.0 mL min^{-1} and the injection volume of 20 uL. To prepare the samples, 5 g of homogenized fruit pulp was weighed and 5 mL of 3% metaphosphoric acid was added. The mixture was filtered through a nylon filter unit with porosity of 0.45 m and protected from light. The values were expressed in citric acid g 100 g pulp.

6. Weight loss.

The sample mass was determined using a digital precision balance (±0.01 g) from Marte AS 2000C. The values were expressed as a percentage of the sample initial weight.

7. Firmness measurement.

Firmness measurements were collected with the assistance of a digital bench texturometer TA.XT Plus Firmness Analyzer®. The compression force was applied into a pulp papaya fruit with the skin by using a cylindrical flat probe of 6 mm (diameter), speed of 2 mm s^{-1} and penetration distance of 3 mm. Papaya fruit were placed with equatorial region perpendicular to the probe to allow penetration. Nine fruits per treatment and three penetrations in each fruit were measured. The results were expressed in Newton (N).

8. Color measurement.

Color parameters of papayas fruits were determined using a Minolta colorimeter CR 300 and expressed in L*, a* and b*, as proposed system by the L'Eclaraige Commission Internationale (CIE). Results were the average of three measurements along each fruit equatorial region.

Sensory analysis

Papaya fruits were submitted to the same treatments described in Experimental design section and analyzed through affective test to assess acceptance performed by a team of 35 panelist not trained (Singh-Ackbarali and Maharaj, 2014). The sensorial test was performed in room at 23°C under fluorescent light. The samples were presented to the panelists in a codified manner, following a complete randomized block design and evaluated for attributes: color, firmness and overall appearance, through to a hedonic scale of 5 points: (1) dislike very much, (2) dislike moderately, (3) neither liked nor disliked, (4) like moderately and (5) like very much

Statistical analysis

The following comparisons between treatments in physicochemical parameters were performed: 1) Increase or decrease rate means in the period between days 0 and 10, whose calculation was made by linear regression for each replica; 2) Parameter's means in the time period in cases where the rates were not significant for most replicas; 3) Parameter's mean in the 12° day, since in this evaluation the temperature was raised Statistical analyses of the physicochemical parameters were performed using univariate parametric analysis of variance by one factor (treatment) with fixed effects in three levels (T1, T2 and T3) and multiple mean comparison Duncan test. The assumptions of normality, homoscedasticity and independence in the residuals of the models were verified. For microbiological analysis, Analysis of variance was used to compare difference means between 10° and 1° days. For sensory analysis, nonparametric analysis of variance was used with treatment as a factor in three levels and multiple comparison test of Kruskal-Wallis.

RESULTS AND DISCUSSION

Film characterization

1. Fourier transform infrared (FTIR) spectroscopy.

The spectra of the distinct PVC films are displayed in Figure 1. The peaks between 600 cm^{-1} and 700 cm^{-1} presented in the both films are characteristic of C-Cl group (stretching mode) of the PVC film (Kayyarapu et al., 2016).

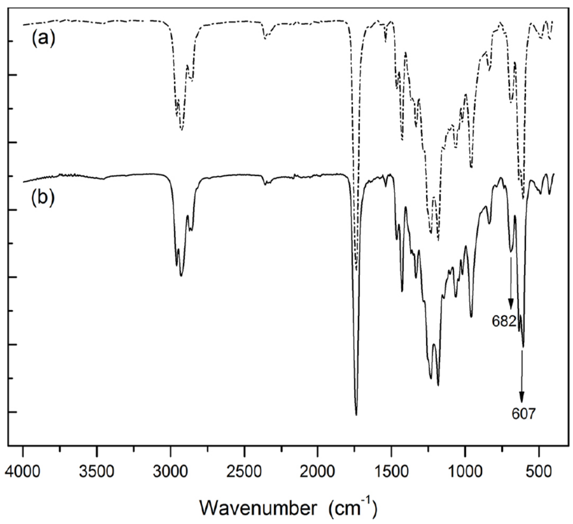

Figure 1. FTIR spectra of conventional PVC film (a) and PVC added with silver (b).

2. Scanning electron microscopy (SEM).

The SEM technique was used to perform the morphological characterization of the PVC films with silver and evaluate its composition through EDS analysis, as displayed in Figure 2, respectively. The agglomerates shown in Figure 2a refer SiO_2, as previously reported by Becaro et al. (2015), which was the carrier employed for silver. The use of a porous carrier, such as silica, has the advantage to avoid agglomeration of silver particles. Silver was not detected by EDS, probably due to the low amount of silver on the films.

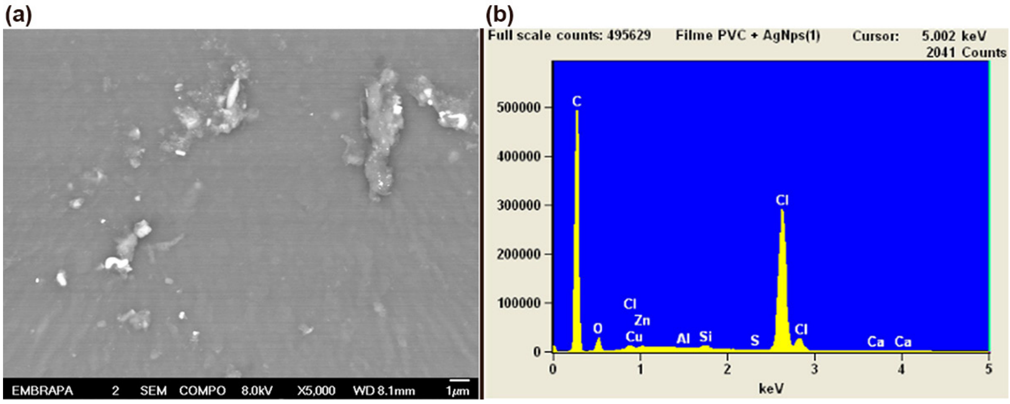

Figure 2. (a) SEM images and (b) EDS analysis of PVC film added with silver.

3. Atomic absorption spectroscopy.

The PVC film analysis by atomic absorption spectroscopy detected and quantified the amount of silver a ratio of 100 μg 100 g^{-1} of film.

4. Microbiological analysis.

No difference in the severity of fungal diseases in the average scores among treatments was observed. The results obtained do not show any evidence to prevent microorganism growth present in the fruit (data not shown).

5. Physicochemical analyses.

Cold storage.

No statistical differences were found among treatments during 10 days of storage at 15°C for titratable acidity (TA), soluble solids (SS) and ascorbic acid (AA). In fact, during the ripening of papaya, TA, TSS and ascorbic acid are not significantly modified. There was a difference between the pH values for the different treatments, and the T1 showed lower values when compared to T2 and T3 values (Table 1) that can be related to delay on ripening on the PVC treatments.

Table 1. Means of ascorbic acid values, firmness, SS, TA, ratio and pH of papayas stored at 15°C for 10 days.

Variable	T1[a]		T2[b]		T3[c]	
	Mean	SD	Mean	SD	Mean	SD
Ascorbic acid (g 100 g $pulp^{-1}$)	59.04 a	1.75	62.53 a	1.48	56.11 a	4.48
Firmness (N)	29.48 a	2.18	25.34 b	3.90	24.98 b	3.6
SS (°Brix)	10.67 a	0.17	10.8 a	0.28	10.59 a	0.03
TA (g 100 g^{-1})	0.16 a	0.02	0.17 a	0.01	0.15 a	0.004
Ratio	73.27 a	3.52	70.33 a	4.58	74.99 a	4.83
pH	5.37 a	0.02	5.46 b	0.003	5.48 b	0.01

2 and 3 of T2 were excluded.

[a]T1: control unwrapped fruits; [b]T2: fruits wrapped with conventional PVC film; [c]T3: fruits wrapped with PVC film containing silver; Means followed by the same letter on the same line do not differ at 5% probability by Duncan test.

A gradual weight loss in papayas fruits were verified during storage for all treatments (Table 2). Fruits wrapped with conventional and AgPs films showed lower weight loss than unwrapped papaya for the whole period. On day 9, maximum weight loss was noticed in non-packaged fruits stored at room temperature (18.3%) and at refrigerated storage (4.36%), while packaged fruits had a modest 2.31% weight loss. Weight loss directly affects the quality of the fresh fruit by reducing fruit firmness and brightness (Lee et al., 2016).

Table 2. Color change mean rate of parameters a *, b * and L* and weight loss in papayas stored under the temperature of 15°C for 10 days.

Variable	Mean change rate until the 10th day[a]					
	T1[b]		T2[c]		T3[d]	
	Mean	SD	Mean	SD	Mean	SD
a*	0.60 a	0.30	0.63 a	0.26	0.64 a	0.45
b*	1.26 a	0.23	1.31 a	0.47	0.70 b	0.40
L*	0.54 a	0.26	0.85 a	0.38	0.47 a	0.46
Weight loss[e] (%)	0.11 a	0.01	0.06 b	0.01	0.06 b	0.01

[a]Daily rate. Means followed by the same letter on the line do not differ at 5% probability by Duncan test; [b]T1: control unwrapped fruits.

[c]T2: fruits wrapped with conventional PVC film; [d]T3: fruits wrapped with PVC film containing silver; [e]Repetition 2 and 3 of T2 were excluded.

During this period of storage, decrease in firmness was lower for control treatment than the others. This behavior can be related to high weight loss (Table 2). According Giuggioli et al. (2015) weight loss can affect positively firmness measurements. The data found in the present study are also in agreement with Pinto et al. (2006), which evaluate the modified atmosphere on papaya fruits cv. Golden packed on LDPE plastic films and kept under refrigerated storage conditions. In that study, decrease in firmness was higher for control treatment until the 4th of storage but in the 12th day of storage the decrease in firmness for control was 73.53%, while for fruits packaged with plastic film was 89.69%. Such behavior could be related to the weight loss that was higher in unpackaged papaya.

For color, parameters L and a* did not differed among treatments. After 10 days of storage, b* values for T3 showed significantly lower values than T1 and T2, causing a delay on color change (to yellow) for papayas wrapped in PVC films added with silver (Table 2). T3 average b*value was almost half of the value for sample T1 (control) and T2 (fruits wrapped with conventional PVC film). Our results agree with previous results of Tucker and Brady (1987), who noticed that tomato fruit tissues treated with ion silver inhibited color change.

Ambient storage.

The data relating to firmness are described in Tables 3 and 4. T1 showed higher values for firmness until the 10th day of storage when compared with T2 and T3, however, on day 12 no difference between treatments were found (Table 3). These results are in agreement with Dias et al. (2011), who observed that room temperature did not affect firmness of packaged and unpackaged fruits.

Table 3. Color parameters a*, b* and L* (mean) and weight loss in papayas stored under the temperature of 22°C on the 12th day of storage.

Variable	12th day					
	T1[a]		T2[b]		T3[c]	
	Mean	SD	Mean	SD	Mean	SD
a*	3.34 a	3.58	-3.95 b	5.23	-6.03 b	5.36
b*	63.94 a	4.34	60.43 ab	3.55	58.21 b	4.46
L*	71.16 a	1.88	70.55 a	2.69	68.52 a	3.08
Weight loss[d] (%)	1.64 a	0.23	0.84 b	0.07	0.84 b	0.1
Firmness	14.31 a	2.88	15.56 a	5.38	17.16 a	4.18

[a]T1: control unwrapped fruits; [b]T2: fruits wrapped with conventional PVC film; [c]T3: fruits wrapped with PVC film containing silver; [d]Repetition 2 and 3 of T2 were excluded.

Means followed by the same letter on the line do not differ at 5% probability by Duncan test.

For lightness, there were no differences among treatments on the two storage temperatures, during 10 days at 15°C and 2 days at 22°C of storage. For parameter a* differences on the 12th day of storage was observed (Table 3). Unwrapped fruits (T1) showed a higher a* value than the other treatments, indicating that papaya wrapped with AgPs films delayed the green color evolution on higher temperature. b* values were statistically different between control and AgPs PVC film, indicating a delay on ripening. Those results were in agreement with b* color change observed during the tenth day of storage (Table 2). Therefore, AgPs PVC film was retained the development of yellow color of papaya peel. The change in the skin fruit color from green to yellow occurs due to the chlorophyll degradation, which causes the carotenoids in the tissue to become visible. This process results from fruit maturation (Fabi et al., 2007).

Table 4. Median score in the papaya fruit acceptance test for color parameters, texture and overall appearance, on the 12th day of storage.

Parameter	T1		T2		T3	
	Median	I. R.[a]	Median	I. R.	Median	I. R.
Color	4 a	1	4 a	1	3 b	1
Firmness	4 a	2	4 a	2	4 a	2
Overall appearance	4 a	1	4 a	1	4 a	1

[a]I.R.: Interquartile range. Values followed by same letter on the column do not differ at 5% of significance (Kruskal-Wallis criteria).

Sensory analysis

Fruits maturity can be determined by the consumers using a simply visual evaluation (Bron and Jacomino, 2006). According Rangel et al. (2003), the preference of consumers in the purchase for papayas are for the ones with maturity ready consumption, in maturation stages between 4 (75% yellow skin color) and 5 (more than 75% of the yellow skin color).The results of the papayas acceptance test (Table 4) for firmness and overall appearance parameters had no significant difference. However, skin colors scores were considered lower for T3 (3) compared to T1 and T2 (4), indicating greener fruits when compared to the two other treatments. This result is related to the data presented in Table 3 for b* parameter. T3 fruit showed lower value for b *, having yellowing peel delayed. AgPs PVC films delaying skin color, although, greener fruits were not attractive for the panelists.

CONCLUSIONS

Our results revealed that PVC films containing silver used to wrap papaya were able to keep papaya peel greener for longer periods compared to the other treatments showing a potential to delay ripening and extend postharvest shelf life of papaya, contributing to reduce postharvest losses.

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