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Quality assessment of beef burgers packaged in active paper with cinnamon essential oil

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Abstract

The aim of this study was to evaluate a new packaging system in which the paper was covered with a solution of sodium alginate and cinnamon essential oil (CEO) that was used as packaging for burger beef. The papers were characterized for their physical, optical, mechanical, and sorption properties. In addition, the burgers were evaluated for their antioxidant activity, lipid oxidation, and color difference. In total, four treatments were developed: Con: paper without coating; Pad: paper with alginate coating; Pco 0.1: paper with alginate coating added with 0.1% CEO; and Pco 0.05: paper with alginate coating added with 0.05% CEO. The analysis of the thickness showed the effectiveness in the formation of the film coating, which was confirmed by the analysis of morphology. The results indicated that the coating had no improvement in mechanical properties nor in water vapor permeability (WVP); however, color changes were noted ($P<0.002$). The sorption isotherms showed that the equilibrium was not modified for the coated papers. All samples showed an increase in the value of malonaldehyde during storage ($P<0.003$) and a decrease in antioxidant activity ($P<0.001$). However, in papers containing CEO, these modifications were lower when compared to Pad and Con. In addition, the samples containing CEO presented a lower color difference ($P<0.002$).

Keywords: alginate; active packagings; meat quality; sustainability; shelf life.

Practical Application: The papers coated with CEO had an effect on meat oxidation, thus helping to maintain the quality of beef burgers during display. In addition, papers with essential oil coating have the advantage of being more sustainable and biodegradable.

1. INTRODUCTION

The depletion of natural resources caused by petroleum-based plastics and the growing concern with the environment have raised interest in the use of new packaging materials (Vital et al., 2016; Vital et al., 2018a; Vital et al., 2018b). Aligned to this new trend are intelligent or bioactive packagings, which, in addition to protection, have added new functions, thus contributing to food preservation and reduction of chemical preservatives (Alexandre et al., 2021; Kempinski et al., 2017).

To meet industrial needs and reduce problems arising from the use of non-biodegradable products, new materials have been studied (Vital et al., 2016; Vital et al., 2018a; Vital et al., 2018b). It is known that the type of cover used should be evaluated for each type of food product depending on its pH characteristics, lipid content, among other requirements (Alexandre et al., 2021; Kempinski et al., 2017; Vital et al., 2016). Specifically, in fresh meats that have relatively short shelf life, even an increase of 1 day in shelf life significantly reduces losses (Van Haute et al., 2017).

Paper-based and cellulosic derivatives are eco-friendly alternatives since they are abundant in addition to being renewable, biodegradable, and recyclable (Zhang et al., 2014). However, for food applications and food safety reasons, food paper should be coated, usually with a plastic material of fossil origin (Battisti et al., 2017). In this context, an alternative to harmful plastics would be natural polymers, and natural raw material packages are promising alternatives due to their biodegradability, biocompatibility, low toxicity, and renewability (Sirviö et al., 2014). In this sense, the polysaccharide derived from brown algae (*Phaeophyceae*), called alginate, is widely used in several segments due to its good film-forming properties and non-toxicity. In addition, the food industry has used it in the form of coatings or hydrogels (Alexandre et al., 2021; Vital et al., 2016).

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Together with natural polymers, the use of essential oils as a substitute for synthetic preservatives to prolong shelf life has become popular as consumers become more aware of potential health problems associated with synthetic products (Alexandre et al., 2021; Vital et al., 2016). However, due to strong aromas and accentuated flavors, the direct use of essential oils in food is still restricted (Ghaderi-Ghahfarokhi et al., 2017). Thus, an alternative to the incorporation of essential oils into foods without sensorially damaging them is their use in packaging (Echegoyen & Nerín, 2015).

Biodegradable packaging may have limitations on some properties when compared to conventional plastic packaging. Thus, the characterization of mechanical and sorption properties becomes essential when the final application of these packages is suggested and studied (Fadini et al., 2013).

This study was realized to develop a new package by applying the coating of cinnamon essential oil (CEO) to beef burger paper and evaluating the packaging for physical and mechanical properties, optics, sorption, and WVP, as well as its maintenance and application to the quality of the hamburgers during their shelf life.

2. MATERIALS AND METHODS

2.1. Reagents

Gallic acid, 2,2-azinobis-3-ethylbenzotiazoline-6-sulfonic acid (ABTS), sodium carbonate, potassium persulfate, trichloroacetic acid (TCA), hydrochloric acid, 1,3,3-tetramethoxypropane, and thiobarbituric acid were obtained from Sigma-Aldrich (USA). Sodium alginate was purchased from Dinamica (Brazil) and CEO from Ferquima® (Brazil).

2.2. Ethics declarations

The consumer analysis was approved by the Committee on Ethics in Research, Faculdade Ingá/Uningá, PR, Brazil, with a protocol number: 1.637.521 CAAE: 56109216.4.1001.5220.

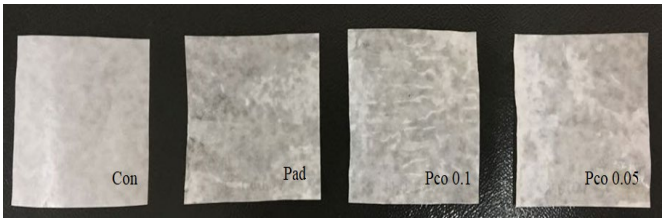
2.3. Coating preparation and packaging development

The film-forming solutions were prepared using the methodology proposed by Wang et al. (2017) with some modifications as follows: 1.5% glycerol was dissolved in water under magnetic stirring at 45°C for 45 min, and then alginate (%) was added and homogenized with the aid of an ultra-turrax (IKA®-T10, USA) at 8,000 rpm for 10 min. After complete dissolution, the mixture was cooled to 25°C. The active solution contained 0.1% CEO, and Tween 80 (0.25% of oil weight) was added to the solution. After the film-forming solutions reached room temperature, they were manually applied onto sheets of paper (1 mL of solution/100 cm^2 of paper). The packaging was dried by forced circulation at 35°C for 24 h and subsequently used as packaging for beef burgers. Table 1 shows the treatments evaluated. Figure 1 shows the image of treatments.

Table 1. Formulations of coatings applied to sheets of paper.

Treatments	Formulations of coatings, %			
	Alginate	Glycerol	Tween 80	Essential oil
CONT	-	-	-	-
PAC	1	1.5	0.25	-
PAC1	1	1.5	0.25	0.1
PAC5	1	1.5	0.25	0.05

CONT: paper without coating; PAC: paper with alginate coating; PAC1: paper with alginate coating added with 0.1% cinnamon oil; PAC5: paper with alginate coating added with 0.05% cinnamon oil.



CONT: paper without coating; PAC: paper with alginate coating; PAC1: paper with alginate coating added with 0.1% cinnamon oil; PAC5: paper with alginate coating added with 0.05% cinnamon oil.

Figure 1. Image of the different papers.

2.4. Packaging characterization: coated paper

2.4.1. Permeability to water vapor

Water vapor permeability was measured using a modified method developed by American Society for Testing and Materials (ASTM) (apud Fadini et al., 2013). The film samples were sealed in an aluminium permeation cup containing calcium chloride anhydrous (2% moisture) with silicone vacuum grease and a rubber gasket. The cups were placed at 24°C in a desiccator at 53% controlled humidity at room temperature (24°C), followed by weighing after every 1 h interval for up to 8 h. In total, five film samples were used for WVP testing. The water permeation rate was calculated according to Equation 1.

$$PVA=\left[\frac{\Delta w}{\Delta t}\right] x \left[\frac{x}{A.\Delta P}\right] \quad (1)$$

Where:

ΔW: the moisture gain weight (g) after 12 h,;

X: the thickness of the paper (m);

A: the exposed area of the paper (m^2);

ΔP: the water vapor pressure difference along the paper, which was calculated based on the chamber temperature and the moisture inside and outside the glass (ΔP=3,167 Pa at 25°C).

2.4.2. Optical properties

Light transmission of films against ultraviolet (UV) and visible light was measured at selected wavelengths between 200 and 600 nm using a UV-visible spectrophotometer (Evolution 201 UV-visible spectrophotometer, Thermo Scientific) according to the method developed by Ahmad et al. (2012). The transparency value of film was calculated by Equation 2 (Han & Floros, 1997):

$$\text{Opacity} = \frac{A_{600}}{x} \quad (2)$$

where:

$_{A600}$: the absorbance value at 600 nm;

x: the thickness (mm).

The color of samples was determined using a CIE colorimeter (Konica Minolta 1 Model, CR-400). The color of the film was expressed as L* (lightness/brightness), a* (redness), and b* (yellowness values). The total difference in color (ΔE*) was calculated according to Equation 3 (Gennadios et al., 1997).

$$\Delta E^* = \sqrt{(\Delta L^*)^2 + (\Delta a^*)^2 + (\Delta b^*)^2} \quad (3)$$

where:

ΔL*, Δa*, and Δb*: differences between color parameters corresponding to standard simple white (L*92.75, a*0.95, b*0.54).

2.4.3. Thickness and grammage

The thickness of film samples was measured using a digital micrometer (Mitutoyo Corp., Kawasaki, Japan). Notably, 10 random locations around each film sample were used for the determination of thickness.

2.4.4. Mechanical properties

Tensile strength (TS) and elongation at break (EAB) of film samples were determined using a TA.TX plus texture analyzer (Texture Technologies Corp., Serial No. 41288, Godalming, Surrey, United Kingdom), as described by Hoque et al. (2011). The measurements of 2.5×8 cm samples with an initial length of 3 cm were cut for testing. The speed was adjusted to 50 mm (5 mm/min).

2.4.5. Scanning electron microscopy

The morphology of the paper samples was investigated by scanning electron microscopy (SEM) at an acceleration voltage of 10–20 kV. Strips of dry paper (obtained by desiccating with silica gel for 2 weeks) were immersed in liquid nitrogen and cryo-fractured manually to observe the surface and cross-section of the paper.

2.4.6. Sorption isotherm

The equilibrium moisture sorption isotherm of the samples at 24°C was evaluated using the method described by AOAC (2005). Equilibrium moisture content at 24°C (g absorbed water/g dry film) was measured for each water activity. Experimental data were modeled using the GAB equation (Equation 4).

$$Mw = \frac{(M_0 \times C \times k \times a_w)}{(1 - k \times a_w) \times (1 - k \times a_w + C \times k \times a_w)} \quad (4)$$

where:

Mw: the equilibrium moisture (g water/g dry paper);

M_0: the moisture in the molecular monolayer (g water/g dry paper);

C: the GAB constant related to sorption in the monolayer;

k: the correction factor related to sorption in the monolayer;

a_w: the water activity (decimal relative moisture).

2.4.7. Beef burger packaging

The package for the beef burgers was prepared according to the method used by Battisti et al. (2017), with modifications. Meat was obtained from four crossbred bulls (½ BonsMara × ½ Nellore), slaughtered at 20 months of age with an average weight of 410 kg. After slaughter, the carcasses were refrigerated at 4°C for 24 h. Then, *Longissimus dorsi* (LD) were removed, vacuum packed, and frozen at -18°C until analysis. The covers were thawed at 4°C and ground in an industrial grinder. Then, beef burgers (70% beef and 30% fat) of approximately 50 g and 2.5 cm thickness were molded and randomly distributed for treatment applications.

The treatments were defined as follows: CON, paper without coating; PAC, paper with alginate coating; PAC1, paper with alginate coating added with 0.1% cinnamon oil; and PAC5, paper with alginate coating added with 0.05% cinnamon oil. Each beef burger was individually packed in paper without or with coated essential oil. Three independent replicates were performed for each treatment (triplicates), and the experiment was performed in duplicate. After packing, the samples were stored at 4°C. Samples were randomly removed at 1, 3, and 7 days of display for analysis.

2.5. Meat quality indicators

2.5.1. Antioxidant activity: ABTS and DPPH

Meat extracts were obtained by homogenizing 5 g of each sample with 10 ml of methanol in an Ultra-Turrax homogenizer (IKA®-T10, USA), followed by centrifugation (15 min, 4,000 rpm) and paper filtration (80 g/m², thickness 205 µm, 14 µm pores). The extracts were used directly to evaluate the antioxidant activity of the samples.

The ABTS assay was conducted according to Re et al. (1999), with modifications. ABTS was generated through the interaction of a 7 mM (5 ml) ABTS solution with 88 mL of 140 mM potassium persulfate. The mixture was incubated in the dark at 25°C for 16 h and then diluted with ethanol to an absorbance of 0.70±0.02. Samples (30 ml) were mixed with the ABTS solution (3,000 µL) and the absorbance was recorded at 734 nm after 6 min. The radical scavenging activity (%) was calculated as follows (Equation 5):

$$\text{ABTS radical scavening activity } (\%) = \left(1 - \left(\frac{A_{sample,t=0}}{A_{sample,t}}\right)\right) * 100 \quad (5)$$

where:

$sample_{t=0}$: absorbance of the sample at time zero;

$sample_t$: absorbance of the sample along time.

The DPPH radical scavenging activity was measured according to the methodology proposed by Li et al. (2009), with modifications. Meat extract (150 µL) was mixed with 2,850 µL of a methanolic solution containing DPPH (60 µM) and reacted for 30 min. The absorbance at 515 nm was measured against pure methanol. Antioxidant activity was calculated as follows (Equation 6):

$$\text{DPPH radical scavening activity } (\%) = \left(1 - \left(\frac{A_{sample,t=0}}{A_{sample,t}}\right)\right) * 100 \quad (6)$$

where:

$sample_{t=0}$: absorbance of the sample at time zero;

$sample_{t}$: absorbance of the sample at 30 min.

2.5.2. Lipid oxidation

The sample (5 g) was mixed with TCA solution (7.5% TCA, 0.1% EDTA, and 0.1% gallic acid) (10 mL), homogenized using a vortex, then centrifuged at 4,000 rpm at 4°C for 15 min. The supernatant was filtered and mixed (1:1 v/v) with thiobarbituric acid reactive substances (TBARS) reagent (1% TBA, 562.5 mM HCl, 15% TCA). The mixture was boiled at 100°C for 15 min and cooled, and then the absorbance was measured at 532 nm.

TBA-reactive substances (TBARS) assay (Vital et al., 2016) included the following steps. The sample (5 g) was mixed with TCA solution (7.5% TCA, 0.1% EDTA, and 0.1% gallic acid) (10 ml), homogenized using an Ultra Turrax, and then centrifuged at 4°C for 15 min at 4,000 rpm. The supernatant was filtered and mixed with TBARS reagent (1% thiobarbituric acid, 562.5 µM, HCl, 15% TCA) (1:1 v/v). The mixture was heated at 100°C for 15 min and cooled to room temperature, and then the absorbance was measured at 532 nm. The concentrations were determined using an MDA standard curve (using 1,3,3-tetramethoxypropane), ranging from 0 to 60 mM. Results were expressed as mg MDA kg^{-1} of beef burger.

2.5.3. Beef burgers instrumental color

The color difference (ΔE*) was evaluated in relation to display time (previously described in Optical properties). The color parameter readings were performed directly in contact with samples at different points of the sample for each treatment.

2.5.4. Statistical analysis

The packing attributes were assessed by analysis of variance using the general linear model (GLM) with SPSS (v.15.0) (IBM SPSS Statistics, SPSS Inc., Chicago, USA) for Windows. The mean and standard deviation were calculated for each variable. The type of treatments and storage time were considered fixed factors in a factorial design, with triplicates per treatment for each analysis. When differences were statistically significant, Tukey's test was performed, with statistical significance set at p=0.05.

3. RESULTS AND DISCUSSION

3.1. Paper characterization

3.1.1. Physical measurements

The coatings increased the paper thickness (P<0.010), which presented thicknesses of 0.022, 0.032, 0.033, and 0.031 mm for CONT, PAC, PAC1, and PAC5, respectively (Table 2). As with the thickness, the grammage of the control paper differed (P<0.010) by 32.666, 40.666, 41.333, and 39.33 g/cm^2, respectively (Table 2). Thus, the increase in thickness and grammage occurred due to the application of the paper coating. According to Ahmed et al. (2016), the thickness and grammage are highly dependent on the type of coating agent and the method used.

The addition of coating increased permeability to water vapor (P<0.001). The incorporation of coating to the papers increased the WVP of 1.730 from CONT paper to 4.106, 2.996, and 4.436 g mm/m^2 day kPa for PAC, PAC1, and PAC5, respectively (Table 2). The decrease in the barrier properties of the coated papers may be related to the modification of the polymer matrix structure due to the presence of alginate and oils (Wu et al., 2017). The addition of lipids to the microstructure of the film is a determining factor in the efficiency of the water barrier, and the hydrophobicity of the oil contributes to the increase of the WVP (Ojagh et al., 2010). The amount of essential oil is also an important factor since the hydrophobicity of the oil contributes to the significant increase of the WVP with the possible formation of areas with large oil droplets, which can cause discontinuity in the paper matrix (Zhang et al., 2015).

3.1.2. Mechanical properties

The TS and EAB values associated with the treatments are provided in Table 2. The TS of the papers containing alginate

Table 2. Properties of the papers.

	Treatments				SEM	P-value
	CONT	PAC	PAC1	PAC5		
Thickness (mm)	0.022[b]	0.032[a]	0.033[a]	0.031[a]	0.001	0.010
Grammage (g cm^{-2})	32.666[b]	40.666[a]	41.333[a]	39.333[a]	1.209	0.010
WVP×10^{-8} (g.mm/m^2.day.kPa)	1.730[c]	4.106[a]	3.996[a]	4.436[a]	0.338	0.001
TS (MPa)	83.034[a]	76.024[b]	75.964[b]	78.139[b]	0.576	0.001
EAB (%)	4.695[c]	6.519[b]	6.095[b]	7.166[a]	0.106	<0.001

The means of treatments with different small letters in the same line are significantly different (P<0.05). CONT: paper without coating; PAC: paper with alginate coating; PAC1: paper with alginate coating added with 0.1% cinnamon oil; PAC5: paper with alginate coating added with 0.05% cinnamon oil; SEM: standard error of means; WVP: permeability to water vapor; TS: tensile strength; EAB: elongation at break.

coating and oil decreased (P<0.001) from 83.034 (CONT) to 76.024, 75.964, and 78.139 for PAC, PAC1, and PAC5, respectively, showing that the coating resulted in the weakening of the papers.

Differences were observed for EAB (P<0.001), where the coatings with alginate and essential oil increased, being 6.519% for PAC, 6.095% for PAC1, and 7.166% for PAC5, respectively, in comparison to 4.695% for CONT (Table 2).

The reduction of resistance is associated with the swelling suffered by the cellulose fibers due to the penetration of the coating, interfering in the fiber-fiber interaction, resulting in the modification of mechanical proprieties (Battisti et al., 2017). The addition of essential oil to polymer matrices causes a weakening in the structure, resulting in an increase in EAB and a reduction in TS (Sayanjali et al., 2011).

3.1.3. Optic properties

The transparency (Table 3) did not present a difference (P<0.061) for any of the papers, showing that the incorporation of coating and essential oil did not affect this property. The parameters L* (P<0.747) and a* (P<0.127) did not differ among the papers analyzed. The coordinate b* (P<0.002), on the other hand, showed an increase in yellow color intensity for the coated papers (PAC, PAC1, and PAC5) compared to uncoated paper (CONT). The coated papers had a high color difference (ΔE) (P<0.002) when compared to the CONT paper. These results suggested that the coating of alginate and alginate with essential oil had an influence on the color of the paper. Ahmed et al. (2016) reported that the incorporation of essential oils affects the coating color due to the presence of colored components in the oil. However, color variations of staining from 1.5 to 5.0 are minimally perceived by the human eye (Obón et al., 2009).

3.1.4. Sorption isotherm

When analyzing Table 4, it is noted that the Mo ($g.g^{-1}$) values increased in the papers with the addition of essential oils (PAC1 and PAC5), reflecting the hydrophilic nature of these compared to CONT and PAC. For our papers, the parameter K ranged from 0.443 to 0.664, indicating that the water is less strongly bound. The correlation coefficients (R^2) showed that the experimental data for all treatments were satisfactorily adjusted to the GAB model, presenting values ranging from 0.982 to 0.995. Ahmat et al. (2014) reported that the GAB model is one of the most suitable for agri-food products.

With the observed sorption isotherms, the papers showed relative humidity equilibrium in the range of 40–50%. The incorporation of biopolymer coatings on cellulose leads to changes in the characteristics of the material since, depending on the composition, these coatings may favor bonds with water molecules by modifying their equilibrium range (Torres et al., 2012).

3.1.5. Morphology

SEM images and paper cross sections with and without coatings are shown in Figure 2. It can be seen that the cross section of the control paper was coarser in relation to the papers with a coating that had a more compact structure. In addition, the surface of the control paper appeared to be rougher than that

Table 4. Calculated parameters of the GAB equation.

Treatments	Mo ($g.g^{-1}$)	C	K	R^2
CONT	0.059	5.103	0.664	0.982
PAC	0.078	3.597	0.547	0.995
PAC1	0.081	6.424	0.479	0.988
PAC5	0.086	7.647	0.443	0.988

CON: paper without coating; PAC: paper with alginate coating; PAC1: paper with alginate coating added with 0.1% cinnamon oil; PAC5: paper with alginate coating added with 0.05% cinnamon oil.

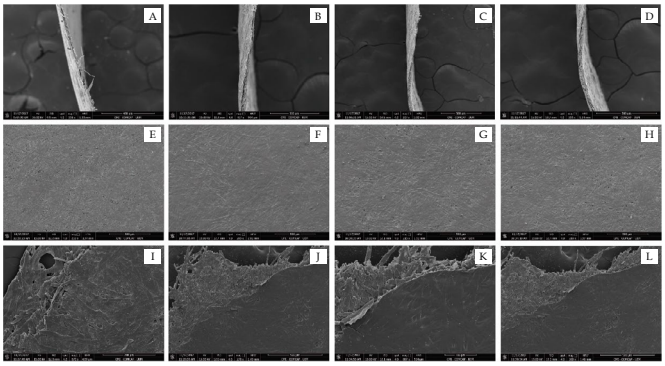


Figure 2. Microscopy of cross sections, surfaces, and fracture surfaces of different papers: (A, E, I) paper without coating; (B, F, J) paper with alginate coating; (C, G, K) paper with alginate coating added with 0.1% cinnamon oil; (D, H, L) paper with alginate coating added with 0.5% cinnamon oil.

Table 3. Transparency and color of papers without and with coating.

	Treatments				SEM	P-value
	CONT	PAC	PAC1	PAC5		
Transparency (A_{600}/mm)	39.935	39.466	31.009	34.926	1.440	0.061
L*	90.637	90.273	90.471	90.335	0.114	0.747
a*	−0.180	−0.131	−0.243	−0.216	0.018	0.127
b*	1.007^{b}	1.323^{ab}	1.633^{a}	1.554^{a}	0.080	0.002
Color difference (ΔE)	1.115^{a}	1.864^{b}	1.606^{b}	1.700^{b}	0.092	0.002

Then means of treatments with different small letters in the same line are significantly different (P<0.05); CONT: paper without coating; PAC: paper with alginate coating; PAC1: paper with alginate coating added with 0.1% cinnamon oil; PAC5: paper with alginate coating added with 0.05% cinnamon oil; SEM: standard error of means.

of the coated papers. The more homogeneous surface after the application of the coating may be associated with pore filling and the formation of a layer on the paper (Ahmad et al., 2012).

3.2. Meat quality indicators

3.2.1. Antioxidant activity

The results (Table 5) show that the samples containing cinnamon oil showed higher antioxidant activity (P<0.001) than the CONT and PAC samples. The interaction between treatments and storage time was observed for the DPPH and ABTS (P<0.05) (Figure 3).

On the first day of display, the inhibition of both DPPH and ABTS did not differ (P<0.05). The antioxidant activity was gradually reduced during the days of display. However, from third to seventh days, the hamburgers with coated paper did not lose radical reduction activity DPPH and ABTS, reaching values of 26.08, 25.70, 32.74, and 31.64% elimination of the DPPH (P<0.001) radical and 26.647, 29.895, and 30.000% of ABTS (P<0.027) radical elimination, respectively, on day 7 of display. During the display, the hamburgers packed with coated papers exhibited better antioxidant activity. Natural antioxidants can inhibit and/or reduce meat oxidation, avoiding sensory modifications. Higher antioxidant activity can help maintain meat quality throughout its shelf life (Oliveira et al., 2017). These results indicate that cinnamon oil can be used as a radical scavenger or inhibitor of oxidation in meat because its compounds have antioxidant activity due to their ability to be donors of hydrogen atoms or electrons and capture free radicals, thus ending the reaction in the peroxide chain, decreasing the adverse effects of display time and the formation of free radicals, prolonging the shelf life of the product (Zhang et al., 2017).

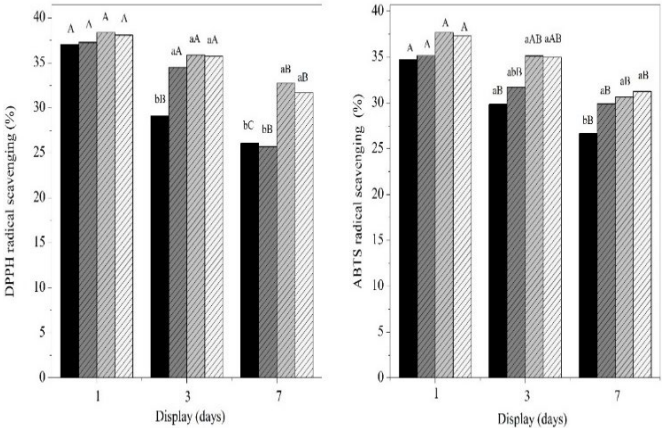
3.2.2. Lipid oxidation

Lipid oxidation was higher (higher TBARS value, P<0.03) in hamburgers from the CONT treatment compared to hamburgers from the PAC, PAC1, and PAC5 treatments, respectively (Table 5). However, no difference was observed in the oxidation of lipids between hamburgers with only alginate coating and those that received, in addition to alginate coating, essential oils (Table 5). In general, the inclusion of essential oils in the diet or in meat and hamburgers reduces lipid oxidation (Kempinski et al., 2017; Vital et al., 2016; 2021).

Lipid oxidation increased (P<0.05), as expected, during display (1–7 days). Oxidation, as well as the growth of microorganisms, leads to the deterioration of quality in foods, loss of quality during display, and is also associated with consumer rejection (Vieira et al., 2017).

When the effects of both factors were evaluated, an interaction between them was observed, as illustrated in Figure 4.

The TBARS values of control, alginate coated (PAC), and CEO coated (PAC1 and PAC5) increased after day 3, reaching values of 0.39, 0.29, 0.21, and 0.24 MDA mg kg^{-1} of beef burger, respectively, at day 7 (P<0.001) of display. The CONT treatment reached the maximum oxidation value after 7 days of storage. However, the differences between treatments were different (P<0.001) after 3 days of storage. TBARS values were 0.395 mg MDA kg^{-1} of meat to CONT and 0.286, 0.207, and 0.236 mg MDA kg^{-1} of beef burger PAC, PAC1, and PAC5, respectively, at the end of storage. All samples presented an increase in MDA value during storage. However, the increase was more accentuated in CONT, which was probably due to the relative lack of compounds with antioxidant activity. Essential oils are known to



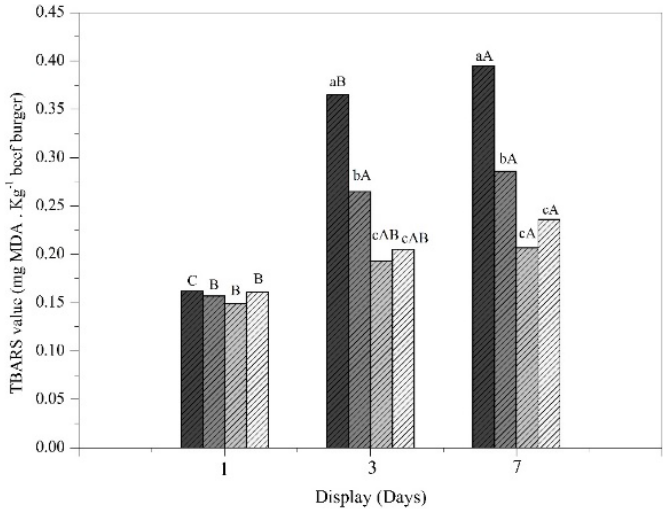
CONT: paper without coating; PAC: paper with alginate coating; PAC1: paper with alginate coating added with 0.1% cinnamon oil; PAC5: paper with alginate coating added with 0.05% cinnamon oil.

Figure 3. Interaction between treatments and storage time on ABTS and DPPH radical scavenging (%) of beef burger. Different lowercase letters in the same line are significantly different. Different uppercase letters in the same column are significantly different (p<0.05). Results are expressed as the mean and standard deviation. Standard error of means of DPPH 1.191 and ABTS 0.588.

Table 5. Quality indicators of hamburgers packed during 7 days of display.

Meat Quality	Treatments				1	3	7	SEM	P_{trat}	P_{disp}	P_{txd}
	CONT	PAC	PAC1	PAC5							
TBARS	0.33^{a}	0.24^{b}	0.18^{b}	0.20^{b}	1.80^{A}	0.25^{B}	0.28^{B}	0.01	0.01	0.03	0.84
DPPH	28.97^{b}	31.33^{b}	39.02^{a}	38.19^{a}	38.70^{A}	34.63^{AB}	29.80^{B}	1.19	0.01	0.01	0.99
ABTS	35.69	34.69	38.06	36.30	36.52	37.09	34.94	0.59	0.28	0.34	0.88
Color difference (ΔE)	2.52^{a}	2.53^{a}	1.84^{b}	2.07^{ab}	0.01^{C}	2.58^{B}	4.14^{A}	0.31	0.02	0.01	0.02

The means of treatments with different small letters in the same line are significantly different (P<0.05). The means of storage with different uppercase letters in the same line are significantly different (P<0.05); CON: paper without coating; PAC: paper with alginate coating; PAC1: paper with alginate coating added with 0.1% cinnamon oil; PAC5: paper with alginate coating added with 0.05% cinnamon oil; SEM: standard error of means; Ptrat: effect of treatment; Pdisplay: effect of days; Ptxd: interaction between treatments and days of storage; TBARS: thiobarbituric acid reactive substances; DPPH: DPPH radical scavenging; ABTS: ABTS radical scavenging.



CONT: paper without coating; PAC: paper with alginate coating; PAC1: paper with alginate coating added with 0.1% cinnamon oil; PAC5: paper with alginate coating added with 0.05% cinnamon oil.

Figure 4. Interaction between treatments and storage time on lipid oxidation (TBARS) expressed as mg malonaldehyde.kg^{-1} of beef burger. Different lowercase letters in the same line are significantly different. Different uppercase letters in the same column are different ($p<0.05$). Results are expressed as mean and standard deviation. Standard error of means 0.015.

have decreased color degradation and increased the antioxidant activity of the product (Vital et al., 2016). The coatings acted as a barrier against oxidative action since the essential oils have compounds with antioxidant activity that can retard oxidation (Ghaderi-Ghahfarokhi et al., 2017).

3.2.3. Meat coloration

CONT and PAC showed the greatest color variation among the treatments. In addition, the difference between colors (ΔE*) significantly increased with increasing storage time ($P<0.001$). When the effects of both factors were evaluated, an interaction among them was observed (Table 5).

The color difference reached a maximum value on the seventh day of storage; however, differences between treatments were significantly different from the third day ($P<0.001$). The total color differences (ΔE*) of the hamburgers packed with control paper and coated papers show that the ΔE* are all below 5.0, indicating that there is a real difference, resulting in a color difference hardly noticed by the consumer. The values of 0.0–1.5 can be considered small visual variations, practically imperceptible; in the range of 1.5–5.0, the difference in color can begin to be perceived, whereas for ΔE* greater than 5, the color difference is considered evident (Obón et al., 2009). Color maintenance can be attributed to the action of the antioxidants added to the treatments (PAC1 and PAC5), which contributes to the stabilization of color by delaying discoloration (Mancini & Hunt, 2005).

4. CONCLUSION

The papers coated with CEO had an effect on meat properties, contributing to the retardation of oxidation and lipid oxidation, thus helping to maintain the quality of beef burgers during display. In addition, papers with essential oil coating have the advantage of being more sustainable and biodegradable and also have antioxidant characteristics, making them an alternative to petroleum-based plastics.

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