Ciência e Agrotecnologia
SCIENCE AND AGROTECHNOLOGY

Ciência e Agrotecnologia, 47:e009223, 2023
http://dx.doi.org/10.1590/1413-7054202347009223

Agricultural Sciences
eISSN 1981-1829

Pectin-based edible coating containing gibberellic acid in the post-harvest conservation of fresh tomatoes

Uso de revestimento comestível à base de pectina contendo ácido giberélico na conservação pós-colheita de tomates frescos

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Received in June 26, 2023 and approved in October 5, 2023

ABSTRACT

Edible coating are commonly used as they minimize post-harvest losses and extend the shelf life of fruits. Therefore, in this study, analyzed the effect of edible coatings containing gibberellic acid (GA_3) on the shelf life of tomatoes (*Solanum lycopersicum* L.). Tomatoes were divided into six groups: Uncoated (CT); coating with 75 and 100 mg L^{-1} of GA_3 solubilized in water without adding pectin (A75 and A100, respectively); coating with 75 and 100 mg L^{-1} of GA_3 with added pectin (P75 and P100, respectively); coating pectin only (PEC). Pectin-based coatings (PEC, P75, and P100) were produced by solubilizing pectin (3%) in water, followed by adding different concentrations of GA3.Treatments A75 and A100 were prepared with distilled water and 75 and 100 mg L^{-1} GA_3. Tomatoes (turning stage) were immersed in the solutions for 3 min, dried at room temperature, and stored at 12 °C (90% RH). The pH, titratable acidity, soluble solids, color and weight loss were analyzed every four days for 32 days, and the firmness of the tomatoes was analyzed every seven days for 35 days. Coatings with GA_3 maintained firmness, delayed weight loss, and decreased acidity, pH, sugar content, and color changes. Pectin-based coatings (P75, P100) were the most effective in delaying weight loss. The application of GA_3 associated with pectin-based coatings delayed the ripening process, maintained the quality, and prolonged the shelf life of fruits. As this is an inexpensive technique, it may be used commercially.

Index terms: Biopolymers; gibberellins; materials technology; shelf life.

RESUMO

Revestimentos comestíveis são comumente utilizados pois minimizam perdas pós-colheita e prolongam a vida útil dos frutos. Neste estudo, analisou-se o efeito de coberturas comestíveis contendo ácido giberélico (GA_3) na vida útil de tomates (*Solanum lycopersicum L.*). Dividiu-se os tomates em seis grupos: Não revestidos (CT); revestimento com 75 e 100 mg L^{-1} de GA_3 sem adição de pectina (A75 e A100); revestimento com 75 e 100 mg L^{-1} de GA_3 com adição de pectina (P75 e P100); revestimento com pectina (PEC). Revestimentos à base de pectina (PEC, P75 e P100) foram produzidos solubilizando a pectina (3%) em água, seguida da adição das concentrações de GA_3. Os tratamentos A75 e A100 foram preparados com água destilada e 75 e 100 mg L^{-1} de GA_3. Os tomates (fase de viragem) foram imersos nas soluções durante 3 minutos, secos à temperatura ambiente e armazenados a 12 ° C (90% UR). O pH, acidez titulável, sólidos solúveis, cor e perda de massa foram analisados a cada quatro dias durante 32 dias, e a firmeza a cada sete dias durante 35 dias. As coberturas com GA_3 mantiveram a firmeza, retardaram a perda de massa e diminuíram a acidez, pH, teor de açúcar e as alterações de cor. Revestimentos à base de pectina (P75, P100) foram os mais eficazes em retardar a perda de peso. A aplicação deste revestimento retardou o amadurecimento, manteve a qualidade e prolongou a vida útil dos frutos. É uma técnica economicamente viável, podendo ser utilizada comercialmente.

Termos para indexação: Biopolímeros; giberelinas; tecnologia de materiais; vida de prateleira.

INTRODUCTION

Tomatoes (*Solanum lycopersicum* L.) are easily perishable fruit due to their high metabolic activity and high water content. These characteristics make them susceptible to major alterations due to changes in humidity and temperature (Ferraz et al., 2012). Tomato ripening is mainly related to increased ethylene production and respiration rates, which can alter the chemical and physical characteristics, such as chlorophyll loss, tissue softening, and carotenoid synthesis (Wang et al., 2015).

The leading causes of post-harvest deterioration caused by inadequate storage, transport logistics and contamination by pests, insects and fungi are nutrient loss, chlorophyll decomposition, substrate oxidation, cell wall softening, and membrane penetration. The nutritional value can vary depending on the temperature, humidity, and air composition (Saltveit, 2019). Weight loss is caused by water loss, which directly affects the appearance of the fruit. In such cases, edible coatings can act as a semipermeable barrier, reducing the transfer of moisture, oxygen, carbon dioxide, lipids, and aromatic and nutritional components between the fruit and the ambient environment (Chiumarelli; Hubinger, 2014), which in turn can increase the shelf life of the fruit.

The natural biopolymers most used in preparing edible films are proteins such as gelatin, ovalbumin, casein, wheat gluten, myofibrillar proteins, and zein. Additionally, polysaccharides, such as starch, cellulose, and its derivatives, pectin, alginate, and carrageenan, are also used (Chen et al., 2019). Pectin is a complex polysaccharide with a branched structure found in the plant cell wall (Kohli; Gupta, 2015). It is a commercially available and inexpensive white carbohydrate widely used in fruit coatings (Anuradha et al., 2010). Additionally, pectin-based coatings have low permeability to gases. They form a barrier and prevent gas exchange, which helps preserve the aroma and delay moisture loss (Hoorfar, 2014)

To improve the characteristics of edible films, antioxidant compounds (Zahedi et al., 2019), antimicrobial substances (Guo; Yadav; Jin, 2017), and antifungal substances (Alotaibi et al., 2019) may be added. Plant regulators, especially gibberellins, can delay fruit senescence (Martínez-Romero et al., 2000; Amarante et al., 2005). Rossetto, Lajolo and Cordenunsi (2004) applied gibberellin to banana slices and found that the phytohormone delayed starch degradation and the accumulation of soluble sugars. Gibberellin can delay the activity of cell wall enzymes, chlorophyll degradation, and carotenoid synthesis, thus reducing the loss of tissue firmness. Gol and Ramana Rao (2011) evaluated the use of coatings with chitosan, sodium chloride, gibberellic acid, and jojoba wax to increase the shelf life and post-harvest quality of bananas and reported that coatings containing GA_3 and chitosan delayed weight loss, sugar build-up, pigment degradation, and reducing the ascorbic acid loss compared to uncoated bananas. Therefore, gibberellic acid can delay fruit ripening, and its association with pectin-based coatings can benefit fruits as these coatings can maintain the brightness and luminosity of fruits, reduce the loss of gas, and maintain the water content, which in turn can prolong the shelf life of fruits. As gibberellic acid is naturally present in plants, the use of gibberellins has no adverse effect on humans. Some studies have shown that the satisfactory dose of gibberellic acid in postharvest fruits ranges from 50 mg L^{-1} to 100 mg L^{-1} (Aquino; Salomão; Azevedo, 2016; Huang et al., 2014). Based on these findings, in this study, we applied pectin-based edible coatings with gibberellic acid to tomatoes and evaluated their shelf life.

MATERIAL AND METHODS

Tomatoes were purchased locally in Dourados (Mato Grosso do Sul, Brazil). The cultivars were of the same species obtained from a single farmer and supplier. Then, they were transported and stored in a refrigerator (12°C 90% RH). Fruits were selected at the turning stage of ripening (10–30% of the surface was red, yellow, pink, or a combination of these colors), based on the USDA standard tomato color classification chart (USDA, 1991). The tomatoes were visually sorted for uniformity in size, color, absence of blemishes, and fungal infection. After selection, they were immediately immersed for 3 min in a 0.02% sodium hypochlorite solution for sanitizing, washed in running water, and finally, dried at room temperature (25 °C) for approximately 4 h.

To produce the edible coatings, we used citrus pectin (PM: 182.17), D-sorbitol P.S. (PM: 182.17) (Dinâmica®), and Gibberellic acid (GA_3) (purchased from ProGibb® 400).

Application of pectin-based edible coatings

Edible coatings based on pectin with and without GA_3 were prepared, and six different formulations were used according Table 1.

- CT: control (uncoated);
- A75: 75 mg L^{-1} gibberellic acid solubilized in water;
- A100: 100 mg L^{-1} gibberellic acid solubilized in water;
- PEC: pectin coating without added gibberellic acid;
- P75: coating with pectin and 75 mg L^{-1} gibberellic acid;
- P100: coating with pectin and 100 mg L^{-1} gibberellic acid

Pectin-based coatings (P75 and P100) were produced by dissolving pectin at a constant concentration of 3% (w/v) in distilled water at 40 °C. The solution was homogenized with a mechanical stirrer at 500 rpm for 60 min using sorbitol as a plasticizer (20% m/m). Next, pre-determined concentrations of GA_3 were added, and the mixture was homogenized at 500 rpm for 20 min.

Table 1: Formulations of edible coatings applied on tomatoes.

Treatments	Pectin (g/100 mL)	Sorbitol (g/100 g)	Gibberellic acid (g/100 mL)
CT	0.0	0.0	0.0000
A75	0.0	0.0	0.0075
A100	0.0	0.0	0.0100
PEC	3.0	0.6	0.0000
P75	3.0	0.6	0.0075
P100	3.0	0.6	0.0100

CT = Control (uncoated). A75 = 75 mg L^{-1} of gibberellic acid. A100 = 100 mg L^{-1} of gibberellic acid. PEC = Pectin coating. P75 = Pectin with added 75 mg L^{-1} of gibberellic acid. P100 = Pectin with added of mg L^{-1} of gibberellic acid.

Treatments A75 (75 mg L^{-1} GA_3) and A100 (100 mg L^{-1} GA_3) were prepared only with distilled water and 75 and 100 mg L^{-1} GA_3, respectively. The mixture was homogenized using a mechanical stirrer (500 rpm) at 25 °C for 20 min.

Tomatoes were immersed in the solutions for 3 min, dried at room temperature (25 °C), and stored in a refrigerator at 12 °C (90% RH). Physicochemical analyses were performed every four days for 32 days. The texture was evaluated every seven days for 35 days. Four whole tomatoes were used from each treatment group for analyzing color and weight loss, which remained constant until the end of the experiment. For analyzing the pH, soluble solids, titratable acidity, and firmness, two tomatoes from each treatment were used per day.

Hydrogen potential (pH), soluble solids, and titratable acidity

The pH was determined with a digital pH meter (PH-2000, Instrutherm) and analyzed in triplicate using two crushed tomatoes for each treatment. Soluble solids were determined with a digital refractometer (Homis) using 10 g of the macerated sample. The values were obtained by dropping the sample on the refractometer prism; all measurements were made with three repetitions.

The acidity was determined using the titration method with a 0.1 N sodium hydroxide (NaOH) solution (Association of Official Analytical Chemists - AOAC, 2012). First, 10 g of tomatoes (two crushed tomatoes for each treatment per day of analysis) were homogenized with 100 mL of distilled water. To the resulting solution, three drops of 1% phenolphthalein (w/v) were added, and then, the solution was titrated with 0.1 M NaOH until a pink color was detected. The content was expressed in g citric acid/100 g sample (Equation 1).

$$\frac{g\ citric\ acid}{100g\ sample}=\frac{V_{NaOH}\times N_{NaOH}\times f_{ac}\times 100}{P\times 1000} \tag{1}$$

Here, V indicates the volume of NaOH (mL), N indicates the normality of the NaOH solution, F_{ac} indicates the predominant acid factor (citric acid = 64), and the value of 1,000 refers to the citric acid content present in 1 L.

Weight loss

Weight loss was determined by weighing the tomatoes on an analytical scale (Analyser-Mark500). The results were expressed as a percentage relative to the initial weight calculated in Equation 2.

$$weight\ loss=\left(\frac{(Af-Ai)}{Ai}\right)*100 \tag{2}$$

Here, Af indicates the final weight and Ai indicates the initial weight.

Colorimetric analysis

Colorimetric analysis was performed using a CR 400 digital colorimeter (Konica Minolta) operating in the CIELab system (L*, chroma a*, chroma b*). The values of L* (brightness), a* (red/green), b* (yellow/blue), and h* (hue-hue) were obtained for the samples. The value of ΔE was calculated relative to the first day of storage of each treatment using Equation 3 and 4.

$$\Delta E=\sqrt{\left[\left(\Delta L^*\right)^2+\left(\Delta a^*\right)^2+\left(\Delta b^*\right)^2\right]} \tag{3}$$

$$h^{\circ}=arctan\frac{b^*}{a^*} \tag{4}$$

Here, h° indicates the hue angle, arctan indicates the arc tangent, and **ΔE** indicates the total color difference

Firmness of the tomatoes

The firmness was determined using the texturometer TA.XT Plus from ExtraLab (cylindrical probe-code P/10). The penetration distance was 20 mm and the speed was 2.0 mm s^{-1}. Two whole tomatoes were used for the analysis; four random points were selected for each treatment, and the final result was expressed in Newton.

Statistical analysis

The InfoStat/L software (version 2020) was used to perform all statistical analyses. The analysis of variance (ANOVA) and Tukey's test were conducted to determine significant differences between sample means in the 95% confidence interval ($p < 0.05$), with three replications. All data were expressed as the mean ±standard deviation (SD).

RESULTS AND DISCUSSION

The results obtained for titratable acidity (TA), pH, and total soluble solids (TSS) are presented in Table 2.

Titratable acidity

Overall, titratable acidity values decreased during storage, which occurred due to the ripening process and respiratory metabolism that continued after harvesting (Chitarra; Chitarra, 2005). On the last day of storage, the titratable acidity values in treatments A75 and P75 were significantly different from the value in the control, but the titratable acidity between the treatments was similar. These treatments showed higher acidity values (0.28 g of citric acid) at the end of the experiment than the control (0.22 g of citric acid), which indicated that using 75 mg L^{-1} GA_3 significantly delayed this parameter.

Panigrahi et al. (2017) studied the application of coatings containing GA_3 to extend the shelf life of green pepper (*Capsicum annuum* L.) and found that samples treated with 2 ppm GA_3 had a higher acidity value (0.307 ±0.006% citric acid), followed by 3 ppm GA_3 (0.223 ±0.006% of citric acid), compared to the control samples (0.127 ±0.006% of citric acid). Their results indicated that the use of GA_3 significantly. Their results indicated that the use of GA_3 significantly delayed change in the decline of titratable acidity. Gol and Ramana Rao (2011) evaluated edible coatings on bananas and found that applying chitosan coating with gibberellic acid (100 ppm) and jojoba wax delayed changes in titratable acidity.

pH

The pH increased significantly in all treatments during the storage period. The P75 treatment differed from the other treatments on the last day, showing a lower pH (4.12). No significant differences occurred among treatments P100, A75, and PEC, which presented pH values of 4.20, 4.18, and 4.22, respectively. The pH in the control and A100 treatment did not differ and showed higher values of 4.30 and 4.27, respectively.

The P75 treatment had the most suitable pH, as acidity reduction was lower in this treatment group, and thus, the increase in pH was lesser. This finding indicated that this coating effectively delayed the fruit maturation process. The pH value increases as the concentration of organic acids decreases, which occurs when they are used as a substrate during respiration (Kaur; Dhillon, 2015).

Quadros et al. (2020) evaluated the effects of edible coatings containing fish protein hydrolysate on the quality and shelf life of cherry tomatoes. They found higher pH in all treatments (4.64 – 5.27) at the end of 21 days of storage. Similarly, Martínez et al. (2020) found that the control and all coatings containing *Flourensia cernua* extract increased the pH with no significant difference between them (pH 4.1 – 4.3).

Soluble solids

The content of soluble solids increased during storage in all treatment groups (Table 2). Minor changes were found in the P75, P100, A75, and A100 groups (4.25), but no difference was found between them at the end of the experiment. The control group showed the highest value for this parameter (ranging from 4.00 to 4.75). Kluge and Minami (1997) found that a greater loss of mass is associated with a greater content of total solids, as these solids are concentrated in the fruit tissues. The samples in the control group showed a higher concentration of sugars at the end of the experiment, which occurred probably due to a higher percentage of mass loss.

Fruits treated with GA_3 showed a late increase in soluble solids, which can be attributed to the delay in senescence. This in turn delayed the conversion of starch into sugars. These series of changes might have occurred due to the anti-senescent properties of GA_3 (Kaur; Jawandha; Singh, 2014). The increase in the content of soluble solids was also associated with the biochemical processes of ripening through starch hydrolysis (Aroucha et al., 2012). Martínez et al. (2020) analyzed edible Candelilla wax coatings with *Flourensia cernua* bioactive compounds applied on tomatoes and recorded a gradual increase in the concentration of soluble solids in all treatments. Gol and Ramana Rao (2011) evaluated the application of coatings on bananas and found that fruits coated with chitosan, chitosan + GA_3 and jojoba wax had lower total sugars (reducing and non-reducing sugars) compared to those in the control set.

Table 2: Titratable acidity (TA) values (g citric acid/100 g of sample), pH, and soluble solids (TSS) for each treatment group during 32 days of storage**.** CT = Control (uncoated), A75 = 75 mg L^{-1} gibberellic acid, A100 = 100 mg L^{-1} gibberellic acid, PEC = Pectin coating, P75 = Pectin added with 75 mg L^{-1} gibberellic acid, and P100 = Pectin added with 100 mg L^{-1} gibberellic acid.

Analysis	Time (Days)	Treatments					
		CT	A75	A100	PEC	P75	P100
TA (g citric acid/100 g of sample)	0	0.43^{aA}±0.00	0.43^{aA}±0.00	0.43^{aA} ±0.00	0.43^{aA} ±0.00	0.43^{aA} ±0.00	0.43^{aA} ±0.00
	4	0.36^{aC} ±0.01	0.27^{cdG} ±0.00	0.28^{cD} ±0.00	0.24^{eD} ±0.00	0.32^{bC} ±0.01	0.25^{deDE} ±0.00
	8	0.39^{abB} ±0.01	0.36^{bC} ±0.01	0.40^{aB} ±0.01	0.29^{cB} ±0.01	0.29^{cDE} ±0.00	0.29^{cBC} ±0.01
	12	0.30^{bE} ±0.00	0.33^{aD} ±0.01	0.31^{bC} ±0.01	0.27^{cC} ±0.00	0.34^{aB} ±0.00	0.27^{cCD} ±0.01
	16	0.28^{bEF} ±0.01	0.30^{aEF} ±0.0	0.22^{cdEF} ±0.00	0.23^{cD} ±0.00	0.30^{aD} ±0.00	0.21^{deF} ±0.00
	20	0.33^{aD} ±0.00	0.31^{bE} ±0.01	0.20^{dF} ±0.00	0.24^{cD} ±0.00	0.30^{bD} ±0.00	0.24^{cE} ±0.00
	24	0.29^{bEF} ±0.00	0.38^{aB} ±0.00	0.21^{dEF} ±0.00	0.24^{cD} ±0.00	0.30^{bDE} ±0.00	0.30^{bB} ±0.00
	28	0.27^{aF} ±0.01	0.29^{aEFG} ±0.00	0.22^{bE} ±0.00	0.23^{bD} ±0.01	0.24^{bF} ±0.00	0.24^{bE} ±0.00
	32	0.22^{bcG} ±0.01	0.28^{aFG} ±0.01	0.22^{cEF} ±0.00	0.24^{bD} ±0.01	0.28^{aE} ±0.00	0.24^{bE} ±0.00
pH	0	3.93^{aE} ±0.01	3.93^{aE} ±0.01	3.93^{aF} ±0.01	3.93^{aF} ±0.01	3.93^{aF} ±0.01	3.93^{aE} ±0,01
	4	3.97^{cD} ±0.01	3.99^{cD} ±0.01	3.97^{cE} ±0.01	4.18^{aCDE} ±0.01	4.06^{bE} ±0.01	4.08^{bD} ±0.02
	8	4.04^{dC} ±0.00	4.09^{cC} ±0.00	4.09^{cD} ±0.00	4.21^{aBCD} ±0.01	4.08^{cDE} ±0.00	4.13^{bC} ±0.02
	12	4.21^{abB} ±0.02	4.09^{cC} ±0.00	4.18^{bC} ±0.00	4.23^{aB} ±0.00	4.11^{cCD} ±0.01	4.22^{aB} ±0.00
	16	4.28^{aA} ±0.00	4.16^{cA} ±0.01	4.20^{bBC} ±0.01	4.28^{aA} ±0.00	4.22^{bAB} ±0.00	4.29^{aA} ±0.00
	20	4.29^{abA} ±0.01	4.12^{dB} ±0.00	4.20^{cC} ±0.01	4.18^{cDE} ±0.02	4.25^{bA} ±0.00	4.31^{aA} ±0.01
	24	4.28^{aA} ±0.00	4.18^{dA} ±0.00	4.23^{bB} ±0.01	4.16^{dE} ±0.00	4.21^{cB} ±0.00	4.23^{bB} ±0.00
	28	4.18^{bB} ±0.00	4.10^{cBC} ±0.01	4.27^{aA} ±0.01	4.17^{bE} ±0.01	4.09^{cCD} ±0.00	4.11^{cCD} ±0.00
	32	4.30^{bcG} ±0.01	4.18^{aFG} ±0.01	4.27^{cEF} ±0.00	4.22^{bD} ±0.01	4.12^{aE} ±0.00	4.20^{bE} ±0.00
TSS (°Brix)	0	4.00^{aC} ±0.00	4.00^{aC} ±0.00	4.00^{aB} ±0.00	4.00^{aC} ±0.00	4.00^{aBC} ±0.00	4.00^{aB} ±0.00
	4	4.00^{abC} ±0.00	3.93^{bCD} ±0.05	3.97^{abB} ±0.05	4.00^{abC} ±0.00	4.13^{aAB} ±0.09	3,97^{abB} ±0.05
	8	4.25^{aB} ±0.00	3.50^{cE} ±0.00	3.97^{bB} ±0.05	4.00^{bC} ±0.00	3.97^{bC} ±0.05	4.00^{bB} ±0.00
	12	3.75^{cD} ±0.00	3.83^{bcD} ±0.12	4.25^{aA} ±0.00	4.25^{aB} ±0.00	3.97^{bC} ±0.05	4.25^{aA} ±0.00
	16	4.00^{cC} ±0.00	4.50^{aA} ±0.00	4.00^{cB} ±0.00	4.23^{bB} ±0.02	4.25^{bA} ±0.00	3.97^{cB} ±0.05
	20	3.50^{bE} ±0.00	3.50^{bE} ±0.00	4.00^{aB} ±0.00	3.50^{bD} ±0.00	3.97^{aC} ±0.05	3.97^{aB} ±0.05
	24	3.75^{aD} ±0.00	3.25^{aF} ±0.00	3.75^{aC} ±0.00	4.00^{aC} ±0.00	3.75^{aD} ±0.00	3.75^{aC} ±0.00
	28	4.23^{aB} ±0.02	3.97^{bCD} ±0.05	3.75^{cC} ±0.00	3.97^{bC} ±0.05	3.97^{bC} ±0.05	4.25^{aA} ±0.00
	32	4.75^{aA} ±0.00	4.23^{cB} ±0.02	4.25^{cA} ±0.00	4.50^{Ba} ±0.00	4.25^{cA} ±0.00	4.25^{cA} ±0.00

Means followed by the same letter do not differ at the 5% significance level by Tukey's test. Capital letters compare means vertically (between days of the same treatment); lowercase letters compare means horizontally (between treatments on the same day). Data are presented as mean ±SD.

Weight loss

The weight loss percentage for all treatments over the storage duration is shown in Figure 1.

The samples treated with P75 and P100 showed significantly lower percentage weight loss than those in the control group since the eighth day. These treatments (P75 and P100) had lower mass loss values at the end of the experiment (4.90% and 3.74%, respectively) (Figure 1); the samples in the control group lost 6.00% of mass. The coatings formed on the surface of the fruits acted as a physical barrier, reducing the loss of moisture from the fruits (Toğrul; Arslan, 2004). This barrier property probably reduced thus water loss and oxidation reaction of fruits thus decreasing the respiration rate and the associated weight loss.

Hakim et al. (2013) evaluated the effect of post-harvest treatments of two banana (*Musa* spp. *L.*) varieties during storage and found that using 400 ppm of GA_3 showed the best result in delaying ripening among the different treatments used. Rao and Chundawat (1984) also reported that bananas treated with GA_3 showed a decrease in physiological weight loss.

Color parameters

Control and coated tomatoes showed some changes in the L*, a*, and b* values during the storage period. The effect of coating on L*, a*, and b* values is presented in Table 3.

The L* values decreased over the 32 days of storage in all treatments. The P100 treatments showed significantly higher L* values than the control on the last day (45.42), indicating that this treatment maintained fruit brightness until the end of the experiment. A low L* value at the end of the experiment might be related to the delay in the ripening process caused by the barrier effect associated with the loss of mass. Baldwin and Hagenmaier (2011) stated that applying edible coatings influences the brightness of food surfaces and contributes to higher L* values.

The reduction in L* values matched with the findings of studies that reported that this change occurs due to the development of the red color during the ripening of fruits, which leads to the loss of brightness caused by carotenoid synthesis and the reduction of the green color (López Camelo; Gómez, 2004). Oliveira et al. (2012) studied the storage of pectin-coated tomatoes and found similar changes in the L* value; they reported that pectin-based coatings considerably delayed the appearance of red color in tomatoes.

We found that the a* (red/green) values increased in all treatments due to fruit maturation. The a* values in the different pectin treatment groups were not significantly different on the last day of the experiment. The application of the coating effectively delayed the appearance of the red color; treatment with P100 (8.86) and P75 (9.18) yielded the best results, compared to the control (12.49).

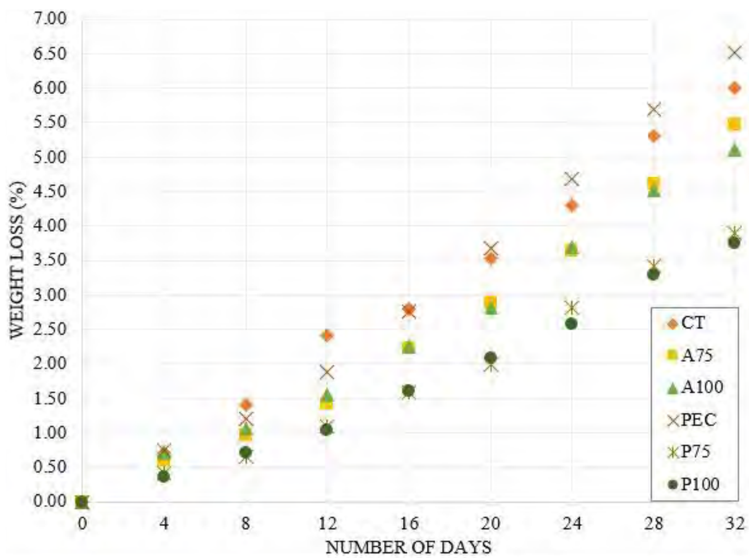

Figure 1: The graph illustrates the percentage of weight loss. CT = Control (uncoated). A75 = 75 mg L^{-1} gibberellic acid. A100 = 100 mg L^{-1} gibberellic acid. PEC = Pectin coating. P75 = Pectin added with 75 mg L^{-1} gibberellic acid. P100 = Pectin added with 100 mg L^{-1} gibberellic acid.

Table 3: Effect of coating on the L*, a*, b*, ΔE, and h° color values. CT = Control (uncoated), A75 = 75 mg L^{-1} gibberellic acid, A100 = 100 mg L^{-1} gibberellic acid, PEC = Pectin coating, P75 = Pectin added with 75 mg L^{-1} gibberellic acid, P100 = Pectin added with 100 mg L^{-1} gibberellic acid.

Analysis	Time (Days)	Treatments					
		CT	A75	A100	PEC	P75	P100
	0	50.26^{abA} ±1.55	48.68^{bcA} ±0.30	51.50^{aA} ±0.91	49.86^{abcA} ±0.88	48.54^{cA} ±1.60	49.83^{abcA} ±0.65
	4	47.15^{abB} ±2.22	47.29^{abAB} ±0.84	48.56^{aB} ±0.66	43.90^{cCDE} ±1.49	4521^{bcB} ±0.74	4764^{aB} ±1.66
	8	48.81^{aAB} ±0.86	45.20^{bcCDE} ±0.94	48.36^{aB} ±1.29	46.76^{bB} ±0.73	45.03^{cBC} ±0.77	46.51^{bcBC} ±1.24
	12	48.17^{aAB} ±0.87	46.02^{bBC} ±0.97	48.16^{aB} ±0.97	45.51^{bBCD} ±1.98	45.13^{bBC} ±1.17	45.91^{bC} ±1.06
L	16	43.92^{cC} ±1.39	45.63^{bCD} ±0.86	47.40^{aBC} ±0.98	46.02^{bBC} ±0.74	44.73^{bcBC} ±0.39	45.83^{bC} ±0.36
	20	43.48^{cC} ±1.53	45.84^{abBCD} ±1.00	47.51^{aBC} ±1.02	45.60^{bBC} ±0.96	44.50^{bcBC} ±1.16	44.83^{bcC} ±0.53
	24	42.58^{abC} ±0.98	44.94^{abCDE} ±1.13	47.51^{abCD} ±0.72	43.87^{bCDE} ±1.42	43.20^{bC} ±1.55	45.55^{aC} ±1.33
	28	44.20^{abC} ±1.89	44.48^{abDE} ±0.76	44.54^{abD} ±1.18	43.23^{bDE} ±1.79	43.26^{bBC} ±0.99	46.19^{aBC} ±0.72
	32	42.75^{bC} ±1.14	43.99^{abE} ±0.84	45.64^{aD} ±0.93	42.82^{bE} ±1.59	44.48^{abBC} ±1.43	45.42^{aC} ±0.85
	0	2.06^{aD} ±0.76	2.87^{aF} ±0.96	2.22^{aF} ±0.41	2.30^{aD} ±1.07	2.71^{aD} ±0.92	2.30^{aE} ±0.54
	4	939^{aCT} ±1.00	5.79^{bE} ±0.71	3.28^{cF} ±0.72	5.45^{bBC} ±1.27	5.58^{bC} ±1.17	3.81^{cDE} ±0.99
	8	957^{aBC} ±1.15	6.59^{bDE} ±0.71	3.71^{cEF} ±0.61	4.60^{cCD} ±0.797	5.38^{bcC} ±1.40	4.48^{cCDE} ±1.49
	12	970^{aBC} ±0.35	7.17^{bCDE} ±1.49	3.66^{cEF} ±0.56	5.11^{bBC} ±1.97	6.93^{bBC} ±0.81	4.79^{cCDE} ±1.79
a*	16	1019^{aBC} ±0.68	8.16^{bCD} ±1.39	5.43^{cDE} ±0.35	5.38^{cBC} ±1.60	8.10^{bAB} ±0.60	5.59^{cBCD} ±1.60
	20	1054^{aBC} ±0.53	8.10^{bCD} ±1.36	6.10^{bCD} ±0.91	6.05^{bBC} ±1.65	8.07^{bAB} ±0.88	6.90^{bABC} ±2.11
	24	1027^{aBC} ±1.23	9.05^{abBC} ±0.81	7.80^{bcBC} ±2.39	6.06^{cBC} ±0.91	8.17^{abcAB} ±1.18	7.78^{bcAB} ±0.94
	28	1087^{aB} ±0.63	10.96^{aAB} ±1.76	9.15^{abAB} ±1.76	7.80^{bAB} ±2.29	9.00^{abcA} ±1.33	7.95^{bAB} ±0.93
	32	1249^{aA} ±0.44	11.21^{abA} ±1.09	9.98^{abA} ±1.05	9.19^{bA} ±1.99	9.18^{bA} ±1.21	8.86^{bA} ±2.71
	0	20.15^{bD} ±1.13	25.51^{aABC} ±1.41	22.34^{bBC} ±1.97	26.61^{aABC} ±0.73	22.21^{bBC} ±2.51	25.84^{aB} ±1.36
	4	22.85^{cdABC} ±1.22	26.30^{abA} ±2.05	20.29^{dCD} ±1.11	23.73^{bcCD} ±2.12	25.87^{abA} ±1.63	27.79^{aAB} ±2.64
	8	23.84^{cAB} ±0.97	19.97^{dE} ±1.03	22.76^{cB} ±0.88	30.22^{aA} ±1.06	23.86^{cAB} ±0.96	27.89^{bAB} ±2.54
	12	23.06^{bcABC} ±1.58	25.87^{abAB} ±1.20	25.52^{abA} ±1.84	26.74^{aABC} ±2.07	22.34^{cBC} ±2.87	27.96^{aAB} ±1.37
	16	22.67^{cdABC} ±0.70	23.90^{bcBCD} ±1.26	20.99^{deBC} ±0.75	25.32^{bBC} ±2.26	19.93^{eC} ±1.34	30.34^{aA} ±1.37
b*	20	25.01^{abA} ±2.75	23.23^{bcCD} ±1.78	22.77^{bcB} ±0.94	28.69^{aAB} ±1.65	20.51^{cC} ±1.16	28.94^{aAB} ±1.78
	24	21.07^{bcCD} ±1.04	2236^{bD} ±.24	21.45^{bcBC} ±.53	20.84^{bcD} ±2.63	20.02^{eC} ±1.13	28.80^{aAB} ±2.51
	28	21.84^{bcBCD} ±1.58	22.57^{bD} ±1.14	18.27^{dD} ±1.05	23.75^{bCD} ±2.76	19.40^{cdC} ±1.86	27.77^{aAB} ±1.09
	32	21.66^{bBCD} ±1.09	18.97^{cE} ±1.01	21.93^{bBC} ±0.65	24.22^{bCD} ±2.39	22.06^{bBC} ±2.51	28.92^{aAB} ±1.88
	0	0.00	0.00	0.00	0.00	0.00	0.00
	4	8.40	3.25	3.10	6.75	6.75	3.47
	8	8.49	5.70	3.53	3.83	5.31	4.60
	12	8.44	5.11	3.67	5.31	5.59	5.22
	16	10.61	6.25	5.25	4.90	6.53	7.05
ΔE	20	11.89	6.15	5.52	5.47	6.60	7.61
	24	11.50	7.58	7.73	7.07	7.48	7.72
	28	10.82	9.47	9.66	8.52	8.16	7.14
	32	12.93	10.00	9.84	9.79	7.70	8.64

Continue..

Table 3: Continuation.

Analysis	Time (Days)	Treatments					
		CT	A75	A100	PEC	P75	P100
h°	0	1.47^{aA} ±0.03	1.46^{aA} ±0.03	1.47^{aA} ±0.01	1.49^{aA} ±0.04	1.45^{aA} ±0.03	1.48^{aA} ±0.02
	4	1.182^{cBC} ±0.02	1.35^{aA} ±0.01	1.41^{aA} ±0.02	1.35^{bCD} ±0.03	1.36^{bB} ±0.03	1.44^{aAB} ±0.02
	8	1.19^{dB} ±0.03	1.25^{aA} ±0.02	1.41^{aA} ±0.02	1.42^{aAB} ±0.02	1.35^{bB} ±0.05	1.41^{aB} ±0.04
	12	1.17^{cBC} ±0.01	1.30^{aA} ±0.04	1.43^{aA} ±0.01	1.39^{aBC} ±0.06	1.27^{bC} ±0.02	1.40^{aBC} ±0.05
	16	1.15^{dCD} ±0.01	1.24^{bB} ±0.04	1.32^{bB} ±0.01	1.36^{aBC} ±0.04	1.18^{dDE} ±0.01	1.39^{aBC} ±0.04
	20	1.17^{dBC} ±0.27	1.24^{bB} ±0.03	1.31^{bB} ±0.03	1.37^{aBC} ±0.04	1.20^{cdD} ±0.02	1.34^{abCD} ±0.03
	24	1.12^{dDE} ±0.03	1.19^{bcC} ±0.03	1.23^{bcC} ±0.08	1.29^{abDE} ±0.01	1.18^{cDE} ±0.03	1.31^{aD} ±0.02
	28	1.11^{bE} ±0.01	1.12^{bD} ±0.05	1.11^{bD} ±0.08	1.26^{aEF} ±0.05	1.14^{bE} ±0.03	1.29^{aD} ±0.02
	32	1.05^{dF} ±0.01	1.04^{cD} ±0.02	1.14^{cD} ±0.03	1.21^{bF} ±0.04	1.18^{bcDE} ±0.02	1.28^{aD} ±0.07

Means followed by the same letter do not differ at the 5% significance level (p > 0.05) by Tukey's test. Capital letters compare means vertically (between days of the same treatment); lowercase letters compare means horizontally (between treatments on the same day). Data are presented as mean ±SD.

For the b* parameter, no significant interaction was recorded between treatments and storage time. The b* value of the P100 treatment differed from that of the other treatments from day 24 onwards, showing a higher value at the end of the experiment (28.92). The total color variation increased for all fruits during storage. The ΔE values in treatments P75 (7.70) and P100 (8.64) were lower than the ΔE value in the control (12.94), indicating that these coatings prevented large color variations.

The hue angle (h°) represents the hue, which can vary from 0° to 90°; values closest to 0° indicate the strongest and most intense shades of red (pure red), while those close to 90° indicate pure yellow (Arias et al., 2000). The P100 treatment (1.273) showed a smaller reduction in this parameter than the control (1.048). These results indicated that the coatings adequately obstructed gas exchange between the fruits and the ambient environment, which prevented various physical and chemical changes from occurring during storage.

Firmness

The results for the firmness of the tomatoes during the storage period are presented in Figure 2.

Firmness decreased over time. The control and the A100 treatments showed the most significant reduction in this parameter, with no significant differences between them. The P75 coating was the best treatment; the initial and final firmness values were 8.371 N and 6.329 N, respectively. Thus, this treatment decreased the respiration rate, delayed ripening, and maintained the firmness and stability of the fruits during storage.

The P75 coating effectively inhibited the softening of fruit tissue by decreasing pectin degradation catalyzed by polygalacturonase (Alexander; Grierson, 2002). This protective layer on the surface of the tomatoes inhibited evaporation and fruit respiration; thus, decreasing water loss, compared to the control. The coating helped maintain the firmness of tomatoes by decreasing ethylene synthesis and enzyme activity.

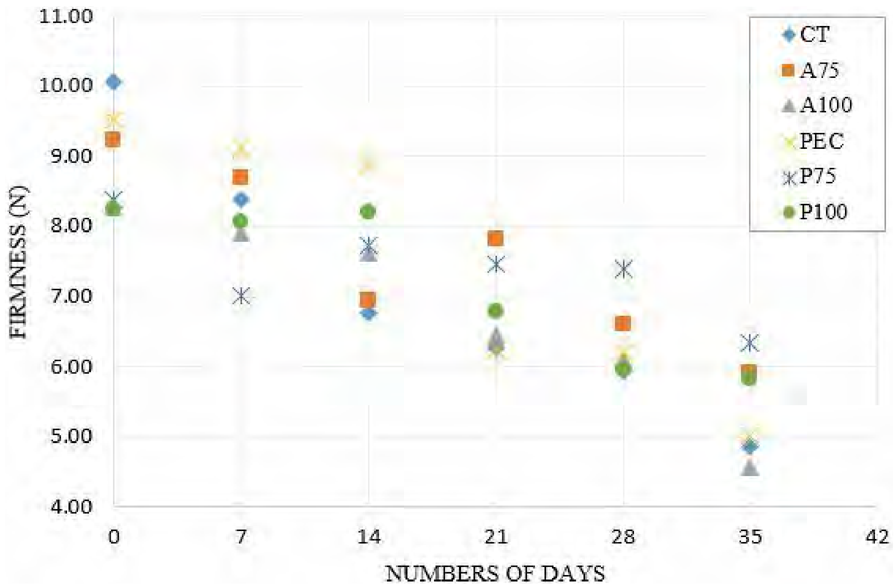

Figure 2: Effect of different treatments on the firmness of tomatoes (N) at different days during the storage period. CT = Control (uncoated). A75 = 75 mg L^{-1} gibberellic acid. A100 = 100 mg L^{-1} gibberellic acid. PEC = Pectin coating. P75 = Pectin added with 75 mg L^{-1} gibberellic acid. P100 = Pectin added with 100 mg L^{-1} gibberellic acid.

CONCLUSIONS

The P75 coating was the most effective in delaying changes in weight, firmness, titratable acidity, pH, and color; thus, it significantly extended the shelf life of tomatoes. The P100 coating also showed promising results regarding the external characteristics of the fruits, such as skin color and weight loss. Therefore, this study provided robust results related to the effects of combining pectin with gibberellic acid on delaying the ripening process, prolonging the shelf life, and maintaining the physical and chemical characteristics of fruits.

AUTHORS CONTRIBUTIONS

Conceptual idea: Karina, S. U. F.; Silvia, M. M; Methodological design: Silvia, M. M.; Karina, S. U F; Data collection: Karina, S. U. F.; Igor, G. S. O.; Vinicius, N. B. S.; Silvia, M.M; Data analysis and interpretation: Karina, S. U. F.; Igor, G. S. O.; Silvia, M.M.; Vitor, A. S. G.; Ângela, D. C. A., Writing and editing: Karina, S. U. F.; Silvia, M.M.; Vitor, A. S. G.; Ângela, D. C. A.

ACKNOWLEDGMENTS

We would like to thank the National Council for Scientific and Technological Development (CNPq) and the Coordination for the Improvement of Higher Education (CAPES) for providing financial support and all collaborators of this study. We would also like to thank Atlas Assessoria Linguística for language editing.

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