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Effects of Yam Starch Films on Storability and Quality of Fresh Strawberries (*Fragaria ananassa*)

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Yam starch films, formulated with yam starch (4.00 g/100 g of solution) and glycerol (1.30 and 2.00 g/100 g of solution) in filmogenic solution, were employed as packaging to extend storage life of strawberries stored at 4 °C and 85% RH. The effects of yam starch films on fruits were compared to the effect of PVC (poly(vinyl chloride)) packaging. Starch and PVC films significantly reduced decay of the fruits compared to control. Compared to starch films, PVC presented the better behavior on weight and firmness retention of fruits, especially in the last 7 days of storage. Considering microbiological counts, the shelf life of control fruits was 14 days, and of all packaged samples, stored at same conditions, was 21 days. Two different formulations of yam starch film were tested and had different mechanical properties as a function of glycerol content (1.30 and 2.00 g/100 g of solution) but showed no difference when employed as strawberries packaging.

KEYWORDS: ***Fruit, edible films; and packaging***

1. INTRODUCTION

Among the berry species, the strawberry has received the best commercial development in recent years, but, according to Maas (*1*), is highly perishable and its storage life is often terminated by fungal infection caused by *Botrytis cinerea* and *Rhizopus.* The most prevalent method of maintaining quality and controlling decay of strawberries is by rapid cooling after harvest and storage at low temperatures ranging from 0 to 4 °C, with high humidity. Since effective control of temperature during transit and storage of strawberries is difficult, other means of preservation have been sought (*2, 3*).

Postharvest decay of strawberries can also be controlled by application of fungicides; however, they leave residues and can affect sensorial and nutritive values of fresh fruit. Additionally, the consumers are choosing natural products, and this has been beneficial for the success of ready-to-eat products, in a freshlike state, termed “minimally processed fruits and vegetables”.

The application of edible coatings to improve shelf life of fruits and vegetables has been reported frequently in last years; on other hand, the use of edible films in packaging of fruits and vegetables is not covered in the specialized literature. To make coatings, the film-forming solution is applied and formed over the product, while, to make films, the solution is applied and dried over an adequate support to obtain a thin and flexible material (*4, 5*).

Several researchers have studied the application of coatings to vegetables such as tomato, cucumber, and red peppers (*2*) and fruits such as apples (*6*) and mangoes (*7*). El Ghaouth, Arul, Ponnampalam, and Boulet (*2*) applied a chitosan coating to strawberry fruits that resulted in a decreased respiration rate of the berries. García, Martino, and Zaritzky (*8*) reported that the storage life of strawberries was extended from 14 to 21 days in fruits that were treated with a starch−glycerol-based coating.

Hydrophilic starch films provide under certain conditions of relative humidity (RH) and temperature a good barrier to oxygen and carbon dioxide transmission but a poor barrier to water vapor (*4, 5*). These characteristics are favorable to quality preservation of fruits and vegetables, because they lead to a reduction in respiration rate by limiting exposure to ambient oxygen and increasing internal carbon dioxide, thus retarding ripening. The poor water vapor barrier allows movement of water across the film, thus preventing water condensation that can be a potential source of microbial spoilage in soft vegetables (*9*).

Yam starch (*Dioscorea alata*) contains about 30% of amylose, and this is important for film production because amylose is responsible for the film-forming capacity of starches. Yam starch films were described as films with a homogeneous matrix, with stable structure at ambient conditions and a poor water vapor barrier compared with synthetic materials, which could be promising in the postharvest conservation of fruits and vegetables (*10*).

The objectives of this work were to analyze the effect of yam starch films on strawberry quality attributes (texture, weight loss, and microbial growth) and on postharvest parameters (pH, titratable acidity, soluble solids, and anthocyanin content).

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2. MATERIALS AND METHODS

2.1. Yam Starch Extraction. Fresh tubers of yam (*Dioscorea alata*), with uniform size and shape, without any mechanical and pathological injuries, were obtained from a local farm (Londrina, PR, Brazil). Yam starch was extracted according to Alves, Grossmann, and Silva (*11*). Amylose and amylopectin content of yam starch was determined simultaneously by the Landers, Gbur, and Sharp (*12*) method.

2.2. Film Preparation. Two different yam starch film formulations were tested for strawberries packaging and were chosen from preliminary studies (*10*) because they showed satisfactory mechanical properties for this purpose. The two filmogenic solution formulations selected were (a) 4.00 g of yam starch/100 g of solution and 1.30 g of glycerol/100 g of solution and (b) 4.00 g of yam starch/100 g of solution and 2.00 g of glycerol/100 g of solution. The films were prepared by casting; yam starch and glycerol were directly mixed with distilled water to make batches with a total weight of 500 g. The filmogenic solutions were transferred quantitatively to the cup of a Brabender Viscograph Pt 100 (OHG, Duisburg, Germany), and they were heated from 30 to 95 °C at a constant heating rate (3 °C/min) and maintained at 95 °C for 10 min, with regular shaking (75 rpm). Gelatinized suspensions were immediately poured on rectangular acrylic plates (20 × 20 cm). For each experiment, the quantity of starch suspension poured onto the plate was calculated to obtain a constant weight of dried matter of approximately 12.25 mg/cm^2, resulting in films of 0.11 mm thickness and a mean standard deviation within the film of about 5% of the average thickness. The starch suspensions were dried (65 °C) in a ventilated oven model TE-394-3 (Tecnal, Piracicaba, SP, Brazil) to constant weight (about 3 h). The result was translucent films, which can be easily removed from the plate. The films were equilibrated at 4 °C and a relative humidity (RH) of 64%, for 48 h, before being tested.

2.3. Characterization of Yam Starch Films. Yam starch films were characterized by scanning electron microscopy (SEM), water vapor permeability (WVP), and mechanical properties at the beginning and end of storage time of the fruits (30 days), and for these analyses, the films were stored at temperature of 4 °C and 64% RH.

SEM analyses were useful to give an insight into system microstructure and were performed with a JEOL JSPM 100 electron microscope (Japan). Film pieces were mounted on bronze stubs using a double-sided tape and then coated with a layer of gold (40−50 nm), allowing surface and cross section visualization. All samples were examined using an accelerating voltage of 5 kV.

WVP tests were conducted using ASTM (*13*) method E96 with some modifications. Each film sample was sealed over a circular opening of 0.00181 m^2 in a permeation cell that was stored at 25 °C in a desiccator. To maintain 75% RH gradient across the film, anhydrous calcium chloride (0% RH) was placed inside the cell, and a sodium chloride saturated solution (75% RH) was used in the desiccator. The RH inside the cell was always lower than the outside, and water vapor transport was determined from the weight gain of the permeation cell. After steady-state conditions were reached (about 2 h), the weight measurements were made at each 2 h, over 24 h. Changes in the weight of the cell were recorded to the nearest 0.0001 g and plotted as a function of time. The slope of each line was calculated by linear regression ($r^2 > 0.99$), and the water vapor transmission rate (WVTR) was calculated from the slope of the straight line (g/s) divided by the transfer area (m^2). After the permeation tests, film thickness was measured and WVP (g Pa^{-1} s^{-1} m^{-1}) was calculated as WVP = [WVTR/$S(R_1 - R_2)d$], where S is the saturation vapor pressure of water (Pa) at the test temperature (25 °C), R_1, the RH in the desiccator, R_2, the RH in the permeation cell, and d the film thickness (m). Under these conditions, the driving force [$S(R_1 - R_2)$] was 1753.55 Pa. All tests were conducted in duplicate.

Puncture tests were made to determine puncture strength (*N*) and deformation (mm) using a TA.TX2 Stable Micro Systems texture analyzer (Surrey, England). Samples with an initial dimension of 40 mm of diameter were analyzed; a cylindrical probe (5 mm of diameter) was moved perpendicularly at the film surface at a constant speed (1 mm/s) until it passed through the film. The force−deformation curves were recorded, and strength deformation values at the puncture point were used to determine hardness and deformation capacity of the films. For each run, the tests were conducted in four random positions of two different samples.

2.4. Packaging of the Fruits. Strawberries (*Fragaria ananassa* Duch, cv Dover) were harvested from a local farm (Londrina-PR, Brasil) and immediately treated. Fruits of uniform size and free of physical damage and fungal infection were used. Strawberries were dipped in chlorinated water (250 ppm Cl_2), dried at room temperature, and put in polypropylene trays (4 × 10 cm). Ten fruits were put in each tray, which was covered with the yam starch and PVC films. The yam starch films were sealed in the trays by a Sealing Machine at a temperature of 120 °C (Tecnal, São Paulo, Brazil) with the help of commercial glue. The fruits were submitted to four treatments: (1) control samples (unpackaged fruits), (2) samples packaged with PVC (poly(vinyl chloride)) film, (3) samples packaged with films formulated with 4.00 g of starch/100 g of solution and 1.30 g of glycerol/100 g of solution, and (4) samples packaged with films formulated with 4.00 g of starch/100 g of solution and 2.00 g of glycerol/100 g of solution. PVC film was tested because it is an important packaging used for fruits and vegetables and it is interesting to compare a synthetic and commercial material with new materials.

All the samples were stored in a biologic oxygen demand oven model TE-390 (Tecnal, Piracicaba, SP, Brazil), at 4 °C and 85% RH. In each experiment, 75 fruits were used for each treatment; thus, the experimental lot contained 300 fruits. The whole experiment with the corresponding determinations was repeated with two different lots of strawberries. Control samples and packaged samples were tested at same time.

2.5. Analysis of the Fruits. *2.5.1. Weight Loss.* A lot of 10 fruits was used to measure weight loss. The same fruits were weighted at the beginning of the experiment and at each 3 days during the storage of the samples. The results were expressed as percentage loss of initial weight. Two replicates were performed for each treatment.

2.5.2. Firmness. The compression force of strawberries was measured with a texture analyzer TA-TX2 Stable Micro Systems (Surrey, England). The fruits were cut longitudinally in two parts and compressed by a cylindrical probe (35 mm of diameter) with a crosshead speed of 2,5 mm/s, and the parameter considered was the maximum peak force at compression (*N*). The fruits were analyzed at the beginning of the experiment and at each 6 days during the storage of the samples. Eight replicates were performed for each treatment.

2.5.3. Anthocyanin Content. Anthocyanin content was determined according to the spectrophotometric method of Fuleki and Francis (*14*), in a Fento 482 spectrophotometer (São Paulo, Brazil), at a wavelength of 515 nm. Total anthocyanin content was expressed in mg of anthocyanins per 100 g of fruit. The fruits were analyzed at the beginning of the experiment and at each 6 days during the storage of the samples. Two replicates were performed for each treatment.

2.5.4. Titratable Acidity and pH. A Walitta mixer (São Paulo, Brasil) was used to obtain homogenates for titratable acidity and pH determinations, using five fruits for each test, according to the Instituto Adolfo Lutz procedure (*15*). Titratable acidity was expressed as percentage of citric acid. The fruits were analyzed at the beginning of the experiment and at each 6 days during the storage of the samples. Three replicates were performed for each treatment.

2.5.5. Soluble Solids. Soluble solids content was determined by AOAC (*16*) procedure with an Abbe refratometer (Germany). The fruits were analyzed at the beginning of the experiment and at each 6 days during the storage of the samples. Three replicates were performed for each treatment.

2.5.6. Microbiological Assays. Control and packaged samples were analyzed at 0, 7, 14, 22, and 28 days of storage at 4 °C for mesophilic and psychrotrophic microorganisms and for yeasts and molds. For each determination, samples of 25 g were homogenized, for 60 s, in a Stomacher Seward model 400 (England) with 250 mL of 10 g/L peptone water. Several dilutions (10^{-1} to 10^{-6}) were prepared from the homogenate with peptone water. Dilutions were performed in duplicate.

For mesophilic microorganism counts, 1 mL of each dilution was plated in PCA (plate count agar, Merck, Germany), and the plates were incubated at 37 °C for 2 days. For psychrotrophic microorganisms counts, 1 mL of each dilution was plated in PCA (plate count agar, Merck, Germany), and the plates were incubated at 10 °C for 10 days.

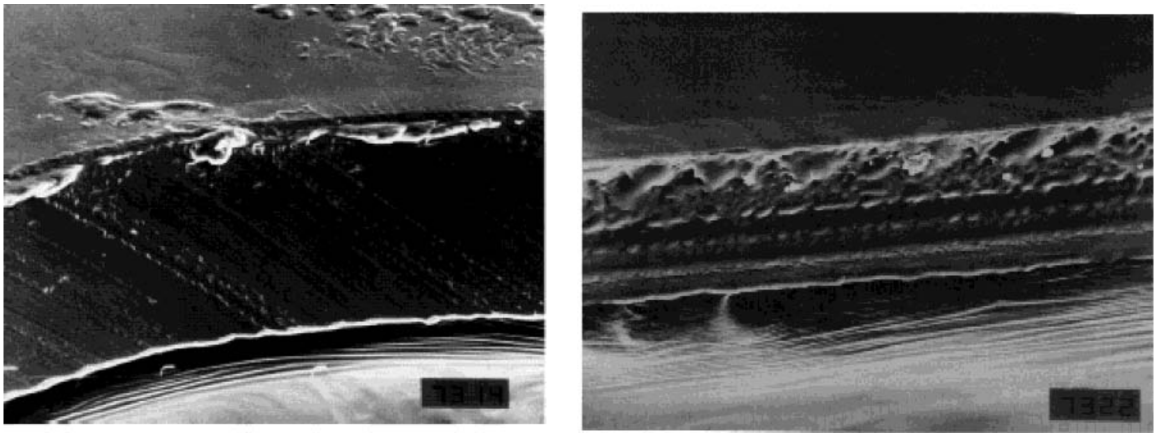

Figure 1. SEM micrographs of cross-section of yam starch films formulated as (a) 4.00 g of starch/100 g of solution and 1.30 g of glycerol/100 g of solution; (b) 4.00 g of starch/100 g of solution and 2.00 g of glycerol/100 g of solution. Magnification: 100 μm between marks.

Table 1. Water Vapor Permeability (WVP) and Mechanical Properties of Yam Starch Films[a]

film formulation		WVP × 10^{10} ($\mathrm{g\ m^{-1}\ s^{-1}\ Pa^{-1}}$)[b]		mechanical properties[b]			
				puncture strength (*N*)		puncture deformation (mm)	
yam starch (g/100 g solution)	glycerol (g/100 g solution)	0 days	30 days	0 days	30 days	0 days	30 days
4.00	1.30	1.599 aA (0.230)	1.585 aA (0.256)	14.60 aA (1.07)	17.42 aB (1.02)	3.73 aA (0.28)	3.57 aA (0.45)
4.00	2.00	1.750 aA (0.205)	1.680 aA (0.289)	12.09 bA (0.99)	12.52 bA (0.53)	4.56 bA (0.21)	4.63 bA (0.35)

[a] Samples stored at 4 °C and 64% RH. [b] Means at same line with different capital letters are significantly different (*t* test, $p \leq 0.05$); means at same column with different small letters are significantly different (*t* test, $p \leq 0.05$). Numbers in bold are the standard deviation of each analysis.

For yeast and mold counts, 1 mL of each dilution was plated in PDA (potato dextrosed agar, Merck, Germany), and the plates were incubated at 25 °C for 5 days. Viable counts were expressed as log colony-forming units (CFU) per gram of fruit.

2.5.7. Statistical Analysis. Analysis of variance (ANOVA), Tukey mean comparison test ($p \leq 0.05$), and regression analysis were performed employing Statistica software (Statsoft).

3. RESULTS AND DISCUSSION

3.1. Characterization of Yam Starch Films. SEM observations did not show differences among the samples containing different concentrations of plasticizer (**Figure** 1a,b). Films presented smooth surfaces without pores or cracks, and a compact structure. The homogeneous matrix of films is a good indicator of their structural integrity and consequently good mechanical properties. The difference observed in the cross-section of the films occurred because, in **Figure 1a**, the film piece was cut with a pair of scissors, and in **Figure 1b**, the piece was torn to mount the stub.

As seen in **Table 1**, storage time (30 days/ 4 °C and 64% RH) did not modify WVP values ($p \leq 0.05$); increasing glycerol concentration did not produce significant ($p \leq 0.05$) differences in WVP, although a tendency to increase WVP of the films was observed. This tendency was reported in previous work (*10*) and could be related to structural modifications of the starch network that might cause it to become less dense, adding to the hydrophilic character of glycerol, which is favorable to adsorption and desorption of water molecules.

With regard to other synthetic polymers, yam starch films have WVP values slightly higher than those of cellophane (0.84×10^{-10} $\mathrm{g\ m^{-1}\ s^{-1}\ Pa^{-1}}$) and higher than low-density polyethylene (LPDE) (0.0036×10^{-10} $\mathrm{g\ m^{-1}\ s^{-1}\ Pa^{-1}}$) (*17*). However, yam starch film permeabilities were lower than those of other edible and biodegradable films such as wheat gluten plasticized with glycerol (7.00×10^{-10} $\mathrm{g\ m^{-1}\ s^{-1}\ Pa^{-1}}$), amylose ($3.80 \times 10^{-10}$ $\mathrm{g\ m^{-1}\ s^{-1}\ Pa^{-1}}$), and hydroxypropylmethylcellulose with plasticizer and oil (1.90×10^{-10} $\mathrm{g\ m^{-1}\ s^{-1}\ Pa^{-1}}$) (*18*).

Puncture strength decreased with increase of glycerol content on film formulation, at the beginning and at the end of storage time (30 days) and increased significantly with storage time ($p \leq 0.05$) only in the sample with 1.30 g of glycerol/100 g of solution. Storage time (30 days) did not modify puncture deformation values ($p \leq 0.05$), and increasing glycerol concentration in the film formulation produces a significant ($p \leq 0.05$) increase in deformation values (**Table 1**). The increase of puncture deformation and the decrease of puncture strength with increasing glycerol content in hydrophilic films have been reported previously (*19*−*21*). According to McHugh and Krochta (*22*), plasticizers are expected to decrease intermolecular forces along polymers chains, imparting increased film flexibility while decreasing barrier properties.

3.2. Analyses of the Fruits. *3.2.1. Weight Loss.* Weight loss of strawberries increased as a function of storage time for both control and packaged fruits (**Figure 2**), but the weight losses of control fruits were significantly higher than the treated fruits. PVC packaging showed the more efficient effect of reducing weight loss; fruits packaged with the two formulations of yam starch presented an intermediary behavior and did not show a difference among them. The results show that PVC and yam starch films provided a beneficial effect on the weight loss of strawberries.

3.2.2. Firmness. The most perceptible changes occurring in fruits and vegetables during prolonged storage are texture loss and changes in appearance, and these changes are related to metabolic changes and water content. The rate and extension of firmness loss during ripening of soft fruits, such as strawberries, is one of the main factors that determine fruit quality

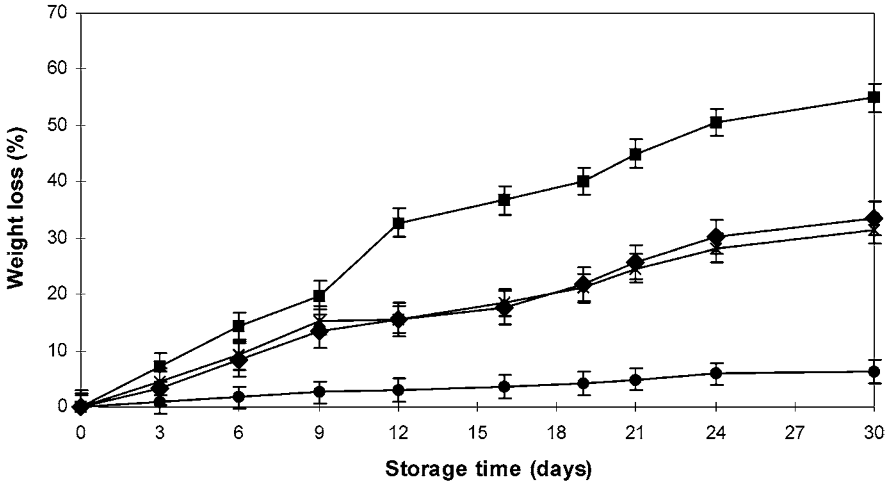

Figure 2. Effect of packaging on weight loss of strawberries stored at 4 °C/85% RH and packaged with (■) control (without packaging), (●) PVC film, (∗) yam starch film formulated with 4.00 g of starch/100 g of solution and 1.30 g of glycerol/100 g of solution, and (♦) 4.00 g of starch/100 g of solution and 2.00 g of glycerol/100 g of solution. Vertical bars represent standard error values.

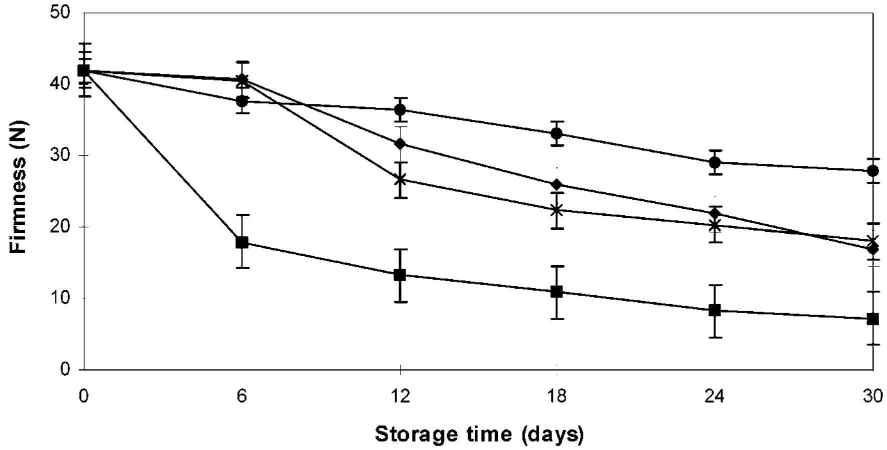

Figure 3. Effect of packaging on firmness of strawberries stored at 4 °C/85%RH and packaged with: (■) control (without packaging); (●) PVC film; (∗) yam starch film formulated with 4.00 g of starch/100 g of solution and 1.30 g of glycerol/100 g of solution and (♦) 4.00 g of starch/100 g of solution and 2.00 g of glycerol/100 g of solution. Vertical bars represent standard error values.

and postharvest shelf life. Fruit softening is attributed to the degradation of cell wall components, mainly pectins, due to the action of specific enzyme activity such as polygalacturonase (*8*, *23*).

Firmness decreased as a function of storage time for both control and packaged fruits (**Figure 3**). Yam starch and PVC films showed a beneficial effect on firmness retention; fruits packaged with PVC showed better firmness retention while the fruits packaged with yam starch films did not show a difference among them. These data correlate well with weight loss data, showing that PVC film was more effective on water and texture retention.

The better behavior of PVC film on weight and firmness retention, compared to yam starch films, could be explained as a result of its water vapor permeability (0.0124×10^{-10} g m^{-1} s^{-1} Pa^{-1}) (*24*), which is approximately 140 times lower than values showed by yam starch films in this work. As result of a lower WVP, the PVC film offered a larger resistance to water vapor and gas transmission during the entire storage time, while the fruits remained in a saturated internal atmosphere, and this factor contributed to the weight and firmness retention.

3.2.3. Anthocyanin Content. The anthocyanins form the red and blue colors of most fruits and vegetables and provide, therefore, the attractive colors of derived products (*25*). Two anthocyanin glycosides, pelargonidin-3-glucoside (P 3-gl) and cyanidin-3-glucoside (Cy 3-gl), are most exclusively responsible for the color of strawberries. These pigments can accumulate after harvest, improving the appearance of underripe fruit; however, continued color development of red fruit could be detrimental to color quality (*26*).

Figure 4 illustrates the changes in the anthocyanin content during storage (4 °C and 85% RH) of control and packaged fruits. All fruits exhibited a similar behavior: anthocyanin content increased with time, reaching a maximum at 24 days of storage and then decreasing; similar results were cited by other researches (*2*, *8*). Control fruits showed the highest anthocyanin content and the fruits packaged with PVC film the lowest. Yam starch films showed an intermediary behavior, and the film formulated with 1.30 g of glycerol/100 g of solution was better in color retention.

The increase of anthocyanins as a function of storage time could be explained as a natural process during the maturation of the fruits, besides the effect of weight loss that could have contributed to a concentration of the pigments. However, when the weight loss is particularly high, the water loss can create morphological changes that will affect color quality. According

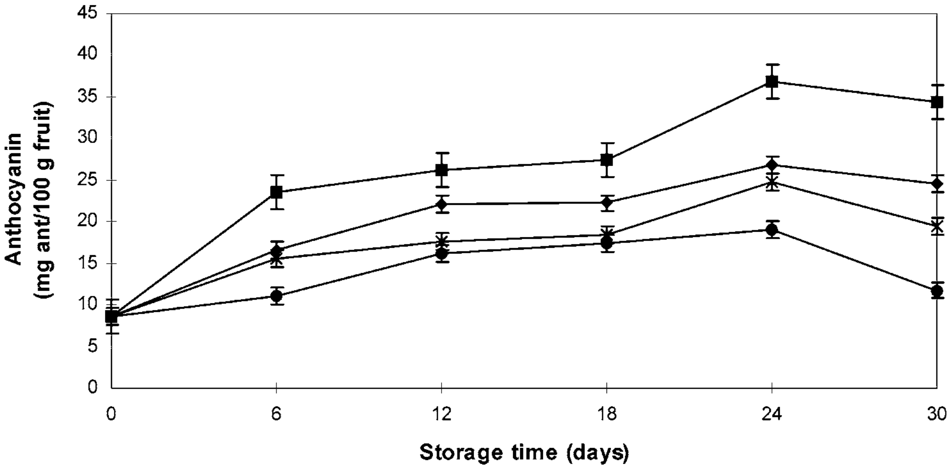

Figure 4. Effect of packaging on anthocyanin content of strawberries stored at 4 °C/85% RH and packaged with (■) control (without packaging), (●) PVC film; (∗) yam starch film formulated with 4.00 g of starch/100 g of solution and 1.30 g of glycerol/100 g of solution, and (♦) 4.00 g of starch/100 g of solution and 2.00 g of glycerol/100 g of solution. Vertical bars represent standard error values.

Table 2. Titratable Acidity, pH, and Soluble Solids on Control and Packaged Strawberry Fruits

		storage time at 4°C in days					
parameter	samples[d]	0	6	12	18	24	30
pH[a]	1	3.26 aA (0.01)	3.34 aB (0.00)	3.45 bC (0.02)	3.46 bC (0.02)	3.45 bC (0.02)	3.46 bC (0.02)
	2	3.26 aA (0.01)	3.34 aB (0.02)	3.37 aBC (0.02)	3.40 aC (0.02)	3.40 aC (0.02)	3.41 aC (0.02)
	3	3.26 aA (0.01)	3.34 aB (0.02)	3.36 aB (0.02)	3.41 aC (0.02)	3.41 aC (0.01)	3.42 aC (0.02)
	4	3.26 aA (0.01)	3.35 aB (0.01)	3.36 aB (0.02)	3.41 aC (0.02)	3.41 aC (0.01)	3.42 aC (0.02)
titratable acidity (% citric acid)[b]	1	1.08 aD (0.07)	0.97 aC (0.02)	0.91 aB (0.01)	0.91 aB (0.01)	0.88 aB (0.02)	0.73 aA (0.02)
	2	1.08 aB (0.07)	0.95 aA (0.05)	0.95 bA (0.02)	0.94 bA (0.00)	0.92 bA (0.01)	0.92 bA (0.06)
	3	1.08 aB (0.07)	0.95 aA (0.04)	0.95 bA (0.02)	0.95 bA (0.03)	0.93 bA (0.02)	0.92 bA (0.05)
	4	1.08 aB (0.07)	0.96 aA (0.03)	0.96 bA (0.02)	0.95 aA (0.03)	0.92 bA (0.01)	0.92 bA (0.06)
soluble solids (° Brix)[c]	1	6.0 aA (0.4)	7.0 bB (0.3)	7.0 bB (0.3)	9.0 cC (0.7)	9.2 cC (0.8)	9.2 cC (0.7)
	2	6.0 aA (0.4)	6.0 aA (0.4)	6.0 aA (0.4)	6.0 bA (0.3)	6.0 aA (0.2)	6.0 aA (0.2)
	3	6.0 aA (0.4)	6.0 aA (0.3)	6.1 aA (0.2)	6.5 aB (0.1)	6.5 bB (0.1)	6.5 bB (0.1)
	4	6.0 aA (0.4)	6.1 aA (0.2)	6.1 aA (0.1)	6.5 aB (0.1)	6.6 bB (0.2)	6.6 bB (0.2)

[a] –cMeans at same line with different capital letters are significantly different (Tukey test, $p \leq 0.05$); means at same column with different small letters are significantly different (Tukey test, $p \leq 0.05$). Numbers in parentheses are the standard deviation of each analysis. [d] Treatment 1 = control, treatment 2 = PVC film, treatment 3 = yam starch film formulated with 4.00 g of starch/100 g of solution and 1.30 g of glycerol/100 g solution and treatment 4 = yam starch film formulated with 4.00 g of starch/100 g of solution and 2.00 g of glycerol/100 g solution.

to Kalt, Prange, and Lidster (*26*), the changes in cellular compartmentalization as a result of water loss may give rise to anthocyanin oxidation that contributes to the loss of berry color during storage. This effect could be observed in our work at the end of storage time (after 24 days), in both control and packaged fruits, in which the anthocyanin content decreased, probably due to the instability of the pigments to oxidation.

According García, Martino, and Zaritzky (*8*), a linear relationship between anthocyanin content of strawberries and the *a/b* ratio of Hunterlab color parameters was found ($r^2 = 0.9499$); when anthocyanins increased, the redness (*a*) significantly increased while the yellowness (*b*) decreased, which led to an *a/b* ratio increase as a function of storage time.

3.2.4. Titratable Acidity and pH. Citric acid is the most abundant acid in strawberries, followed by malic acid, and ascorbic acid, which is biologically important because of its antioxidant activity. According to Green (*27*), total acidity increases during fruit development until a maximum (big green stage), and then it decreases toward a minimum at the overripened stage, due to an increase mainly of malic acid.

Table 2 contains the data of titratable acidity and pH and shows that as fruit pH increased, the titratable acidity decreased as a function of storage time; the acidity decrease demonstrates maturation development. During the entire storage time (30 days), the more pronounced changes occurred in the control fruits, which showed the higher values of pH (3.46) and the lower values of titratable acidity (0.73% citric acid). These results agreed with those found by El Ghaouth, Arul, Ponnampalam, and Boulet (*2*) and García, Martino, and Zaritzky (*8*).

3.2.5. Soluble Solids. The soluble solids modifications in fruits are related to the metabolic changes (respiration process) that increase the reducing sugar content and the fruit sweetness during storage (*8*, *28*). As seen in **Table 2**, control fruits presented the greater increase in soluble solids content as a function of storage time, the fruits packaged with yam starch films showed a similar behavior and did not present changes in soluble solids until 12 days of storage, and fruits packaged with PVC film showed a constant soluble solids content during the entire storage time. These results showed that control fruits presented a maturation development more pronounced that packaged fruits, and this occurred because these fruits were stored without any protection against the external atmosphere. Compared to control fruits, yam starch and PVC films were effective in retardation of the metabolic process, and the better behavior of PVC probably occurred because PVC film acts as a better barrier against oxygen permeation than yam starch films;

Table 3. Mesophilic, Psychrotrophic, and Yeast and Mold Counts on Control and Packaged Fruits

		storage time at 4°C in days				
parameter	samples ^{d}	0	7	14	21	28
mesophilic microorganisms (log CFU/g fruit) ^{a}	1	2.46 aA (0.75)	4.60 bB (0.69)	6.70 bC (1.02)	7.80 bC (1.20)	10.15 aC (3.08)
	2	2.46 aA (0.75)	2.81 aA (0.87)	4.81 aB (0.75)	5.92 aB (0.55)	7.92 aC (0.89)
	3	2.46 aA (0.75)	2.87 aA (0.77)	5.12 abB (0.74)	6.10 aB (0.42)	8.02 aC (0.88)
	4	2.46 aA (0.75)	2.90 aA (0.80)	5.82 abB (0.55)	6.70 abB (0.87)	8.78 aC (0.79)
psychrotrophic microorganisms (log CFU/g fruit) ^{b}	1	2.12 aA (0.69)	3.90 aB (0.80)	6.92 bC (1.32)	8.02 bC (1.17)	10.13 bD (1.25)
	2	2.12 aA (0.69)	2.37 aA (0.90)	4.47 aB (0.30)	6.01 aC (0.63)	7.72 aD (0.89)
	3	2.12 aA (0.69)	2.42 aA (0.88)	4.95 aB (0.40)	6.74 abC (0.32)	7.34 aC (0.75)
	4	2.12 aA (0.69)	2.39 aA (0.98)	5.13 aB (0.40)	6.60 abC (0.65)	7.57 aC (0.88)
yeasts and molds (log CFU/g fruit) ^{c}	1	1.88 aA (0.55)	4.98 bB (0.67)	6.15 bB (1.05)	8.25 bC (0.89)	11.12 cD (1.62)
	2	1.88 aA (0.55)	3.20 aB (0.68)	3.85 aB (1.15)	5.30 aB (0.99)	7.05 aC (0.56)
	3	1.88 aA (0.55)	3.71 aB (0.55)	4.62 aB (0.44)	6.50 aC (0.75)	8.12 abD (0.82)
	4	1.88 aA (0.55)	3.61 aB (0.17)	4.72 aC (0.20)	6.70 aD (0.45)	8.92 bE (0.42)

$^{a-c}$ Means at same line with different capital letters are significantly different (Tukey test, $p \leq 0.05$); means at same column with different small letters are significantly different (Tukey test, $p \leq 0.05$). Numbers in parentheses are the standard deviation of each analysis. ^{d} Treatment 1 = control, treatment 2 = PVC film, treatment 3 = yam starch film formulated with 4.00 g of starch/100 g of solution and 1.30 g of glycerol/100 g solution, and treatment 4 = yam starch film formulated with 4.00 g of starch/100 g of solution and 2.00 g of glycerol/100 g solution.

PVC film shows a oxygen permeability (3.04×10^{-18} cm^3 O$_2$ m^{-1} s^{-1} Pa^{-1}) much lower than yam starch films (3.34×10^{-10} cm^3 O$_2$ m^{-1} s^{-1} Pa^{-1}) studied previously (*29*). Moreover, the significantly higher weight loss of control samples could have contributed to the concentration of solids in the fruits.

3.2.6. Microbiological Assays. Washing the fruits with chlorinated water (250 ppm Cl$_2$) was effective in reducing microbial counts and in eliminating coliforms. No coliforms were detected during storage of the fruits at 4 °C.

Compared to control fruits, the three types of packaging used in strawberry fruits were effective as a barrier against microbial contamination (**Table 3**), including mesophilic and psychrotrophic bacteria and yeasts and molds. In all cases, fruits packaged with PVC did not differ significantly ($p \leq 0.05$) from those packaged with either of the yam starch films.

To compare packaging effectiveness, shelf life of strawberries was limited to the time necessary to reach 10^6 CFU/g of fruit. According to Howard and Dewi (*30*), when microbial counts exceed this limit, toxic substances may be produced; this parameter has been used by other researchers (*8*). Brackett (*31*) noted that damaged or defective fruits could contain as many as 10^7 CFU/g of fruits. Thus, considering the microbiological parameter, shelf life of control fruits, stored at 4 °C, was 14 days, and of all packaged samples, stored at same conditions, was 21 days.

Regarding the difference in water vapor permeability between PVC and yam starch films, the lower characteristic value of PVC was prejudicial because it did not allow movement of water across the film, leading to water condensation inside the packaging, which was a potential source of microbial spoilage in the fruits and prejudicial to acceptance by consumers.

4. CONCLUSIONS

Compared to yam starch films, PVC film presented the better behavior on weight and firmness retention of the fruits, especially in the last 7 days of storage; however, yam starch films could be considered as a viable packaging alternative for strawberry fruits, considering the global analysis of quality retention of the samples. Two different formulations of yam starch films were tested in this work, which had different mechanical properties as a function of glycerol content (1.30 and 2.00 g/100 g of solution), but showed no difference when employed as packaging for the strawberries.

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