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Chitosan and arrowroot-based coatings increase shelf life and post-harvest quality of tomatoes

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Abstract

Tomatoes have a prominent market position, providing various healthy compounds. Besides the ample fresh consumption, several tomato derivatives have great interest in worldwide culinary. However, this vegetable has a short post-harvest life due to its climacteric metabolism, impairing its consumption viability. In this context, studies to mitigate post-harvest losses are frequent, where edible coatings are alternatives to prolong the shelflife of food. Here we show the efficiency of using edible coating based on arrowroot starch and chitosan in conservation the post-harvest quality of tomatoes. Our results indicate that the arrowroot starch edible coating at 3% is able to prolong the shelflife and promote the safe consumption of this vegetable.

Keywords: Starch; chitosan; shelflife; *Solanum lycopersicum* L.; storage.
Abbreviations: RH_relative humidity; SS_soluble solids; TA_acidity titratable; SS/TA_ratio; pH_hydrogenation potential.

Introduction

Tomato (*Solanum lycopersicum* L.) is one of the most widespread and consumed vegetables worldwide, with great socioeconomic importance for generating employment, income, and contribution to agribusiness. However, this vegetable is highly perishable and has a short post-harvest life due to its high metabolic activity, climacteric metabolism, and interaction with extrinsic factors, such as atmospheric gases, temperature, and relative humidity, causing significant losses for agroindustry (Battacharyya et al., 2015). Tomatoes provide essential nutrients and antioxidants that eliminate free radicals, help prevent degenerative diseases, and benefit the cardiovascular and immune systems (Nawab et al., 2017). These properties arise from bioactive compounds, such as ascorbic acid, phenolic compounds, and carotenoids, such as lycopene (Salehi et al., 2019). Although tomatoes' demand is quite wide due to their high consumption in several areas, post-harvest losses are still a severe problem. It is one of the most critical steps in commercializing these products (Nawab et al., 2017). Several techniques cannot guarantee the tomatoes' useful life, which leads to sudden price increases and influences inflation rates (Macheka et al., 2018). Thus, technologies that preserve the fruits' chemical and physical attributes and prolong their shelf life are essential to ensure the quality of highly perishable foods and meet consumer demand (Suhag et al., 2020). The food industry has made extensive use of edible coatings in recent years. The coatings comprise thin layers of easily degradable materials, controlling the fruit's metabolism by reducing breathing and preventing internal moisture loss, thus maintaining the organoleptic and nutritive food qualities (Ascencio et al., 2018). They can be polysaccharide, lipid, or protein, but they should not alter the fruit's taste, coagulate, crack or discolor during handling and storage (Thakur et al., 2019). The chitosan, a material used to manufacture edible coatings, is a polysaccharide obtained from crustaceous chitin's deacetylation. Its high potential for fruit conservation enables it for use in the post-harvest process, showing satisfactory results to increase food shelf life (Limchoowong et al., 2016; Kaewklin et al., 2018; Zhu et al., 2019). The arrowroot starch extracted from *Maranta arundinacea* L. roots has peculiar properties for use in the food industry, especially as an edible coating (Astuti et al., 2018). However, this robust raw material requires more research for post-harvest applications. This work evaluates edible coatings based on chitosan and arrowroot starch in tomatoes' post-harvest quality during storage.

Results

Weight loss, firmness, and color

Coating with 3% arrowroot starch reduced tomatoes' weight loss during storage, whereas fruits coated with 2% chitosan had the highest weight loss. The fruits uncoated and coated with 3% chitosan and 2% arrowroot starch did not differ in weight loss from each other (Figure 1). The evaluation of the isolated factors of coating ($P \leq 0.05$) and storage period ($P \leq 0.05$) showed that fruits coated with chitosan at 3% resulted in greater firmness, not differing from treatments with 3% arrowroot starch and 2% chitosan (Figure 2A). Firmness decreased from the fourth day until the end of the experiment, totaling a loss of 51% of firmness, regardless of edible coating types (Figure 2B).

The type of coating ($P \leq 0.05$) and storage time ($P \leq 0.05$) affected luminosity but did not interact with each other. The highest average luminosity occurred in fruits coated with 3% chitosan but did not differ significantly from those treated with 2% chitosan and 2% and 3% starch. Uncoated tomatoes showed the least light. The tomatoes' brightness remained unaltered until the eighth day of storage; however, on the 12th day occurred a reduction in averages, reaching a loss of 19.90% at the end of storage (Table 2).

The interaction between coating types and storage days influenced the chroma and Hueº values of tomatoes ($P < 0.05$). Chromaticity increased in tomatoes with or without coverage throughout the storage, mainly in the control fruits and 2% arrowroot starch. Only the fruits with 3% of chitosan at the end of storage showed a lower chromaticity than the other coatings and control (Table 3). Control tomatoes decreased Hueº more quickly, while the fruits with 3% chitosan maintained their hue until the 12th day, not differing from the fruits with 2% chitosan on the same day. At 16 days, the coatings did not differ in terms of shade (Table 3).

Soluble solids, titratable acidity, and SS/TA ratio

Soluble solids remained stable in all treatments until the fourth day; however, between 8 and 12 days, fruits coated with 2% chitosan increased the soluble solids content followed by reduction ($P \leq 0.05$). In these two periods, the control had the greatest reduction in soluble solids, although it did not differ from the others coated at the end of storage (Figure 3).

Titratable acidity increased in control fruits until the fourth day ($P \leq 0.05$), resulting in lower percentages, similar to fruits with 2% chitosan. Coatings did not differ from each other until 12 days. Acidity increased at 12 days and decreased at the storage end, except for 2% arrowroot starch, not differing from 3% arrowroot starch and 3% chitosan at 16 days (Figure 4).

The SS/TA ratio increased during storage in control tomatoes and treatments with 2% chitosan and 3% starch, obtaining the highest SS/TA ratios on the last day ($P \leq 0.05$). Fruits with 3% chitosan and 2% starch did not change throughout the period and showed lower averages at the end of storage (Figure 5).

Ascorbic acid and total phenolics

The interaction between the coatings and the storage period significantly affected the ascorbic acid content ($P \leq 0.05$). The ascorbic acid content in control tomatoes and those coated with 2% chitosan and 2% arrowroot starch increased until the eighth day, followed by a reduction until the last day of storage. The fruits covered with 3% arrowroot starch preserved the ascorbic acid content during storage. However, it did not differ from the fruits coated with 2% chitosan on the last day, while the control fruits and coated with 3% chitosan obtained lower averages in this period (Figure 6).

The average total phenolics content in tomato fruits changed over the storage period ($P < 0.05$), but it was independent of coatings. Until the 12th day, the total phenolics content remained constant, showing a significant increase at the end of storage (Figure 7).

Discussion

The coatings applied to tomatoes reduced the physical-chemical changes during metabolic processes of ripening, suggesting that coatings function as barriers against gas exchanges, decreasing respiratory rates and oxidation reactions. Weight loss is an essential indicator of quality decline in tomatoes, resulting from perspiration during post-harvest handling and storage. The edible coating can delay this adverse effect and prevent water loss by decreasing the fruit's perspiration (Nawab et al., 2017). Coating with 3% arrowroot starch created an efficient barrier to conserve the fruit mass, unlike the concentration of 2% starch (Wang et al., 2018; Thakur et al., 2019). Choosing suitable coatings with permeability compatible with the fruit's respiratory rate is essential for the product's storage conditions.

Firmness reduction results from the softening of fleshy fruits due to changes in cell walls' composition (Salas-Méndez et al., 2019) caused by solubilization and depolymerization of polysaccharides such as pectin, hemicellulose, and cellulose (Romero and Rose, 2019). Although this condition is acceptable to some degree, the excessive reduction in firmness leads to consumer rejection and, consequently, to post-harvest losses (Chea et al., 2019). This process varies among vegetables according to species, varieties, and environmental conditions and can be delayed or induced over time (Sucheta et al., 2019). These texture changes and weight loss promote wrinkling and withering. However, coating mechanisms that reduce the fruit's perspiration can prevent these effects.

Brightness has great importance for consumers' appreciation since its intensity is an indicator of fresh fruit. However, brightness reduction in tomatoes naturally occurs during the ripening, as proved in several studies (e.g., Buendía-Moreno et al., 2020).

When harvested at the proper period, the epicarp color of climacteric fruits tends to change until reaching maturity, a characteristic used by consumers to assess food quality. The red epicarp of tomatoes is one of the best commercialization characteristics, as it is more acceptable to most consumers (Salas-Méndez et al., 2019). Coating fruits with 3% chitosan maintained the hue values (Hueº), delaying the color change during the storage period.

The increase in chromaticity and the decrease in Hueº values indicate the degradation of chlorophylls and the conversion of xanthophylls into carotenes, responsible for the ripening of the red color in climacteric fruits (Sucheta et al., 2019).

Soluble solids content allows assessing the degree of ripeness, measured in ºBrix, which relates to quality and flavor. The ºBrix increases over time until the fruit reaches maturity. This process results from the hydrolysis of polysaccharides to simple sugars (Oliveira, 2010). The increase in soluble solids also happens due to the loss of mass that increases concentration. Our experiment showed that fruits covered with 2% chitosan had the highest mass loss.

Organic acids are the primary substrates in climacteric fruits' respiration process (Pareek, 2016). Therefore, occurs a reduction in acidity over the storage period in fruits such as tomatoes. The coatings that matched the decrease in respiratory rate of fruits limited the consumption of organic acids in respiratory reactions. On the other hand, the increase in acidity probably relates to galacturonic acids released during the hydrolysis of cell wall components responsible for tissues' firmness (Germano et al., 2019). For

Table 1. Initial characterization of tomatoes after harvest (FAEP, 1982).

Group	Subgroup	Class	Caliber	Category
Oblong	Geen	Large	6	Extra

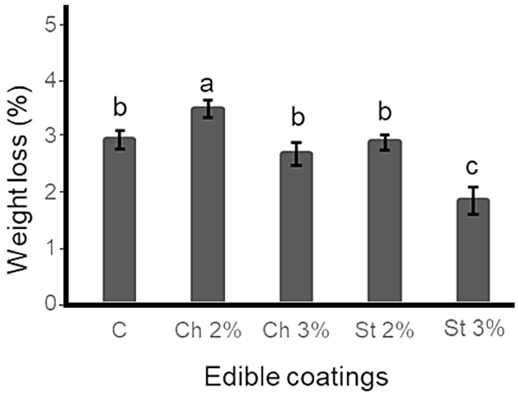

Figure 1. Weight loss of tomatoes with edible coatings after 16 days of storage. (C _ Control; Ch 2% _ Chitosan 2%; Ch 3% _ Chitosan 3%; St 2% _ Starch of arrowroot at 2%; St 3% _ Starch of arrowroot at 3%). Means followed by the same letter do not differ by Tukey's test (P <0.05).

Table 2. Luminosity of tomatoes with edible coatings and during the storage period.

Luminosity			
Edible coatings	Means	Storage (days)	Means
Control	46.58 b	0	52.67 a
Chitosan 2%	48.70 ab	4	51.39 a
Chitosan 3%	51.22 a	8	50.58 a
Starch 2%	49.41 ab	12	47.15 b
Starch 3%	49.13 ab	16	43.24 c

Means followed by the same letter do not differ by Tukey's test (P <0.05).

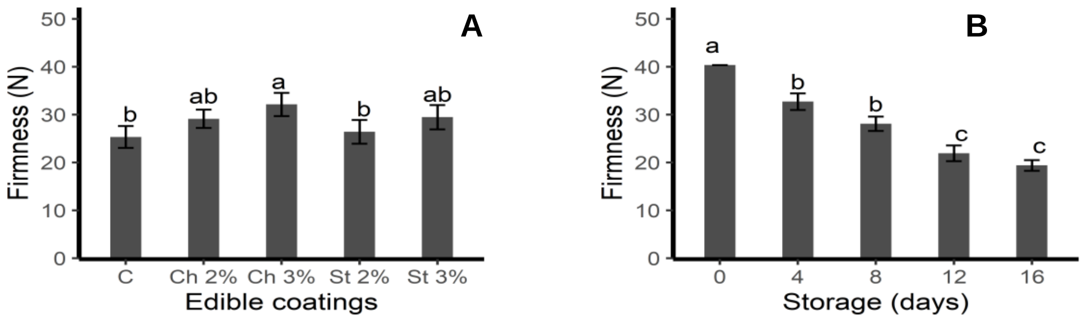

Figure 2. Firmness of tomatoes (A) with edible coatings and (B) during the storage period. (C _ Control; Ch 2% _ Chitosan 2%; Ch 3% _ Chitosan 3%; St 2% _ Starch of arrowroot at 2%; St 3% _ Starch of arrowroot at 3%). Means followed by the same letter do not differ by Tukey's test (P <0.05).

Table 3. Chroma and Hueº of tomatoes with edible coatings during the storage period.

	Chroma	Hueº	Chroma	Hueº	Chroma	Hueº	Chroma	Hueº	Chroma	Hueº
	Storage (days)									
Edible coating	0		4		8		12		16	
Control	27.60 ± 0 aD	91.10 ± 0 aA	33.27 ± 1.17 aC	0.96 ± 0.05 bB	34.03 ± 0.71 aBC	0.96 ± 0.03 cB	37.33 ± 1.03 aAB	0.76 ± 0.06 bB	38.43 ± 0.61 aA	0.82 ± 0.03 aB
Chitosan 2%	27.60 ± 0 aB	91.10 ± 0 aA	30.43 ± 0.37 abB	91.18 ± 0.02 aA	30.03 ± 1.68 bB	31.34 ± 42.44 bcB	29.47 ± 0.94 bB	91.05 ± 0.09 aA	37.57 ± 0.77 aA	0.82 ± 0.02 aB
Chitosan 3%	27.60 ± 0 aB	91.10 ± 0 aA	30.13 ± 0.63 abAB	91.14 ± 0.01 aA	27.07 ± 0.45 bB	91.40 ± 0.09 aA	26.80 ± 1.54 bB	91.39 ± 0.03 aA	32.40 ± 0.29 bA	0.22 ± 0.03 aB
Starch 2%	27.60 ± 0 aD	91.10 ± 0 aA	31.77 ± 0.82 abCD	91.23 ± 0.05 aA	29.53 ± 0.59 bBC	61.43 ± 42.41 abA	34.33 ± 0.53 aAB	0.57 ± 0.12 bB	36.30 ± 0.74 aA	0.64 ± 0.08 aB
Starch 3%	27.60 ± 0 aB	91.10 ± 0 aA	29.63 ± 0.46 bB	91.12 ± 0.01 aA	29.37 ± 0.94 bB	91.05 ± 0.59 aA	35.13 ± 4.23 aA	0.72 ± 0.12 bB	36.47 ± 1.83 aA	0.73 ± 0.03 aB

Means followed by the same lowercase letter in the column and uppercase in the row do not differ by Tukey's test (P <0.05).

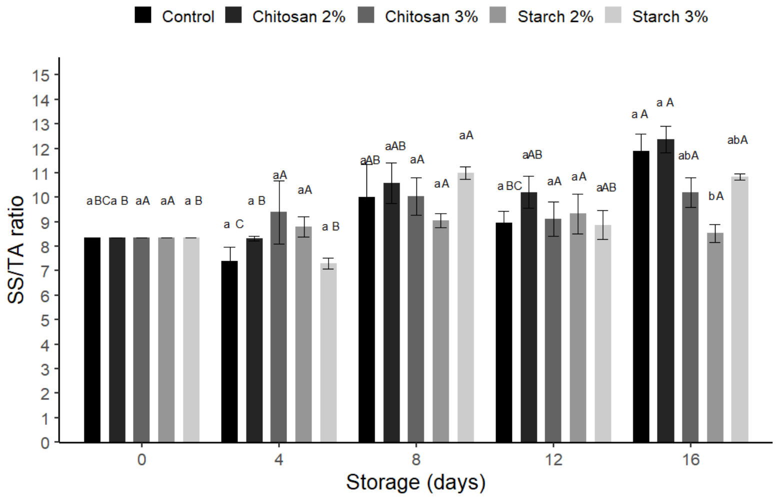

Figure 3. Levels of soluble solids (SS) of tomatoes in the interaction between edible coatings and storage period. Lower case letters compare means between coatings within each storage period by the Tukey test (P <0.05).

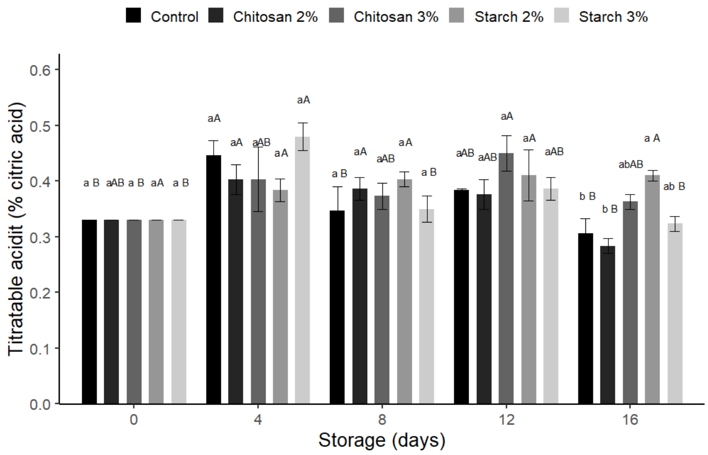

Figure 4. Titratable acidity (TA) of tomatoes in the interaction between edible coatings and storage period. Lower case letters compare means between coatings within each storage period by the Tukey test (P <0.05).

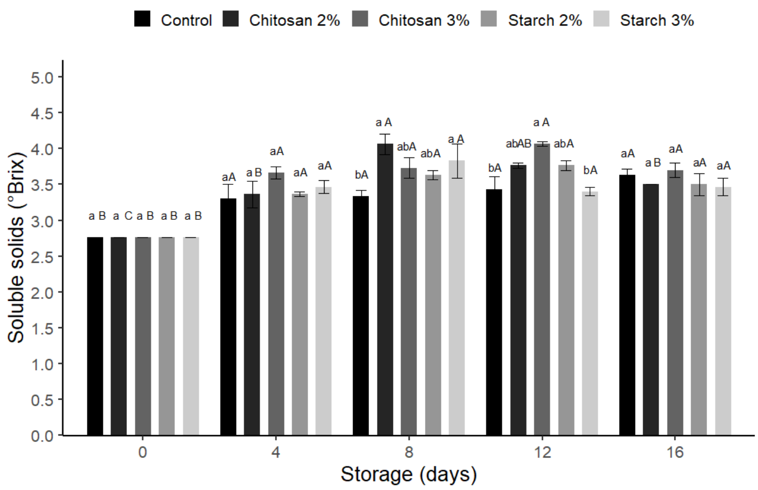

Figure 5. SS/AT ratio in tomatoes in the interaction between edible coatings and storage period. Lower case letters compare means between coatings within each storage period by the Tukey test (P <0.05).

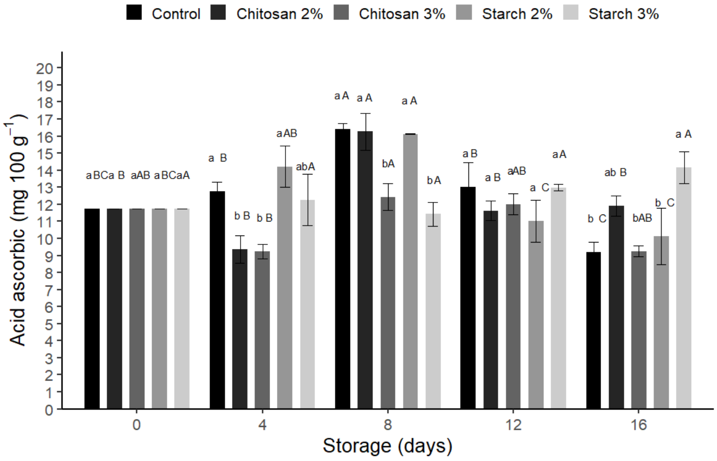

Figure 6. Ascorbic acid content in tomatoes in the interaction between edible coatings and storage period. Lower case letters compare means between coatings within each storage period by the Tukey test (P <0.05).

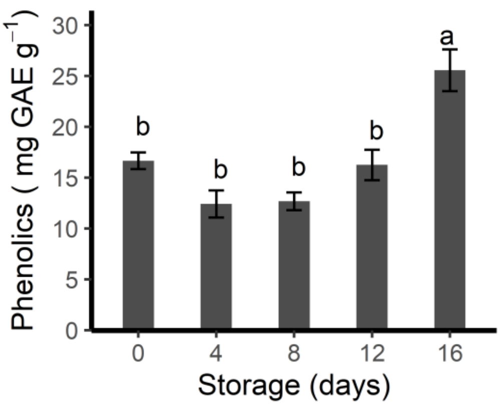

Figure 7. Total phenolics contents of tomatoes during the storage period. Means followed by the same letter do not differ by Tukey's test (P <0.05).

vegetables, both the absolute content of soluble solids and organic acids and their ratio are fundamental parameters to represent the flavor. Consequently, these characteristics affect the appreciation of the products (Bertin and Génard, 2018). According to Kader et al. (1978), high-quality fruits contain an SS/TA ratio greater than 10, SS greater than 3%, and titratable acidity greater than 0.32%.

Variations in ascorbic acid content in vegetables suffer influence from light, oxygen, and heat. The enzymes peroxidase and ascorbate oxidase are mainly responsible for the oxidation of vitamin C (Cheftel et al., 1983). However, the degradation process of ascorbic acid is reversible. Free radicals, which are the oxidation product, can be converted to vitamin C, which may increase during fruit ripening (Teixeira and Monteiro, 2006). Another explanation for the gradual increase in ascorbic acid is the continuous translocation and synthesis of L-ascorbic acid from the accumulation of soluble solids and reducing sugars in the maturation stages (Ferreira et al., 2010). Nair et al. (2018) describe a similar process in their study.

Phenolic compounds are organic molecules with a benzene ring attached to one or more hydroxyls. It consists of secondary metabolites that act in the plants' defense mechanisms. The increase in polyphenols' content may be related to the plant's defense system against the storage's stress. Liu et al. (2018) found increasing values of polyphenols throughout tomato storage, ranging between 0.14 and 11.20 µg g^{-1}. However, unlike Sucheta et al. (2019), tomato polyphenols stored at 25 ºC decreased in different coatings over 30 days of storage.

Materials and methods

Characterization of plant material

The work was developed at the Fitotechnics Laboratory of the Center for Science and Agri-food Technology at the Federal University of Campina Grande. The fruits used in the experiment were hybrid 'Lampião' tomatoes, of the Saladette type. They are fruits with variations of up to 8.5 cm in longitudinal diameter, 6.0 cm in transversal diameter and average weight of 170 g. It has a smooth appearance, with small peduncular insertion and an intense red color when mature.

The tomatoes were harvested in a commercial plantation in the municipality of Desterro - PB and transported to the laboratory. Only healthy fruits were selected, with no mechanical damage and no apparent pathogenic activity. They were sanitized in chlorinated water (100 ppm) for four minutes, rinsed with running water and dried at room temperature. Then, they were standardized in the commercialization norms (FAEP, 1982), according to the format, the color of the bark, size, caliber and category (Table 1).

Experimental design

A completely randomized design was used, with the treatments distributed in a 5 x 5 factorial scheme, in which the first factor corresponded to the types of coverings and the second factor to the storage period, totaling 25 treatments, with three repetitions. The tomatoes were submitted to the following coatings: control (without coating); chitosan at 2%; chitosan at 3%; arrowroot starch at 2% and arrowroot starch at 3%, during periods of 0, 4, 8, 12 and 16 days of storage.

For the preparation of the edible coatings based on chitosan, medium molecular weight material was used, with 99.5% purity and 75 to 85% deacetylation. Chitosan solutions were prepared in concentrations of 2% and 3% (w v-1), containing 0.5 ml (v v-1) of glacial acetic acid. The solutions were made one day before application, the pH being adjusted to 4.8 with 2N NaOH. Tween 20 was used as a surfactant, according to Ziani et al. (2008). The fruits were immersed in the solutions for one minute and then drained for four hours to remove the excess.

To prepare the coating based on arrowroot starch, the concentrations of 2% and 3% were prepared by stirring the suspensions by heating at 70 ° C to gel. After the solutions were cooled to 25 ° C, the fruits were immersed for one minute in the concentrations and then dried naturally for four hours.

All treatments were stored at constant temperature (18 ºC ± 2 ºC), in plastic trays of ethylene terephthalate (PET), in a room with 75% RH (%).

Variables analyzed

Weight loss - obtained by the difference between the initial mass and the final fruit mass at the end of the experiment, using a semi-analytical scale (BEL Engineering ®). The results were expressed as a percentage of weight loss.

Peel color - it was analyzed on two opposite sides of the equatorial region of the fruit. Digital colorimeter (Konica Minolta ®) was used to obtain luminosity, chromaticity and hue values (Hueº), referring to a coordinate system in a color space - CIELab.

Firmness - was evaluated by measuring the maximum penetration force for a 6 mm diameter steel tip, using a digital penetrometer (Lutron Colombia ®). The fruits were placed so that the plunger penetrated the pericarp to a depth of 10 mm. The results were expressed in Newton (N).

Titratable acidity (TA) - the samples were diluted in water and titrated against sodium hydroxide solution (0.1 M), until reaching a constant pink color, using phenophthalein (1%) as a synthetic acid-base indicator. To calculate acidity, the following formula was used: Titratable acidity (% citric acid) = G x N x Mq x VT x 100 / PxA. Where: G = mL of NaOH spent on titration; N = Normality of the NaOH used (0.1 N); Mq = Citric acid milliequivalent (0.064); VT = Total sample volume; P = Weight of the sample used; A = Sample rate used for titration (Horwitz, 1995).

Soluble Solids (SS) - obtained from the reading made in a digital refractometer at 25 ºC (IAL, 2008).

SS/TA Ratio - obtained from the ratio between the content of soluble solids and that of titratable acidity.

Ascorbic acid - was determined based on the spectrophotometric method by Terada et al. (1978). The samples (0.5 g) were homogenized with oxalic acid (0.5%) and centrifuged at 6000 rpm for 20 minutes at a temperature of 4 ° C. A 1000 µL aliquot was taken from the supernatant where 150 µL of a 0.25% aqueous solution of 2,6-Dichlorophenolindophenol (DCFI), 1000 µL of 2% and 50 µL 2,4-Dinitrophenylhydrazine (DNPH) was added 10% thiourea. The mixture was subjected to heating in a water bath for 15 minutes, then it was cooled on ice, adding 5000 µL of 85% sulfuric acid. The reading was performed on a spectrophotometer, at a wavelength of 525 nm. The results were compared with the standard curve of ascorbic acid and expressed in mg of ascorbic acid 100 g^{-1}.

Total phenolics - were determined using the method according to the methodology described by Folin-Ciocalteu (Horwitz, 1995). The samples (0.5 g) went through the extraction process with the addition of 5000 µL of 5% cooled acetone, immersion in an ultrasonic bath for 20 minutes and centrifugation at 5000 rpm for 10 minutes to remove the supernatant. This process was repeated and then 900 µL of deionized water, 500 µL of Folin-Ciocalteu and 2500 µL of 20% sodium carbonate were added to the total supernatant. After resting for an hour, the samples were read on a spectrophotometer with a wavelength of 725 nm. The results were obtained by the standard curve of gallic acid and expressed in µg of gallic acid g^{-1}.

Statistical analysis

The data were submitted to analysis of variance by the F test at the level of 5% probability. For the significant variables, the means were compared using the Tukey test ($p < 0.05$) with the aid of the Software - R (R CORE TEAM, 2017).

Conclusions

The arrowroot starch at 3% provided the most significant reduction in tomatoes' loss of mass. It maintains firmness and luminosity during an extended storage period, increasing the fruit's shelflife. The 3% arrowroot starch also provides the highest vitamin C content at the end of storage, not differing from the 2% chitosan coating.

Over 16 days of storage, tomatoes coated with 2% arrowroot starch were similar to those of control in terms of firmness, hue, titratable acidity, and ascorbic acid.

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