ORIGINAL RESEARCH

Biodegradable and Edible Film Based on Persimmon (*Diospyros kaki* L.) Used as a Lid for Minimally Processed Vegetables Packaging

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Abstract

Biodegradable films based on persimmon (*Diospyros kaki* L.) with glycerol and pectin were developed, characterized, and applied as a lid for bowls with minimally processed vegetables (MPV) (cucumber, carrot, and beetroot), with PVC as a positive control. Microbiological and physical parameters of MPV were investigated during refrigerated storage. The films presented high values of water vapor permeability (WVP) ($5.77–6.63 \times 10^{-6}$ g h^{-1} m^{-1} Pa^{-1}) and water solubility (WS) (68.80–80.86 %) and 0.75–1.35 MPa, 17.71–20.55%, and 3.82–10.06 MPa of tensile strength (TS), elongation at break (EB), and Young's modulus (YM), respectively. The addition of glycerol and pectin decreased TS and increased YM, EB, and WS of films. Thermogravimetric analysis showed two important steps of degradation related to glycerol, polymer backbone, pectin, and monosaccharide ring: 205 and 335 °C. Scanning electron microscopy revealed a homogenous microstructure of the films. The film with lower WVP and thickness, higher TS, good flexibility, and a more vivid color was selected as a lid for MPV bowls. Vegetables covered with film or PVC presented similar results regarding thermotolerant coliform evolution (< 3 to 160 MPN g^{-1}); psychrophiles and fungi count (< 2 to 8.72 log CFU g^{-1}); pH value (5.95 to 6.18 for cucumber; 5.96 to 6.10 for carrot; 6.02 to 5.75 for beetroot); and optical properties. Persimmon film reduced the dehydration process of MPV, though to a lower extent than PVC. This study indicates the potential of persimmon-based film as an alternative to synthetic lids for vegetable packaging.

Keywords Casting technique · Edible film · Fresh-cut vegetables · Postharvest storage · Shelf life · Quality parameters

Introduction

Consumers are more aware today of the importance of the nutritive value of vegetables, and they demand fresh foods without chemical additives. To address this request, the food market and researchers are investing efforts in developing innovative postharvest technologies to preserve and extend the shelf life of minimally processed vegetables (MPV) (Hussein et al. 2015; Lucera et al. 2010). On the one hand, these fresh products are healthy and convenient for daily consumption; on the other hand, the demand for plastic packaging usually increases with their storage and commercialization. Thus, an important challenge is to reduce the amount of plastic package of MPV (Ferreira et al. 2016; Hussein et al. 2015).

In this sense, among the new approaches for MPV packaging is the use of biodegradable films (De Barros-Alexandrino et al. 2019; Ferreira et al. 2016), like those based on papaya (*Carica papaya* L.) (Rangel-Marrón et al. 2019), banana (*Musa*) (Jirukkakul 2016), mango (*Mangifera indica* L.), and guava (*Psidium guajava*) (Viana et al. 2018) among others.

Some studies in literature found that persimmon fruit also presents a carbohydrate profile suitable for obtaining biopolymer-based films (Matheus et al. 2020; Yaqub et al.

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2016). In addition, it is a fruit with several bioactive compounds with antioxidant and antimicrobial properties, such as phenolic compounds, carotenoids, tannins, and others (Persic et al. 2018; Yaqub et al. 2016; Hernández-Carrión et al. 2014; Sentandreu et al. 2015; Giordani et al. 2011; Veberic et al. 2010). Investigating new technical feasibilities to obtain technological products with higher added value from persimmon is an important way to reduce its significant post-harvest loss observed in countries like Brazil (De Corato and Cancellara 2019; Matheus et al. 2020).

Minimally processed carrots, beetroot, and cucumber are largely consumed in several countries (Condurso et al. 2020; De Brito Nogueira et al. 2020) and represent one of the major MPV products used as ready-to-eat foods or vegetable salad in Brazil (De Barros-Alexandrino et al. 2019). This way, they are interesting food models to investigate the effects of alternative food packaging materials. As far as we know, there are no literature reports on the application of films produced from persimmon on MPV, which proves the innovative character of this research.

The goal of this study was to (a) produce and characterize a biodegradable film based on persimmon and (b) evaluate the effect of storage time on microbiological and physical properties of minimally processed carrot, beetroot, and cucumber packed in plastic bowls covered by a persimmon film lid.

Materials and methods

Fruit and vegetables

Persimmon fruits (*Diospyros kaki* L.) with full physiological maturity were purchased from a local agroecological street market in Rio de Janeiro/Brazil. Ripe fruits were washed with tap water, to remove surface dirt, and properly sanitized. Fruits were stored at −12 °C until film elaboration. Carrots (*Daucus carota*), beetroots (*Beta vulgaris*), and cucumbers (*Cucumis sativus*) were purchased from a local market in Rio de Janeiro/ Brazil at the commercial maturity stage.

Preparation of persimmon biodegradable film

Unfrozen whole persimmons were triturated for 3 min with an industrial blender. The puree prepared from persimmon presented the following chemical composition, in dry basis per 100 g: 81.09 ± 0.82 g of moisture; 0.23 ± 0.02 g of ash; 0.76 ± 0.12 g of protein; 0.35 ± 0.01 g of lipids; and 17.57 ± 0.76 g of carbohydrate. These data were analyzed according to the Association of Official Analytical Chemists (AOAC 2000). Whole persimmon fruit samples were triturated to homogeneous puree. The moisture and ash

(gravimetry), lipid (Soxhlet method), protein (Kjeldahl method), and total carbohydrate content (by difference) were obtained in triplicate.

Three film-forming solutions were developed considering different proportions of persimmon puree and different concentrations of glycerol and pectin per kilogram of puree (Table 1). The solutions were homogenized in a commercial blender for 3 min, dispersed (about 10 kg m^{-2}) on polystyrene plates, and dried in a ventilated oven (55 °C/20 h) (casting technique). Then, the films were manually removed from the plates and kept in a glass desiccator at 23 ± 2 °C and 55% of relative humidity for 4 days for subsequent characterization on mechanical, physical, physicochemical, and optical properties and application as cover to MPV.

Characterization of persimmon biodegradable film

Mechanical properties and thickness

The mechanical properties of the produced films, such as maximum tensile strength (TS) (MPa), elongation at break (EB) (%), and Young's modulus (YM) (MPa) were assayed using a Universal Testing Machine (EMIC−DL2000, Instron, Brazil), according to American Society for Testing and Materials method D882 (1995). The final values for TS, EB, and YM were calculated by TESC Version 3.05 Program, using an average of five measurements. Film thickness was analyzed by averaging six random points using a digital micrometer (0–25 mm Digimess, Brazil) according to Andrade et al. (2016).

Water solubility and water vapor permeability

The water solubility (WS) and water vapor permeability (WVP) were analyzed according to Andrade et al. (2016), in triplicate. The WS of the films was determined by the ratio between the initial and the final (after immersion in distilled water) dry mass.

To the WVP test, film samples sealed the top of permeation cells with silica gel and were then deposited in a desiccator containing distilled water (100 % RH) at 25 °C. The

Table 1 Formulations of the filmogenic solutions of the persimmon-based films (F1, F2, and F3)

Formulations	F1	F2	F3
Persimmon puree (fruit:water)	1:0	0.75:0.25	1:0
Pectin[1]	0	15	30
Glycerol[1]	0	20	40

[1] Pectin and glycerol concentration (g kg^{-1} of persimmon puree)

permeation cells were subsequently weighed during a period of 24 h to constant weight. The determination of WVP of the films is defined by the following Eq. 1:

$$WVP = \frac{g}{t \times A} \times \frac{X}{\Delta P} \tag{1}$$

where A is the surface permeation area of the exposed film (m^2); gt-1 was obtained by the silica gel weight gain values (g) in time (t) at steady-state; X is the mean film thickness (mm) and ΔP is the vapor pressure difference of the silica gel-containing environment (0) and containing pure water (3.16746 kPa at 25 °C).

Fourier transform infrared spectroscopy

The Fourier transform infrared spectroscopy (FTIR) analysis was performed using a spectrometer (Perkin-Elmer Spectrum One) equipped with a total reflectance accessory. Transmission spectra were obtained with 4 cm^{-1} resolution, from 4000 to 600 cm^{-1} and 60 scans.

Thermogravimetric analysis

The thermal stabilities of the films were analyzed using a thermogravimetric analysis (TGA) (TGA Q500, TA Instruments) in the temperature range of 50 to 500 °C at 20 °C min^{-1} under a nitrogen atmosphere. The methodology for onset temperature is defined as a relation between the results at 100 °C and at the first peak, calculated by the Universal Analysis Software 2000. This point represents the beginning of weight loss related to moisture evaporation.

Optical properties

Color measurements were performed using a Konica Minolta colorimeter (model CR 400, Minolta Co. Ltd., Japan) on five different points of the film. The samples were settled juxtaposed on a white standard plate ($L* = 97.41$, $a* = -0.02$, $b* = 1.99$) to obtain the film coordinates $L*$, $a*$, and $b*$. From these values, Chroma ($C*$) (Eq. 2) (Fai et al. 2016) and transparency (Eq. 3) (Capitani et al. 2016) are calculated. The equations are expressed as follows:

$$C* = \left[\left(a^{*2} + b^{*2} \right) \right]^{1/2} \tag{2}$$

$$Transparency\ value = \frac{Absorbance\ at_{600\ nm}}{Film\ thickness\ (mm)} \tag{3}$$

The absorbance was measured with a UV–Vis spectrophotometer (UV-2700; Shimadzu, Kyoto, Japan).

Scanning electron microscopy

The morphology of the persimmon films was analyzed by scanning electron microscopy (SEM) in a JEOL model JSM-6510LV microscope. Films were fixed on metal stubs using carbon tape and covered with carbon, allowing surface visualization with the electron-bean acceleration of 5 kV. The samples were magnified 45 and 1000 times, and the 15 spot size (Ojagh et al. 2010).

Preparation of MPV

Carrots, beetroots, and cucumbers were selected based on uniformity of size and color and no visible mechanical injury or fungal deterioration. Vegetables were washed with tap water to remove surface dirt and then immersed for 15 min in chlorinated water (sodium chloride 1% w/v; sodium hypochlorite, 2.5% w/v) followed by a tap water rinse. All vegetables were shredded (grated) using a vegetable processor (Cadence MPR853, Brazil).

Biodegradable film experiment: packaging and storage

Shredded vegetables were arranged regularly on polystyrene bowls (6.4 cm height × 6.1 cm diameter; 88 mL total capacity) and randomly assigned to three different groups: covered with persimmon film; covered with polyvinyl chloride (PVC) (0.01 mm of thickness) (positive control); and uncovered (negative control). For covered samples, films were uniformly cut and manually applied to the bowls containing shredded vegetables. These films were fixed using a rubber band for better film adhesion. Each group was distributed in three bowls (40 g per bowl with 2.0 cm of headspace) for each period of analysis (0, 2, 4, and 9 days, corresponding to T0, T2, T4, and T9, respectively). Exemplifying, the minimally processed beetroot uncovered, covered with PVC, and covered with persimmon film in one day of analysis is presented in Fig. 1. All samples were stored in a refrigerator at 4 °C. For covered samples, the film or the PVC was removed from the top of the bowl just before performing the analyses.

Analysis of MPV

Microbiological analysis

To evaluate the microbiological quality of the covered and uncovered MPV samples, the thermotolerant

Fig. 1 Persimmon film formulated using 0.75:0.25 persimmon:water, 15 g kg^{-1} of pectin, and 20 g kg^{-1} glycerol, by casting technique (55 °C/ 20 h) (**a**); the minimally processed beetroot uncovered (on the top), covered with PVC (in the middle), and covered with persimmon film (formulated using 0.75:0.25 persimmon:water, 15 g kg^{-1} of pectin, and 20 g kg^{-1} glycerol) (in the bottom) throughout storage at 4 °C (**b**)
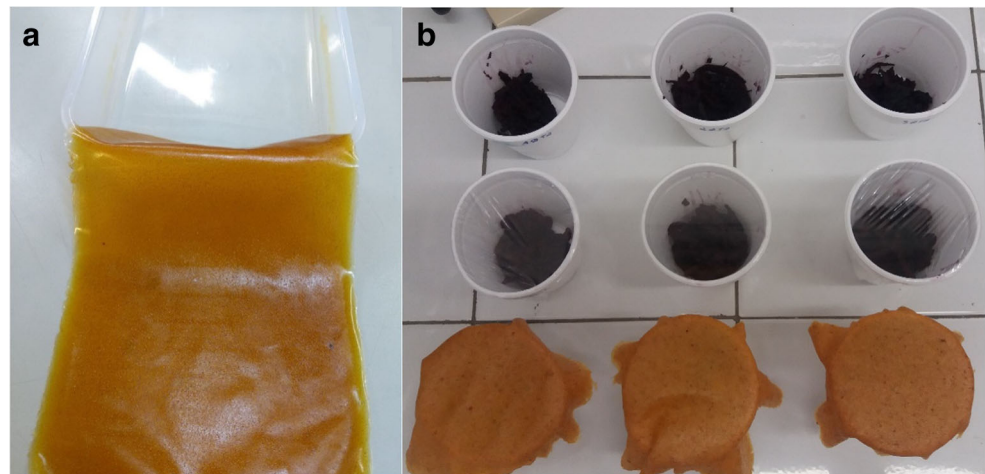
coliforms (expressed as the most probable number per gram—MPN g^{-1}), total psychotropic bacteria, and total fungi counts (expressed as the logarithm of the colony-forming units per gram—log CFU g^{-1}) were assayed at T0, T2, T4, and T9. *Salmonella* sp. (presence or absence in 25 g) was only evaluated at T0. All microbiological analyses were carried out according to the methodology described by APHA (2015) and Silva et al. (2010). At T0, the covered samples were assayed after the treatment. The measurements were taken in duplicate for each sample.

Weight loss

The samples were weighted in triplicates at T0, T2, T4, and T9 of storage time. The weight loss was calculated as a percentage of the fresh weight determined on T0 (Ferreira et al. 2016).

pH analysis

The MPV were triturated, homogenized with distilled water, and immediately analyzed. All analyses were performed in triplicate at T0, T2, T4, and T9 of storage. The pH value was measured using a pH meter (TEC–3MP, Tecnal, Brazil) calibrated with buffer solutions of pH 4.0 and 7.0 (AOAC method 13010).

Optical properties

Color measurements were performed as described in the "Optical properties" section. Three samples (about 30 g each) from each treatment of covered and uncovered vegetables were arranged on single plastic Petri dishes for color measurements. The Petri dish with the sample was settled juxtaposed on a white standard plate to

obtain the coordinates L^*, a^*, and b^* of the MPV. At T0, samples were analyzed immediately after processing. Analyses were performed in triplicate, and each assay was measured three times, recording the average value. The color was evaluated at T0, T2, T4, and T9 of storage. From these values, C^* (Eq. 1) and the total color difference (ΔE^*) (Eq. 4) were calculated for all samples. This last measures the difference between two colors, according to the following classification: $\Delta E^* = 0–0.5$ trace level difference; $\Delta E^* = 0.5–1.5$ slight difference; $\Delta E^* = 1.5–3.0$ noticeable difference; $\Delta E^* = 3.0–6.0$ appreciable difference; $\Delta E^* = 6.0–12.0$ large difference; and $\Delta E^* > 12.0$ very obvious difference (Goyeneche et al. 2014).

$$\Delta E^* = \sqrt{(\Delta L^*)2 + (\Delta a^*)2 + \overset{C}{(\Delta b^*)}} \qquad (4)$$

Besides, a whiteness index (WI^*) (Eq. 5) was calculated (Fai et al. 2016). Throughout the storage period, cucumber usually develops a not whitish appearance, as carrot and beetroot do, turning more yellow (Al-Juhaimi et al. 2012). Therefore, WI^*, which represents this change into whitening of the sample, was only calculated for carrot and beetroot.

$$WI^* = 100 - \left[\left(100 - L^*\right)^2 + a^{*2} + b^{*2}\right]^{1/2} \qquad (5)$$

Statistical analysis

Results are expressed as a means of three independent trials. Experimental data were processed by analysis of variance and Tukey's test by setting the statistical significance at the 95% level using GraphPad Prism (Graph Pad Software, Inc., San

Diego, CA) and Excel (Excel version in Microsoft Office 2013 for Windows).

Results and discussion

Films characterization

The films obtained were continuous, orange-ish in color, malleable, with a few pores and without cracks on the surface. They were easily detached from the plates without tearing and were not brittle or too sticky. The persimmon film characterization (physical, mechanical, and optical properties) is described in Table 2.

In this study, films presented a high thickness, as expected, once viscous solutions tend to form thicker films (Arquelau et al. 2019). The F2 had the lowest thickness among all. Considering the same amount of filmogenic solution for all films, the addition of water in its formulation contributed to reducing the solids content, favoring the efficient molecular chain packing (Shankar and Rhim 2016; Shimazu et al. 2007). Furthermore, other studies reported that the addition of fruit puree makes it difficult to homogenize the formulation, which was also observed in this work (Kadzińska et al. 2020; Espitia et al. 2014; Martelli et al. 2013).

Mechanical properties

The results of TS found in this study were similar to others of fruit films in the literature (Crizel et al. 2018; Reis et al. 2015; Martelli et al. 2013). The puree can lead to an increase in TS of the films. The F2 presented a TS similar to F1, despite its smaller amount of persimmon puree. This data can be attributed to the addition of pectin in F2, since its incorporation improves the TS, even though the presence of glycerol may promote negative effects on this property (Martelli et al. 2013). The improvement in TS attributed to pectin is associated with its high chemical affinity to fruit puree, which is even more important when the fruit itself presents a relevant content of pectin (Viana et al. 2018), which is the case of persimmon (Matheus et al. 2020).

Although glycerol has more complex effects on the mechanical properties of films, water also has its impact, especially in films based on hydrophilic compounds (Shimazu et al. 2007). When observing F2, we can infer that the addition of water promoted a more compact and cohesive structure by its chemical interactions in the polymeric network. This fact may have contributed to the lower thickness observed in this film, as well as the maintenance of the mechanical resistance seen in F1, even with the addition of plasticizer. In this case, both the addition of glycerol and water in the formulation may have led to the preservation of the flexibility of F2. The lowest resistance of the films can be explained by the high concentration of sugars in fruit such as persimmon (Matheus et al. 2020; Conesa et al. 2019; Veberic et al. 2010), which decreases intermolecular forces in the film matrix (plasticizer action) (Martelli et al. 2013). Furthermore, glycerol content interacts with the polymer matrix, causing a structural disruption and impacts the mechanical properties, reducing TS and YM and increasing EB (Liu et al. 2013; Rocha Plácido Moore et al. 2006), which might explain the statistical difference between the samples. The EB found in this study is in the same range as others, such as 9.6% for tomato puree (Du et al. 2008); 18.5% for mango puree (Sothornvit and

Table 2 Persimmon films characterization: physical, mechanical, and optical properties

Barrier and mechanical properties	F1	F2	F3
Water vapor permeability ($\times 10^{-6}$ g h^{-1} m^{-1} Pa^{-1})	6.50 ± 0.24^a	5.77 ± 0.07^b	6.64 ± 0.31^a
Water solubility (%)	68.80 ± 6.02^b	80.86 ± 2.40^a	79.89 ± 1.44^a
Thickness (mm)	0.73 ± 0.02^a	0.53 ± 0.01^b	0.76 ± 0.03^a
Tensile strength (MPa)	1.30 ± 0.18^a	1.35 ± 0.20^a	0.75 ± 0.15^b
Elongation at break (%)	17.71 ± 2.50^b	18.37 ± 1.18^b	20.55 ± 1.79^a
Young's modulus (MPa)	10.06 ± 1.10^a	8.29 ± 0.74^b	3.82 ± 0.97^c
Optical properties	**F1**	**F2**	**F3**
$L*$	41.73 ± 1.04^b	53.04 ± 1.09^a	$48.39 \pm 6.01^{a,b}$
$a*$	20.79 ± 1.05^b	28.59 ± 0.22^a	22.61 ± 1.42^b
$b*$	25.82 ± 2.00^b	46.84 ± 2.30^a	37.51 ± 9.47^a
Transparency	3.11 ± 0.30^a	3.24 ± 0.10^a	3.49 ± 0.30^a
Chroma	33.15 ± 2.16^c	54.89 ± 1.87^a	44.03 ± 8.05^b

Persimmon biodegradable films: F1 (formulated using 1:0 persimmon:water, 0 g kg^{-1} of pectin and glycerol); F2 (formulated using 0.75:0.25 persimmon:water, 15 g kg^{-1} of pectin, and 20 g kg^{-1} glycerol); and F3 (formulated using 1:0 of persimmon:water, 30 g kg^{-1} of pectin and 40 g kg^{-1} of glycerol).

[a,b,c] Different letter superscripts in the same line indicate a statistically significant difference ($p < 0.05$). Results expressed as mean ± standard deviation of three replicates

Rodsamran 2008); 15.0% for banana puree and glycerol (Martelli et al. 2013); 17.4% for fruit and vegetable residue (Fai et al. 2016); 9.8–19.6% for banana peel flour and cornstarch (Arquelau et al. 2019); 12.4% for bean starch, sorbitol, and goji berry powder extract (Kim et al. 2020); and 24.6% for banana nanocomposite film (Orsuwan and Sothornvit 2018). In the case of YM, other studies also presented similar values, such as 8.3 MPa for mango puree film (Sothornvit and Rodsamran 2008) and 15.4 MPa for alginate-acerola puree (Azeredo et al. 2012).

WS and WVP

All films presented a high WS, mainly F2 and F3, which may be related to the addition of plasticizers, such as glycerol and pectin, and the intrinsic hydrophilic characteristic of other polar compounds in the film. These molecules interact with water, leading to higher mobilization and consequent solubility (Arquelau et al. 2019; Capitani et al. 2016; Andrade et al. 2016). Films presenting higher WS may be more suitable for application in ready-to-eat products and to be consumed with the food. On the other hand, low WS may be necessary to maintain the quality of liquid foods or products with exuding aqueous solution (Ferreira et al. 2016; Fakhouri et al. 2015). Therefore, the ideal WS value is closely related to the film's purpose. This study presents films with a high value of WVP. The films present hydrophilic characteristics due to their composition: rich in carbohydrates, such as saccharides, and low lipids content. Furthermore, the presence of glycerol and pectin also favors the absorption of water. These factors may be associated with their rather high permeability (Arquelau et al. 2019; Gonçalves et al. 2019; Stoll et al. 2017). Furthermore, the plasticizer produces a secondary effect, weakening the intermolecular interactions of polymer chains, which also may increase the permeability (Seslija et al. 2018). The F2 presented the lowest WVP, which may be attributed to its lower thickness. Stoll et al. (2017) and Arquelau et al. (2019) also observed that thicker films composed of hydrophilic molecules present higher water diffusion, which increases their WVP.

Other works have presented WVP of similar magnitude: 2.11–2.68, 2.39, and 8.88 × 10^{-6} g h^{-1} m^{-1} Pa^{-1} for films of tomato puree with pectin and carvacrol (Du et al. 2008), banana nanocomposite film (Orsuwan and Sothornvit 2018), and mango puree (Sothornvit and Rodsamran 2008), respectively. The films in this study presented a higher thickness than those mentioned previously, making it difficult to compare their permeability values (Arquelau et al. 2019; Stoll et al. 2017).

FTIR

FTIR analysis (Fig. 2) demonstrated that C–OH (1099 cm^{-1}) and ester groups (1230 and 1020 cm^{-1}) may be present due to pectin (Seslija et al. 2018). Saccharide bonds are typically related to the range from 1165 to 980 cm^{-1} (Basiak et al. 2018). The other peaks from this figure are common to structures present in glycerol, starch, and cellulose, among others (Gonçalves et al. 2019; Cao et al. 2018; Hajji et al. 2018; Wang et al. 2018; Seslija et al. 2018; Capitani et al. 2016). Sample spectra were similar at all absorption peaks. This might indicate that the difference between the film-forming solutions did not affect the chemical structure to the extent of changing the peak absorption positions and magnitude.

TGA

All films presented two important steps of thermal degradation in the TGA analysis (F1: 204 °C and 331 °C; F2: 203 °C and 339 °C; F3: 210 °C and 335 °C) (Fig. 3). The F2 sample presented a lower onset temperature when compared to the other films. This indicates higher water activity, with less bonded molecules to the film matrix, which might be associated with the addition of water in the film formulation (Wang et al. 2018). This result is following the lower WVP found for this sample.

Tannins, present in persimmon fruit (Matheus et al. 2020), and glycerol might be attributed to the weight loss near 166 °C and 180 to 240 °C, respectively (Wang et al. 2018; Moliner et al. 2016). The first point for all samples was very similar and might be related to the thermal decomposition of polymer backbone (Wang et al. 2018), and the degradation of cellulose and pectin chain (Seslija et. al. 2018; Nanda et al. 2016). Furthermore, the range from 250 to 350 °C indicates the degradation of monosaccharide rings and depolymerization (Capitani et al. 2016), while the weight loss slows down after 400 °C, leading to the biochar generation (Nanda et al. 2016).

Optical properties

The values of $a*$ and $b*$ indicate that the films are more reddish and yellow, attributed to the persimmon original color. The values of $L*$ indicate darker films with high color intensities, once the $L*$ is the lightness of the color and the values range from 0 (black color) to 100 (white color). The F1 sample presented the lowest $L*$ value; this result might be attributed to the absence of water, pectin, and glycerol in the film-forming solution, which contributes to the lightening of the films. This fact can occur due to the opening of the polymer network structure by water, pectin, and glycerol, allowing greater light penetration into the film (Fakhouri et al. 2015). The thickness also influenced the luminosity of the films; the thinner the film, the higher the value of $L*$ (Table 2). The parameters of

Fig. 2 FTIR for persimmon films: F1 (formulated using 1:0 persimmon:water, 0 g kg^{-1} of pectin and glycerol); F2 (formulated using 0.75:0.25 persimmon:water, 15 g kg^{-1} of pectin, and 20 g kg^{-1} glycerol); and F3 (formulated using 1:0 of persimmon:water, 30 g kg^{-1} of pectin and 40 g kg^{-1} of glycerol)
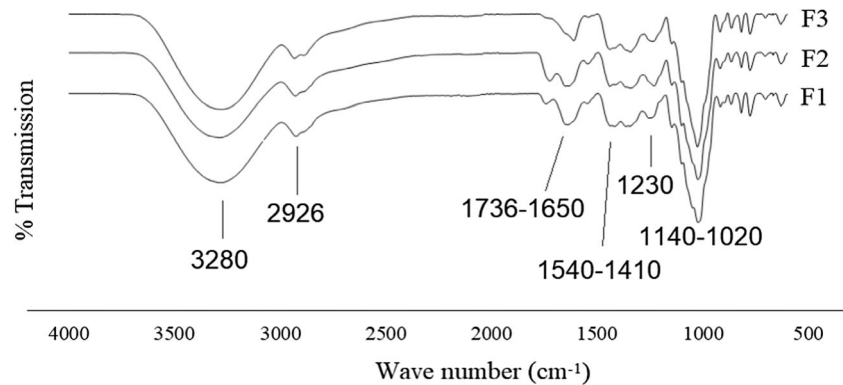
color saturation, expressed by the C^*, additionally indicate a vivid color (Nouraddini et al. 2018; Fai et al. 2016). The F2 presented a C^* higher than the other samples, which is the most vivid. This result may be explained due to a more compact and cohesive structure because of the higher intermolecular bonding of this film (Espino-Díaz et al. 2010). The films presented low transparency values (3.11–3.49), what, in addition to their coloration, might work as a barrier for the packaged food against environmental light and, thus, protect it against changes in the nutritional quality of food (Tao et al. 2018; Kaewprachu and Rawdkuen 2016). This characteristic can be considered a differential in the market, as it is an important feature for food packaging.

SEM

The images show the microstructure of the biodegradable films as smooth surfaces with compact, homogeneous structures (Fig. 4). Despite this, the film's surfaces were crumpled. The characteristics observed are similar to other study with films of different formulations with a complex matrix (Basiak et al. 2018). As plasticizers were added, the surfaces became a bit rougher, but smooth. This observation is in accordance with the literature (Wang et al. 2018; Nanda et al. 2016). Agglomerates of plasticizer were not identified in the films, suggesting the additives were dispersed into the puree matrix.

Analysis of MPV

The F2 sample (Fig. 1) was selected for application as a bowl lid for MPV because of its results regarding physical and mechanical properties. It presented lower WVP and thickness, higher TS, good flexibility, and more vivid color (higher L^* and C^* values).

Microbiological analysis

Microbial population analyses at T0, T2, T4, and T9 are presented in Table 3. Microbiological criteria for food products established by Brazilian resolution (Brasil 2001) demand the analysis of *Salmonella* sp. and thermotolerant coliforms for MPV. The results in this study for the entire storage period agree with the established parameters, which are the absence of *Salmonella* sp. in 25 g of product and up to 10^2 MPN g^{-1} of thermotolerant coliforms.

Microbiological determinations of psychrophiles and fungi were performed to complement the evaluation of the microbiological condition of MPV. Differences regarding the continued growth of these microorganisms during refrigeration were not observed between samples covered with film and PVC. Therefore, the type of lid material had no influence on microbial growth. It is worth noting that microbial counts and other analyses were checked until the vegetables reached a sensorial threshold, considering the formation of off-odors, mucilaginous material accumulation, and loss of texture of the covered samples. Therefore, the cucumber samples were analyzed until the fourth day of storage while the carrot and beetroot samples until the ninth day. It is known that cucumber is perishable and deteriorates rapidly, owing to its higher moisture content (around 95%) when compared to carrot (around 90%) and beetroot (around 86%). Besides that, after being processed, cucumber releases more exudate than the other vegetables due to the greater fragility of the plant tissue. During the storage period, it presents high dehydration, oil loss, and yellowing, provoked usually for stress, cold lesion, ethylene exposure, or enzyme activity (Olawuyi et al. 2019; Patel and Panigrahi 2019; Al-Juhaimi et al. 2012).

Weight loss

The weight loss gradually increased over the period for all samples (Fig. 5). The film was efficient as a barrier for the water loss of MPV, once uncovered samples presented higher dehydration rates. However, compared to samples covered with PVC, film-covered vegetables presented significantly higher values of weight loss. This is probably because persimmon film has a WVP higher than PVC, which is 0.09×10^{-6} g

Fig. 3 The TGA curve of persimmon films (the onset, 1st and 2nd points): F1 (formulated using 1:0 persimmon:water, 0 g kg^{-1} of pectin and glycerol); F2 (formulated using 0.75:0.25 persimmon:water, 15 g kg^{-1} of pectin, and 20 g kg^{-1} glycerol); and F3 (formulated using 1:0 of persimmon:water, 30 g kg^{-1} of pectin and 40 g kg^{-1} of glycerol)
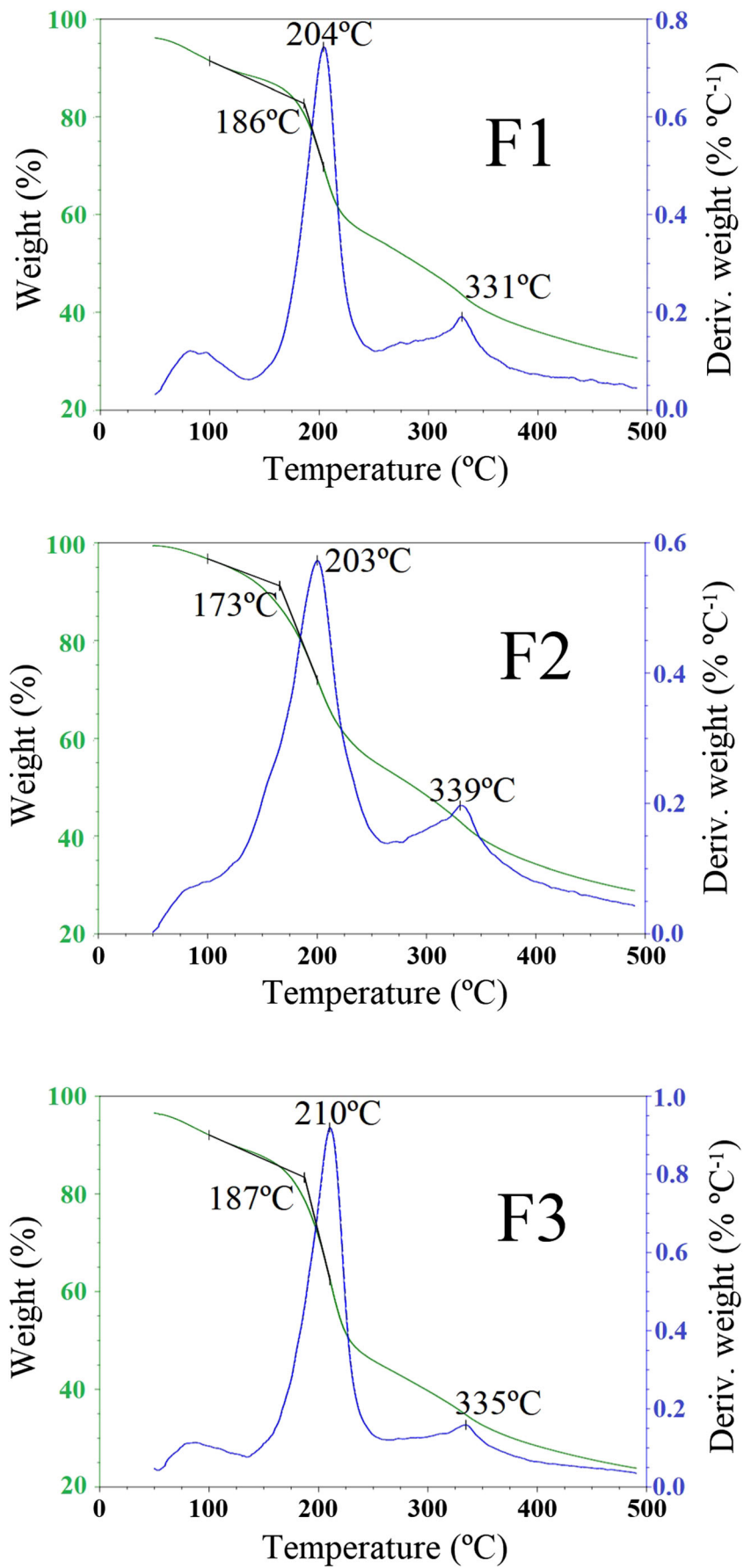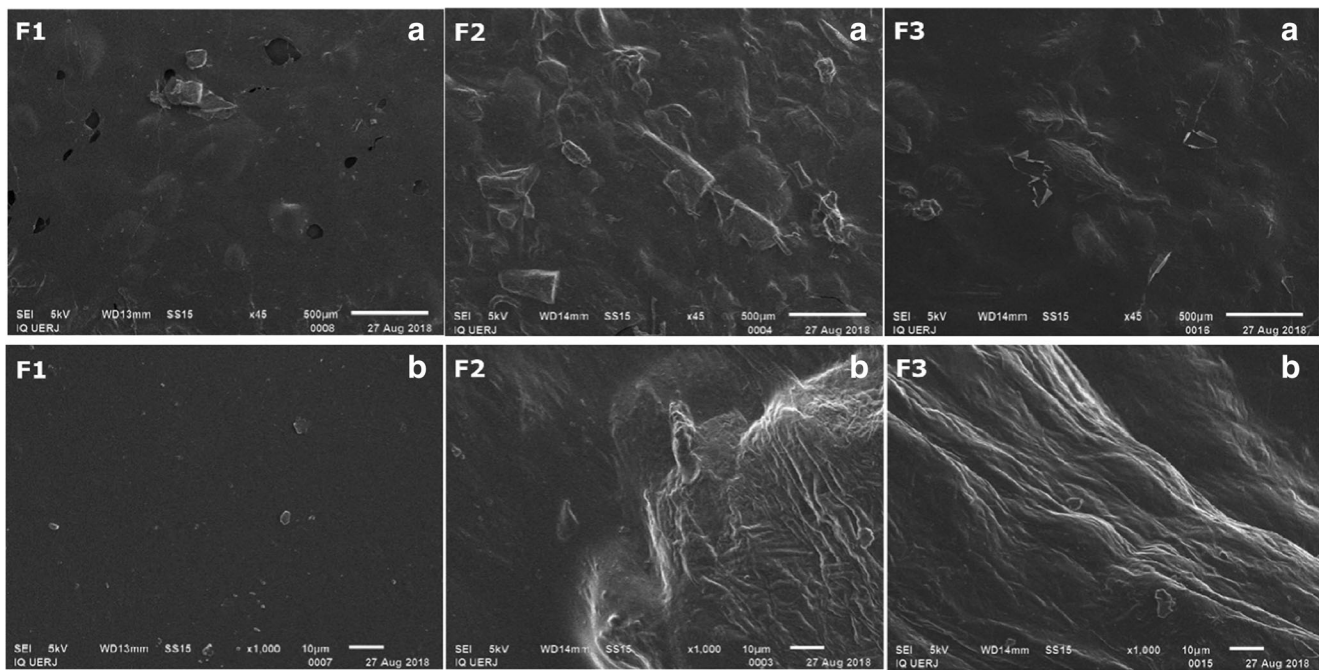
Fig. 4 Scanning electron microscopy images of the surface of biodegradable films using a ×45 (**a**) and ×1000 magnitude (**b**). F1 (formulated using 1:0 persimmon:water, 0 g kg^{-1} of pectin and glycerol); F2 (formulated using 0.75:0.25 persimmon:water, 15 g kg^{-1} of pectin, and 20 g kg^{-1} glycerol); and F3 (formulated using 1:0 of persimmon:water, 30 g kg^{-1} of pectin and 40 g kg^{-1} of glycerol)

Table 3 Evolution of the population of microorganisms (psychrophiles, fungi, thermotolerant coliforms, and *Salmonella* sp.) for minimally processed vegetables (cucumber, carrot, and beetroot) with different covers (persimmon film—F2 and PVC) and uncovered samples (UN) throughout storage at 4 °C

Microorganisms	Samples	Storage time (days)			
		0	2	4	9
Cucumber					
Psychrophiles	F2	< 2.00^c	4.78 ± 0.11^b	6.94 ± 0.65^a	–
(log CFU g^{-1})	PVC	< 2.00^c	6.07 ± 0.21^b	7.70 ± 0.22^a	–
Fungi	F2	< 2.00^c	4.85 ± 0.19^b	7.12 ± 0.13^a	–
(log CFU g^{-1})	PVC	< 2.00^c	6.07 ± 0.10^b	8.21 ± 0.05^a	–
Thermotolerant coliforms (MPN g^{-1})	F2	< 3.00	< 3.00	< 3.00	–
	PVC	< 3.00	< 3.00	< 3.00	–
Salmonella sp.	F2	Absence	–	–	–
(25 g)	PVC	Absence	–	–	–
Carrot					
Psychrophiles	F2	< 2.00^c	5.95 ± 0.09^b	7.44 ± 0.43^a	7.95 ± 0.07^a
(log CFU g^{-1})	PVC	< 2.00^c	6.67 ± 0.30^b	7.65 ± 0.33^a	8.21 ± 0.27^a
Fungi	F2	< 2.00^c	5.92 ± 0.27^b	7.28 ± 0.25^a	7.79 ± 0.04^a
(log CFU g^{-1})	PVC	< 2.00^c	6.90 ± 0.06^b	7.64 ± 0.21^a	7.99 ± 0.08^a
Thermotolerant coliforms	F2	< 3.00	< 3.00	< 3.00	< 3.00
(MPN g^{-1})	PVC	< 3.00	< 3.00	< 3.00	< 3.00
Salmonella sp.	F2	Absence	–	–	–
(25 g)	PVC	Absence	–	–	–
Beetroot					
Psychrophiles	F2	< 2.00^d	5.31 ± 0.21^c	6.39 ± 0.21^b	8.72 ± 0.07^a
(log CFU g^{-1})	PVC	< 2.00^d	5.14 ± 0.16^c	6.63 ± 0.12^b	8.54 ± 0.24^a
Fungi	F2	< 2.00^d	4.95 ± 0.45^c	6.08 ± 0.08^b	8.26 ± 0.14^a
(log CFU g^{-1})	PVC	< 2.00^d	4.82 ± 0.05^c	6.30 ± 0.27^b	8.05 ± 0.58^a
Thermotolerant coliforms	F2	< 3.00	< 3.00	< 3.00	160.00
(MPN g^{-1})	PVC	< 3.00	< 3.00	< 3.00	93.00
Salmonella sp.	F2	Absence	–	–	–
(25 g)	PVC	Absence	–	–	–

Results were expressed as a mean ± standard deviation of three replicates. Values in the line followed by different lowercase letters and values in the column followed by different upper case letters differ statistically from each other, for each MVP and parameters (Tukey, $p < 0.05$)
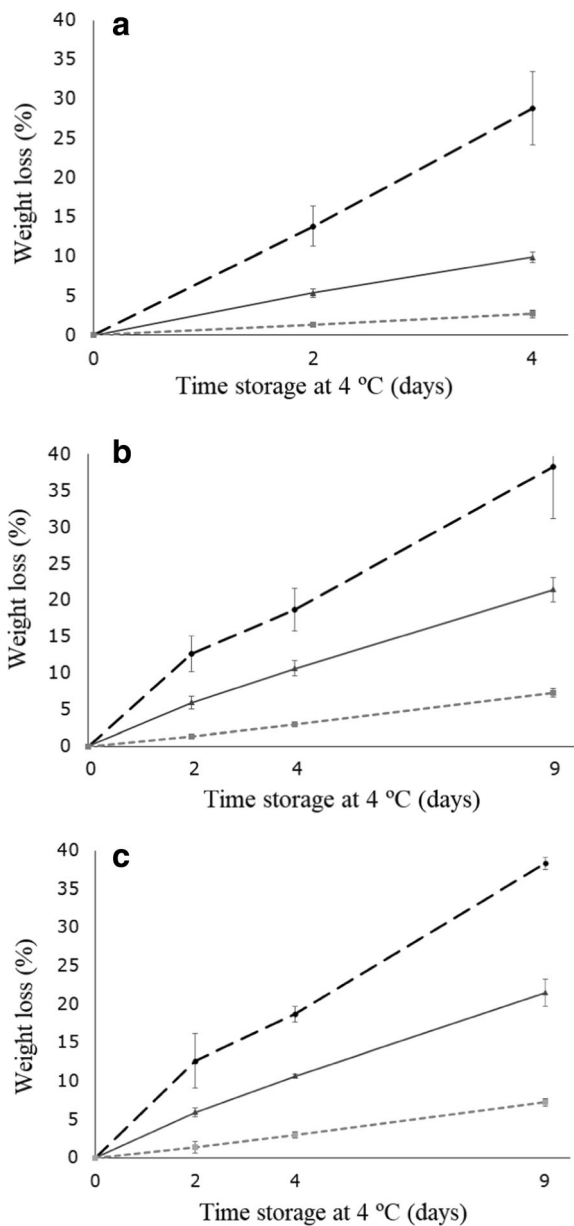
—●—Uncovered —▲—Covered with film --■--Covered with PVC

Fig. 5 Change in physiological weight loss for minimally processed cucumber (a), carrot (b), and beetroot (c) uncovered and covered with persimmon film and PVC throughout storage at 4 °C. Error bars represent the standard deviation of three replicates

h^{-1} m^{-1} Pa^{-1} (Kaewprachu et al. 2016), allowing greater respiration and moisture evaporation from MPV. Similar behavior was found in other studies (Robles-Flores et al. 2018; Fai et al. 2016; Ferreira et al. 2016; Al-Juhaimi et al. 2012). Considering the importance of biodegradability of this persimmon film, additional efforts should be taken to improve resistance to mass transfer by adding other materials, such as lipophilic surfactants (Comaposada et al. 2018; Senturk Parreidt et al. 2018).

pH and color

Significant pH differences were found throughout the storage period for covered and uncovered samples (Table 4). The results found in this work are supported by other studies (Becaro et al. 2016; Leceta et al. 2015). There was an increase in pH for cucumber and carrot samples. This may be due to the natural maturation process that promotes the degradation of organic acids, observed in other studies (Rojas-Bravo et al. 2019; Ferreira et al. 2016; Stülp et al. 2012). It is possible to note that the uncovered carrot presented a more pronounced increase in pH than covered carrot samples (on the 9th day), which might be related to the lower water loss in covered vegetables (Hernández-Muñoz et al. 2006). In the case of beetroot, specifically for samples covered with film and PVC, a reduction in pH occurred (on the 9th day), which may be associated with the consumption of these acids during vegetable transpiration and respiration (Stülp et al. 2012).

The color indices are shown in Table 4 and Fig. 6. For covered samples, the L^* value did not show significant oscillation over time. As expected, ΔE^* values were appreciable, presenting a trend of increased color difference at the end of the storage period, mainly for beetroot. All vegetables (covered or uncovered) showed a decrease in color saturation. The WI^* increased for carrots and beetroots throughout the storage period. The processed carrots tend to discolor due to surface dehydration (Cisneros-Zevallos, Saltveit & Krochta 1997); a similar mechanism of depigmentation over time was observed for the beetroot. Uncovered beetroot samples oscillated significantly, while covered samples, despite WI^* increasing, were more stable over time. On the ninth day, uncovered samples obtained a higher value of WI^*, and the samples covered with PVC and with the film were similar.

Conclusion

Persimmon puree proved to be a suitable and promising raw material for the formulation of an edible, malleable, orangeish, and biodegradable film by casting technique. As far as we know, this is the first study reporting the development of a film based on persimmon puree and its application as a lid for fresh-cut vegetable packaging. Vegetable samples covered with persimmon film and PVC did not differ significantly from each other regarding microbial population evolution, pH parameters, and optical properties. Those covered with PVC presented lower values of weight loss than those with persimmon film. This result indicates that the incorporation of hydrophobic components in the polymeric matrix might be an interesting strategy to confront this issue. It is noteworthy that the film, unlike synthetic PVC, is biodegradable and edible, being a trend for the food packaging area, since there are a growing environmental concern and greater demand for

Table 4 The pH analysis, and colorimetric parameters ($L*$, $a*$, $b*$, $\Delta E*$, and chroma—$C*$) for minimally processed vegetables (cucumber, carrot, and beetroot) with different covers (persimmon film—F2 and PVC) and uncovered samples (UN) throughout storage at 4 °C

Parameters	Samples	Storage time (days)			
		0	2	4	9
Cucumber					
pH	UN	5.95 ± 0.05[bA]	6.13 ± 0.07[aA]	6.16 ± 0.03[aA]	–
	F2	5.95 ± 0.05[bA]	6.15 ± 0.08[aA]	6.18 ± 0.02[aA]	–
	PVC	5.95 ± 0.05[bA]	6.02 ± 0.06[a,bA]	6.10 ± 0.01[aB]	–
$L*$	UN	48.78 ± 4.60[aA]	55.15 ± 3.01[aA]	52.24 ± 0.64[aA,B]	–
	F2	48.78 ± 4.60[aA]	49.07 ± 3.99[aA]	52.63 ± 4.46[aA]	–
	PVC	48.78 ± 4.60[aA]	51.24 ± 2.43[aA]	45.19 ± 2.04[aB]	–
$a*$	UN	−7.95 ± 0.89[aA]	−8.53 ± 0.24[aA]	−5.11 ± 0.31[bB]	–
	F2	−7.95 ± 0.89[aA]	−6.15 ± 1.32[aB]	−6.04 ± 0.30[aA,B]	–
	PVC	−7.95 ± 0.89[aA]	−6.09 ± 0.30[bB]	−6.36 ± 0.53[bA]	–
$b*$	UN	13.38 ± 2.02[a,bA]	14.41 ± 1.31[aA]	9.49 ± 1.60[bB]	–
	F2	13.38 ± 2.02[aA]	12.66 ± 2.01[aA]	14.02 ± 0.80[aA]	–
	PVC	13.38 ± 2.02[aA]	10.97 ± 0.75[a,bA]	8.90 ± 1.03[bB]	–
$\Delta E*$[1]	UN	–	LD	AD	–
	F2	–	AD	AD	–
	PVC	–	AD	LD	–
$C*$	UN	15.57±2.14[aA]	16.75±1.25[aA]	10.81±1.28[bB]	–
	F2	15.57±2.14[aA]	14.18±1.15[aB]	15.27±0.67[aA]	–
	PVC	15.57±2.14[aA]	12.56±0.54[a,bB]	10.96±0.90[bB]	–
Carrot					
pH	UN	5.96 ± 0.07[cA]	6.05 ± 0.05[cA]	6.20 ± 0.03[bA]	6.27 ± 0.02[a,bA]
	F2	5.96 ± 0.07[bA]	5.99 ± 0.05[bA]	6.23 ± 0.06[aA]	6.10 ± 0.03[a,bB]
	PVC	5.96 ± 0.07[b,cA]	5.81 ± 0.07[cB]	6.12 ± 0.06[aA]	6.09 ± 0.03[a,bB]
$L*$	UN	51.48 ± 1.47[bA]	54.71 ± 2.42[a,bA]	56.29 ± 2.71[aA]	53.66 ± 1.53[a,bA]
	F2	51.48 ± 1.47[bA]	54.96 ± 2.18[a,bA]	55.74 ± 0.83[aA]	54.65 ± 1.96[a,bA]
	PVC	51.48 ± 1.47[bA]	56.17 ± 1.12[aA]	54.90 ± 2.02[a,bA]	55.27 ± 2.11[a,bA]
$a*$	UN	16.18 ± 1.08[aA]	18.46 ± 2.21[aA]	17.96 ± 1.17[aA]	16.97 ± 0.64[aA]
	F2	16.18 ± 1.08[aA]	17.25 ± 1.36[aA]	17.21 ± 1.76[aA]	15.46 ± 1.38[aA]
	PVC	16.18 ± 1.08[a]	17.51 ± 0.45[aA]	15.75 ± 2.10[aA]	15.75 ± 1.60[aA]
$b*$	UN	25.93 ± 3.01[aA]	27.60 ± 4.16[aA]	26.44 ± 3.22[aA]	20.45 ± 0.73[aA]
	F2	25.93 ± 3.01[aA]	26.33 ± 1.71[aA]	26.32 ± 1.40[aA]	23.18 ± 1.85[aA]
	PVC	25.93 ± 3.01[aA]	27.38 ± 1.60[aA]	27.77 ± 1.48[aA]	25.87 ± 3.55[aA]
$\Delta E*$[1]	UN	–	LD	AD	LD
	F2	–	ND	AD	AD
	PVC	–	AD	AD	AD
$C*$	UN	30.59±2.84[aA]	33.21±4.68[aA]	31.97±3.24[aA]	26.57±0.91[aA]
	F2	30.59±2.84[aA]	26.57±0.91[aA]	31.45±2.14[aA]	27.87±2.29[aA]
	PVC	30.59±2.84[aA]	32.50±1.57[aA]	31.94±2.29[aA]	30.29±3.87[aA]
Beetroot					
pH	UN	6.02 ± 0.17[aA]	6.12 ± 0.07[aA]	6.16 ± 0.05[aB]	6.13 ± 0.05[aA]
	F2	6.02 ± 0.17[a,bA]	5.94 ± 0.04[b,cB]	6.20 ± 0.05[aA,B]	5.75 ± 0.02[cB]
	PVC	6.02 ± 0.17[bA]	6.12 ± 0.07[a,bA]	6.28 ± 0.03[aA]	5.65 ± 0.08[cB]
$L*$	UN	24.28 ± 0.47[dA]	27.71 ± 0.72[cA]	29.57 ± 0.75[bA]	35.66 ± 0.53[aA]
	F2	24.28 ± 0.47[dA]	26.09 ± 0.69[cA]	28.56 ± 0.78[bA]	33.27 ± 0.49[aB]
	PVC	24.28 ± 0.47[cA]	26.41 ± 1.98[b,cA]	29.53 ± 1.01[bA]	33.07 ± 1.02[aB]
$a*$	UN	5.86 ± 0.33[bA]	4.87 ± 0.68[bA]	4.93 ± 0.44[bA,B]	10.45 ± 0.53[aA]
	F2	5.86 ± 0.33[aA]	5.29 ± 0.53[aA]	6.28 ± 0.54[aA]	6.83 ± 0.87[aC]
	PVC	5.86 ± 0.33[bA]	6.15 ± 0.49[bA]	4.18 ± 0.74[cB]	8.56 ± 0.45[aB]
$b*$	UN	0.64 ± 0.16[bA]	0.49 ± 0.08[bA]	0.28 ± 0.19[bB]	2.47 ± 0.36[aA]
	F2	0.64 ± 0.16[bA]	0.61 ± 0.16[bA]	1.14 ± 0.11[aA]	1.18 ± 0.05[aB]
	PVC	0.64 ± 0.16[bA]	0.60 ± 0.26[bA]	0.55 ± 0.52[bA,B]	2.51 ± 0.50[aA]
$\Delta E*$[1]	UN	–	AD	AD	VOD
	F2	–	ND	AD	LD
	PVC	–	SD	AD	LD
$C*$	UN	5.90±0.34[bA]	4.90±0.67[bA]	4.94±0.45[bA,B]	10.74±0.56[aA]
	F2	5.90±0.34[a,bA]	5.33±0.55[bA]	6.39±0.55[a,bA]	6.93±0.85[aC]
	PVC	5.90±0.34[bA]	6.18±0.50[bA]	4.24±0.77[cB]	8.93±0.30[aB]

Results were expressed as a mean ± standard deviation of three replicates. Values in the line followed by different lowercase letters and values in the column followed by different upper case letters differ statistically from each other, for each MVP and parameters (Tukey, $p < 0.05$). [1] Legend for total color difference ($\Delta E*$): 0–0.5 (trace level difference (TLD)), 0.5–1.5 (slight difference (SD)), 1.5–3.0 (noticeable difference (ND)), 3.0–6.0 (appreciable difference (AD)), 6.0–12.0 (large difference (LD)), and > 12.0 (very obvious difference (VOD)). "–" means not determined

Fig. 6 Whiteness index of minimally processed carrot (a) and beetroot (b) uncovered and covered with persimmon film and PVC throughout storage at 4 °C. Error bars represent the standard deviation of three replicates. Different lowercase letters differ statistically from each other, for each analysis day
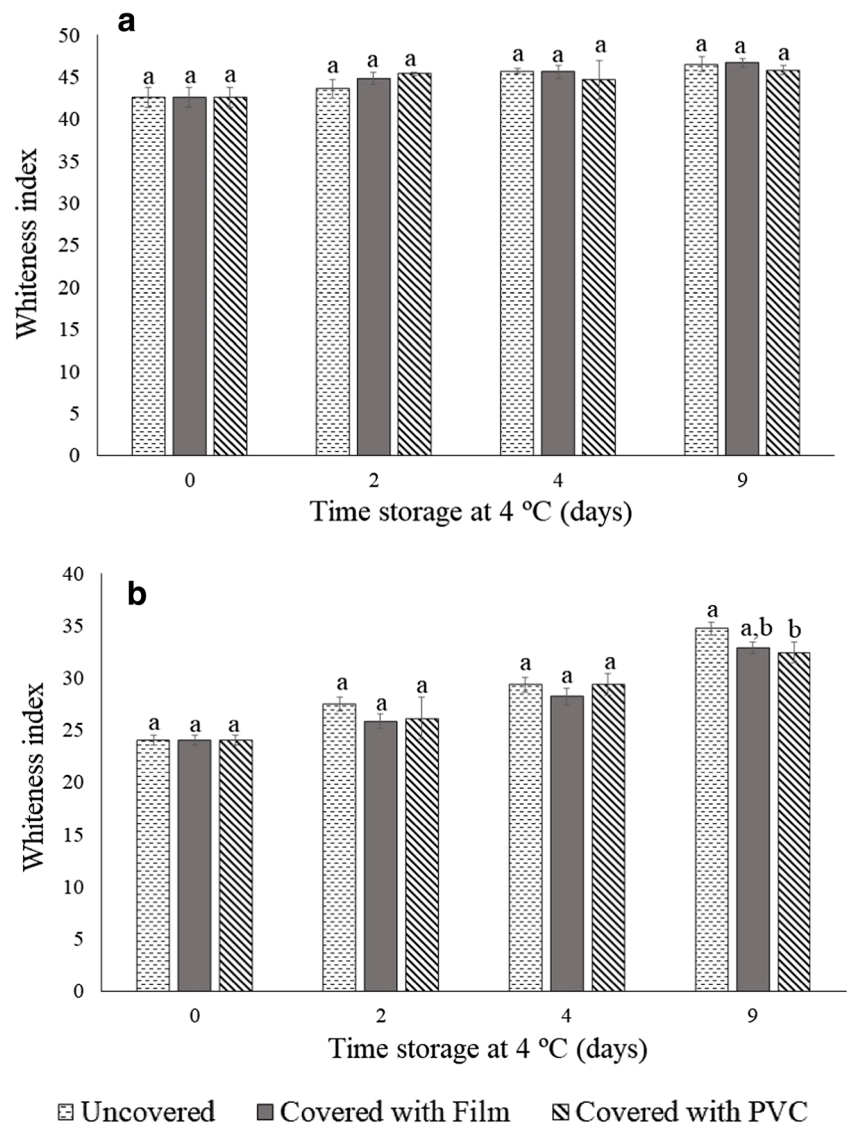
technology in the context of the circular economy. Thus, the films produced in this study seem to be a promising alternative as biodegradable lids for fresh food packaging.

Declarations

Conflict of Interest The authors declare no competing interests.

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