Food Science and Technology
ISSN 0101-2061 (Print)
ISSN 1678-457X (Online)
DOI: https://doi.org/10.1590/fst.23117

Effects of chitosan-tomato plant extract edible coatings on the quality and shelf life of chicken fillets during refrigerated storage

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Abstract

The aim of this study was to evaluate the effects of chitosan-tomato plant extract (C-TPE) edible coating (EC) applications on the physicochemical, microbiological, sensory and antioxidant capacity of chicken during storage. Edible coatings prepared with chitosan 1%, acetic acid 1%, glycerol and TPE (0.1 and 0.3%) were tested. The slices were submerged for 1 minute in different treatments (T1: C 1%; T2: C 1% + TPE 0.1%; T3: C 1% + TPE 0.3%; T4: control) and stored at 4 °C. At the end of the storage period, the treatments exhibited the greatest physicochemical and microbiological effects in the slices, reducing the microbial population relative to the control. The T2 treatment exhibited the highest antioxidant capacity, total phenolic content and overall acceptance. The results demonstrate that the application of C with the addition of a natural extract, such as those from the tomato plant, can be an alternative method for preserving chicken meat.

Keywords: chitosan; meat products; quality; by-products.

Practical Application: The use of edible coatings made from chitosan-tomato plant extract could be an alternative method for preserving the quality and increasing the shelf life of chicken.

1 Introduction

Meat is a popular food around the world with increasing consumption, and chicken meat is one of the most popular because is a nutritious food and its low-fat content. To satisfy the consumer demand the export rates have increased considerably. Because chicken meat is highly perishable and its shelf life is relatively short even in refrigeration storage, the food industry must apply modern preservation methods to extend its shelf life considering the rapid loss of quality and freshness it's due to the biochemical and microbial mechanisms (Boziaris et al., 2011; Mantilla et al., 2011; Kapetanakou et al., 2014). Edible coatings (ECs) have been used as an alternative method to improve the quality and extend the shelf life of fruit, vegetables, and food of animal origin (Suseno et al., 2014; Wu, 2014). They are classified according to their origin as proteins, lipids or polysaccharides (Khanafari et al, 2008; Sánchez-Ortega et al., 2014). Chitosan, which is derived from the deacetylation of chitin, is the most widely used polymer in EC production because of its broad applicability and characteristics, including its ability to form a film and non-toxic property (Mirabella et al., 2014; Suseno et al., 2014). Chitosan edible films provide some characteristics that help to preserve the freshness in meat; additional, these types of films present some antioxidant activity and act like antimicrobial agents against pathogens and spoilage bacteria in foods (López-Mata et al., 2015). The antimicrobial and antioxidant compounds in edible coatings address many of the health and environmental concerns of consumers (Cao et al., 2013; Qin et al., 2013). Nevertheless, despite of these properties of chitosan edible films, some plant extracts have been added because their properties. Tomato plant (leave and steem) represent an agro-industrial byproduct because is discarded after harvesting, however, it possesses bioactive substances with interesting properties (Silva-Beltrán et al., 2015). As bioactive agents incorporated into films, plant extracts, has received attention due to their phenolic content and high antioxidant capacity, which can improve food safety and quality (Huang et al., 2014).

The addition of natural extracts to ECs seeks to potentiate the effects of these extracts on the conservation of food by exploiting the properties of these extracts against bacteria and as antioxidants (Soultos et al., 2008). The aim of the present study was to evaluate the effects of chitosan-based ECs with tomato plant extract on the physicochemical, microbiological, sensory and antioxidant properties of chicken during refrigerated storage changes.

Received 21 Aug., 2017
Accepted 11 Sept., 2018
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2 Materials and methods

2.1 Reagents

Potassium persulfate, 2, 2-azino-bis (3-ethylbenzthiazoline-6-sulfonic acid) diammonium salt (ABTS), 2, 2-diphenyl-1picrylhydrazyl (DPPH), 6-hydroxy-2, 5, 7, 8-tetramethylchroman-2-carboxylic acid (Trolox), and gallic acid were purchased from Sigma-Aldrich (St. Louis, MO, USA). Folin-Ciocalteu reagent, sodium carbonate, hydrochloric acid, hydrogen peroxide 3%, acetic acid, red-violet bile agar, trypticase soy agar, phosphate buffer and sodium chloride were obtained from JT Baker (Baker-Mallinckrodt, México). Sodium hydroxide was purchased from Merck (Merck-Darmstadt, Germany), and glycerol was purchased from HYCEL (Zapopan, Jalisco).

2.2 Raw material

Chicken fillets were obtained from local distributors in Cd. Obregon, Sonora. The samples were placed in a sealed cooler with a layer of ice between the samples and transported to the Laboratory of Sanitary Microbiology and Food Safety at the Instituto Tecnológico de Sonora, where they were stored for further analysis.

2.3 Chitosan

The chitosan was obtained by thermo-alkaline deacetylation of chitin. 1 g of chitin was homogenized with 15 mL of 50% w/v NaOH at 95 °C for 2 h (Khanafari et al., 2008). The degree of acetylation of chitosan used in this study was 34% with an average molecular weight of 128 kDa as previously described by López-Mata et al. (2015).

2.4 Plant material

Residues of tomato plants (*Lycopersicon esculentum*) of the Pitenza variety were used in the current study and were obtained from greenhouses in the Yaqui Valley in Sonora, México. Twenty sample fresh plants were collected and were washed with distilled water. The plants were dried at 45 °C by 24 h, later were pulverized.

2.5 Extract preparation

The tomato plant extracts were obtained using methods described by Silva-Beltrán et al. (2015). A 35 g of dried sample was mixed with a solution of ethanol and 5% acetic acid (95:5 ratio) and macerated in constant stirring for 72 h in complete darkness at room temperature. The samples were filtered and concentrate by evaporation using a rotatory evaporator (Buchi Rotavapor R-200). Finally, the extract was lyophilized for 48 h (Freeze zone 4.5, Labconco), and the dried extracts were maintained at -20 °C for subsequent analysis.

2.6 Preparation and application of EC

The emulsions were prepared by dissolving 1% chitosan (C 1%) in 1% acetic acid and glycerol as a plasticizer. Later, tomato plant extracts (TPE) at different concentrations was added. The solution was homogenized at 15,500 rpm (López-Mata et al., 2013) until homogenization was complete. Finally, raw chicken slices were immersed in this solution for one min and allowed to dry after immersion and before storage. Four treatments were prepared: T1 (C 1%), T2 (C 1% + TPE 0.1%), T3 (C 1% + TPE 0.3%) and T4 (control). The control was the chicken slice with no edible film treatment.

2.7 Evaluation of quality and shelf life

The coated chicken samples were stored in plastic trays with food grade polyethylene at 4 °C for 16 days. Samples were taken on days 0, 1, 4, 8, 12 and 16 for the physicochemical, microbiological, sensory and antioxidant analyses.

2.8 Sensory evaluation

Ten semi-trained panelists scored the samples for odor, flavor, color, texture and overall acceptability on each day of storage. A nine-point hedonic scale (9 = extremely like; 8 = like it very much, 7 = like it moderately; 6 = like it slightly, 5 = I do not like or dislike, 4 = dislike a little; 3 = dislike moderately, 2 = dislike very much 1 = extremely dislike) was used to classify the samples. The score of each sample was determined by calculating the mean value. A score of 5 or below was considered to be unsalable. By the sensory evaluation the chicken slices of the different treatments were cooked previously.

2.9 Physicochemical analysis

The muscle pH was determined based on methods described by the AOAC (Association of Official Analytical Chemists, 1995). Ten g of samples were mixed with 50 mL of distilled water and the pH was measured using a digital pH meter (HANNA model 213, Woonsocket, USA).

For the color measurement, three chicken slices of each treatment were chosen, from which five mediations was taken. The color of chicken was measured by tri-stimulus colorimetry using a system with a colorimeter (X-rite model SP6, Michigan, USA). Color coordinates for degree of lightness (L), redness/greenness (+a/-a), and yellowness/ blueness (+b/-b) were obtained.

The exudate loss (EL) was determined by measuring the weight before and after a certain period according to each sampling day; the results were expressed as a percentage (%).

The water retention capacity (WRC) was determined in the raw samples using a method described by Zhang et al. (1995) with modifications. The meat sample (5 g) was finely minced, followed by the addition of 8 mL of NaCl (0.6 M). The meat sample was then stirred (1 min) and placed in an ice bath for 30 min and centrifuged at 11,500 g for 15 min at 4 °C, and the supernatant was recovered. The WRC of the cooked samples was determined as follows: the meat samples were weighed, wrapped in aluminum, subjected to a temperature of 165 °C on an electric grill and cooked to an internal temperature of 70 °C (10 min for each side), as measured using a penetration thermometer (Thermco®, Lafayette, NJ). The samples were cooled for 30 min at room temperature (25 °C), and the final weight was determined. The WRC was expressed as the loss of water with respect to the initial content (%) in the raw and cooked samples.

The shear force value (texture) was expressed as the N of the raw and cooked samples were measured in a texturometer (Food technology corp., Virginia, USA). The samples were cut (30 mm x 10 mm x 10.5 mm), and a transverse force in the direction of the muscle fiber was applied

2.10 Microbiological analysis

Chicken meet samples (10 g) were homogenized with sterile phosphate buffers (90 mL) using a stomacher blender (Model 400) for 2 min at 230 rpm. The homogenate was serially diluted by a ten factor. For each dilution, 1 mL was plated on each medium according to Mexicans Official Norms (NOM). The total microbial count was determined according to the parameters established by NOM-092-SSA1-1994 (México, 1994a) for both aerobic mesophilic and psychrophilic bacteria using the trypticase soy agar (TSA) procedure; the total coliforms were determined by NOM-113-SSA1-1994 (México, 1994b) in red-violet bile agar.

2.11 Antioxidant capacity

For the extract preparation, 10 g of the sample was homogenized, and a volume equivalent of 10% phosphate buffer (pH 7) was added. The mixture was centrifuged at 12,000 rpm for 60 min at 4 °C. The supernatant was used to estimate the ABTS, DPPH and total phenolics.

The ABTS assay was conducted using methods described by Erel (2004) with some modifications. ABTS radical cations were generated in a mixture of 5 mL of a 7 mmol ABTS solution and 88 µL of a 0.139 mmol $K_2S_2O_8$ solution. The extracts were diluted with absolute ethanol. Then, 1.98 mL of the adjusted solution was reacted with 15 µL of the supernatant, centrifuged at 13,000 rpm for 5 min at 4 °C and left to rest for 7 min. The absorbance was measured at 750 nm using a microplate reader (Bio-rad iMark 168-1135, Tokyo Japan). The results were expressed as µmol Trolox eq/g of meat.

The DPPH assay was conducted using methods described by Qwele et al. (2013) with some modifications. To prepare the radical, DPPH was dissolved in 100 mL of methanol. A volume of 1 mL of the adjusted solution, 200 µL of the supernatant and 800 µL of distilled water were mixed and centrifuged at 13,000 rpm for 5 min at 4 °C and left to rest at room temperature for 30 min. The absorbance was measured at 490 nm using a microplate reader (Bio-rad iMark 168-1135, Tokyo Japan). The results were expressed as µmol Trolox eq/g of meat.

The concentration of the total phenol content was determined according to the method described by Qwele et al. (2013), with modifications. For the reaction mixture, we added 66 µL of the supernatant, 133 µL of Folin Ciocalteau, followed by the addition of 2 mL of sodium carbonate. The mixture was stirred manually and then incubated at room temperature for 1 h and filtered. The absorbance was read at 750 nm using a microplate reader (Bio-rad iMark 168-1135, Tokyo Japan). The results were expressed as mg of GAE/g of meat.

2.12 Experimental design and statistical analysis

The experiment was conducted two times, and each determination was performed in triplicate. The statistical tests were performed using Statgraphics Plus v. 5.1. The experiment was performed by applying a randomized complete block design in which the sampling days were considered blocks and the applied treatments were considered factors. The Tukey-Kramer test was used to determine the differences between the treatments. The results were expressed as the mean values ± SD, and the level of significance was $p < 0.05$.

3 Results and discussion

3.1 Sensory evaluation

The T2 treatment presented the highest value for the evaluated attributes (odor, color, taste, texture and general acceptability) in both products and was slightly higher than T3, although this difference was not significant ($p > 0.05$) (Table 1), except on the 16th day of storage. On day 0, the odor and taste were satisfactory. The addition of the edible coating was pleasant for the panelists. The overall acceptability value of the control on day 4 was 4.9 and on day 8 this samples were inedible. The coated chicken exhibited a fresh odor over a long period of time. The products treated with the edible coating with added extracts remained edible for all 16 days of storage. This indicates that the treatments were effective in maintaining the quality of chicken meat with respect to control. Moreover, the punctuation indicates that the addition of extracts at lower concentrations did not negatively affect the sensory properties and instead significantly improved some of these properties throughout the storage period. This could have been due to the antioxidant properties of the tomato extract, which have a significant effect on color. In this study, the T2 treatment was the favorite of the panelists because it produced a slightly dark color, natural taste, odor and pleasant texture, whereas the other parameters had lower punctuations as higher concentrations were added, with taste being the most sensitive attribute (Selani et al., 2011; Huang et al., 2012; Petrou et al., 2012; Radha-Krishnan et al., 2014; Qi et al, 2015).

3.2 Physicochemical analysis

The pH of the meat is used to evaluate the durability, quality and suitability of various types of processing. The pH values of the chicken slices with edible coating with and without tomato plant extract are shown in Table 2. The initial values ranged from 5.9 to 6.36, showing a slight decrease on the 1st day. The values increased as the storage time progressed. The peak pH values were 6.48, 6.18 and 6.17 for the T1, T2 and T3 treatments, respectively, whereas T4 (control) reached a pH of 6.72 ($p < 0.05$). Radha-Krishnan et al. (2014) observed the same behavior in chicken slices with spicy extracts, with the values ranging from 5.63 to 5.1-6.6, and the control showed the highest values. In addition, Olaimat & Holley (2015) reported the same behavior but with lower values following the application of edible coating with carragenin and chitosan, mustard extract or a combinations of these. The decrease in the pH values may have been due to the production of lactic acid in the muscle via anaerobic glycolysis

Table 1. Effects of chitosan-tomato plant extract coatings on the sensory evaluation of chicken during refrigerated storage.

Parameter	Storage time (days)						
	Treatment	0	1	4	8	12	16
Odor	T1	8.8 ± 0.42^{a}	8.9 ± 0.31^{a}	8.6 ± 0.51^{a}	7.5 ± 0.52^{b}	7.2 ± 0.91^{a}	6.8 ± 0.63^{a,b}
	T2	8.8 ± 0.42^{a}	8.9 ± 0.31^{a}	8.8 ± 0.42^{a}	8.4 ± 0.51^{a}	7.6 ± 0.51^{a}	7.1 ± 0.73^{a}
	T3	8.8 ± 0.42^{a}	8.9 ± 0.31^{a}	8.5 ± 0.52^{a}	8.0 ± 0.47^{a}	7.6 ± 0.51^{a}	6.3 ± 0.67^{bc}
	T4	8.9 ± 0.31^{a}	8.8 ± 0.42^{a}	4.6 ± 0.36^{b}	NE	NE	NE
Flavor	T1	8.3 ± 0.82^{a}	8.3 ± 0.82^{a}	7.9 ± 0.56^{a,b}	6.6 ± 0.51^{b}	6.4 ± 0.51^{b}	4.9 ± 0.99^{b}
	T2	8.3 ± 0.82^{a}	8.3 ± 0.82^{a}	8.3 ± 0.82^{a}	7.9 ± 0.56^{a}	7.5 ± 0.52^{a}	6.6 ± 0.51^{a}
	T3	8.0 ± 0.94^{a}	7.8 ± 0.91^{a}	7.5 ± 0.52^{b}	6.4 ± 0.51^{b}	5.8 ± 0.78^{c}	4.1 ± 0.99^{c}
	T4	8.3 ± 0.82^{a}	8.1 ± 0.73^{a}	4.8 ± 0.32^{c}	NE	NE	NE
Color	T1	8.5 ± 0.84^{a}	8.5 ± 0.84^{a}	7.9 ± 0.56^{b}	7.7 ± 0.48^{b}	7.6 ± 0.51^{a}	6.6 ± 0.84^{b}
	T2	8.7 ± 0.48^{a}	8.9 ± 0.31^{a}	9.0 ± 0.0^{a}	8.4 ± 0.51^{a}	7.9 ± 0.31^{a}	7.3 ± 0.48^{a}
	T3	8.5 ± 0.84^{a}	8.5 ± 0.84^{a}	7.6 ± 0.69^{b}	7.6 ± 0.51^{b}	6.8 ± 0.78^{b}	6.0 ± 0.66^{c}
	T4	8.8 ± 0.42^{a}	8.7 ± 0.48^{a}	4.8 ± 0.42^{c}	NE	NE	NE
Texture	T1	8.7 ± 0.67^{a}	8.2 ± 0.63^{a}	7.7 ± 0.48^{a}	7.2 ± 0.63^{b}	6.1 ± 0.73^{c}	4.2 ± 0.91^{b}
	T2	8.4 ± 0.84^{a}	8.6 ± 0.69^{a}	7.7 ± 0.48^{a}	7.0 ± 0.47^{b}	6.7 ± 0.48^{b}	5.8 ± 1.13^{a}
	T3	8.5 ± 0.84^{a}	8.5 ± 0.70^{a}	7.7 ± 0.48^{a}	7.9 ± 0.31^{a}	7.8 ± 0.63^{a}	4.6 ± 1.17^{b}
	T4	8.7 ± 0.42^{a}	8.5 ± 0.52^{a}	4.6 ± 0.26^{b}	NE	NE	NE
Overall acceptability	T1	8.4 ± 0.51^{a}	8.4 ± 0.51^{a}	8.0 ± 0.0^{a}	7.3 ± 0.48^{a}	6.8 ± 0.42^{b}	5.4 ± 0.69^{b}
	T2	8.5 ± 0.52^{a}	8.8 ± 0.42^{a}	8.2 ± 0.42^{a}	7.9 ± 0.31^{b}	7.4 ± 0.51^{a}	6.9 ± 0.31^{a}
	T3	8.3 ± 0.67^{a}	8.3 ± 0.48^{a}	7.6 ± 0.51^{b}	7.3 ± 0.48^{a}	6.5 ± 0.52^{b}	5.6 ± 0.51^{b}
	T4	8.5 ± 0.42^{a}	8.3 ± 0.48^{a}	4.9 ± 0.12^{c}	NE	NE	NE

Different letters in the same column indicate significant differences ($p < 0.05$) among treatments. NE: Not evaluated.

Table 2. Effects of chitosan-tomato plant extract coatings on the physicochemical parameters of chicken during refrigerated storage.

Parameter	Storage time (days)						
	Treatment	0	1	4	8	12	16
pH	T1	5.94 ± 0.08^{a}	5.86 ± 0.09^{a}	6.09 ± 0.04^{a}	6.31 ± 0.03^{a}	6.38 ± 0.01^{a}	6.48 ± 0.01^{a}
	T2	5.85 ± 0.02^{b}	5.85 ± 0-05^{a}	6.01 ± 0.04^{b}	6.11 ± 0.01^{b}	6.16 ± 0.05^{b}	6.18 ± 0.03^{b}
	T3	6.01 ± 0.03^{c}	5.96 ± 0.08^{b}	6.03 ± 0.02^{b}	6.15 ± 0.05^{c}	6.15 ± 0.04^{b}	6.17 ± 0.10^{b}
	T4	6.36 ± 0.03^{d}	6.41 ± 0.08^{c}	6.72 ± 0.07^{c}	NE	NE	NE
L*	T1	60.80 ± 1.61^{a}	55.33 ± 1.67^{a}	52.48 ± 1.17^{a}	53.53 ± 1.51^{a}	52.67 ± 1.50^{a}	50.81 ± 1.16^{a}
	T2	61.95 ± 1.98^{a}	56.51 ± 1.93^{a}	52.37 ± 2.01^{a}	53.01 ± 1.85^{a}	52.83 ± 1.79^{a}	52.08 ± 1.10^{b}
	T3	58.81 ± 1.97^{b}	55.06 ± 1.97^{a}	52.59 ± 1.97^{a}	53.21 ± 1.84^{a}	52.62 ± 2.25^{a}	50.41 ± 1.95^{a}
	T4	54.34 ± 1.86^{c}	52.79 ± 2.34^{b}	50.37 ± 2.28^{b}	NE	NE	NE
a*	T1	0.09 ± 0.50^{a}	1.21 ± 0.79^{a}	2.61 ± 1.23^{a}	2.89 ± 0.84^{a}	2.71 ± 0.91^{ab}	2.37 ± 0.51^{a}
	T2	1.19 ± 1.80^{b}	2.74 ± 1.80^{b}	4.19 ± 1.85^{b}	4.12 ± 1.92^{a}	3.88 ± 1.66^{b}	3.10 ± 1.27^{b}
	T3	-0.21 ± 1.11^{a}	0.85 ± 1.03^{a}	2.12 ± 1.07^{a}	1.86 ± 0.82^{b}	2.31 ± 1.20^{a}	1.80 ± 1.03^{a}
	T4	1.37 ± 1.19^{b}	2.28 ± 1.17^{b}	4.52 ± 1.45^{b}	NE	NE	NE
b*	T1	8.14 ± 1.80^{a}	10.12 ± 2.04^{a}	11.26 ± 2.28^{a}	12.75 ± 1.48^{a}	12.02 ± 1.99^{a}	12.05 ± 1.69^{a}
	T2	13.31 ± 1.90^{b}	16.49 ± 1.90^{b}	16.14 ± 2.04^{b}	17.25 ± 1.99^{b}	17.25 ± 1.86^{b}	16.65 ± 1.90^{b}
	T3	9.40 ± 1.49^{a}	11.22 ± 1.63^{a}	11.72 ± 1.29^{ac}	12.28 ± 1.71^{a}	11.99 ± 1.37^{a}	12.16 ± 1.27^{a}
	T4	11.29 ± 2.93^{b}	12.59 ± 2.96^{b}	11.98 ± 2.77^{c}	NE	NE	NE
Exudate loss (%)	T1	3.38 ± 0.37^{a}	3.57 ± 0.13^{a}	3.71 ± 0.24^{a}	4.10 ± 0.22^{a}	4.99 ± 0.27^{a}	5.12 ± 0.17^{a}
	T2	1.74 ± 0.27^{b}	3.18 ± 0.21^{b}	3.68 ± 0.25^{b}	3.78 ± 0.40^{b}	4.22 ± 0.32^{b}	5.66 ± 0.21^{b}
	T3	1.86 ± 0.39^{c}	3.85 ± 0.33^{c}	4.57 ± 0.33^{c}	4.50 ± 0.42^{c}	5.33 ± 0.27^{c}	5.28 ± 0.07^{c}
	T4	3.84 ± 0.20^{d}	4.42 ± 0.26^{d}	5.35 ± 0.13^{d}	NE	NE	NE

Different letters in the same column indicate significant differences ($p < 0.05$) among treatments; NE: Not evaluated.

(Márquez-Ríos et al., 2011); however, the application of the edible chitosan coating can affect the pH due to its acetic acid content (Ahmed et al., 2017). Moreover, the pH value increased as the storage time increased due to the growth of proteolytic bacteria, which causes protein degradation and the liberation of nitrogen compounds (Cao et al., 2013).

The *L** values are shown in Table 2. The initial values ranged from 54 to 61. By the end of the storage period, the values had decreased to 50.81, 52.02 and 50.41 for the T1, T2 and T3 treatments, respectively. The *L** values of the control (T4) reached 50.37 on day 4 (at end of the shelf life). The *a** values initially ranged from -0.21 to 1.37 and increased significantly by day 4 to 4.52, 4.19, 2.61 and 2.12 for T4, T2, T1 and T3, respectively. By the end of the storage period, the values had decreased to 2.37 (T1), 3.10 (T2) and 1.8 (T3). The initial *b** values ranged from 8 to 13 for all treatments and progressively increased by day 8. By day 16, the values had decreased to 12.05 (T1), 16.65 (T2) and 12.16 (T3), which were higher than the values observed in the control (11.98). Latou et al. (2014) used edible coatings with the addition of modified atmospheres in chicken and obtained initial *L** values of 59 and 60. On day 14, the values increased to 61 and 63, which were higher than those observed in the control at the end of its shelf life on day 6 (*L** value of 56). The initial *a** and *b** values were 4 and 5, respectively, for all of the treatments. The final *a** values were 3.5 and 4, and the final *b** values were 16.1 and 15. These values were higher than the a* and b* values measured in the control (3.3 and 14.5, respectively). Petrou et al. (2012) reported similar *L** values with the application of oregano oil, 1.5% chitosan and the combination in chicken. The initial *L** value was 51 for all of the treatments. On day 18, the values increased to 58, 56 and 52 for the oregano oil, chitosan and combination treatments, respectively; these values exceeded the value measured in the control (50). The initial *a** and *b** values reported by Petrou et al. (2012) (9.1, 8.9 and 11 for *a** and 17.9, 16.1 and 15 for *b**) were higher than those obtained in the current study (8 and 15, respectively) and exceeded the a* and b* values observed in the control (3.3 and 14.5, respectively). The addition of chitosan to the chicken slices increased the L* values, which are directly related to muscular protein decomposition. Therefore, the rate of fresh meat discoloration is related to the pigment oxidation rate, oxygen consumption and system efficiency of meta-myoglobin reduction (MacDougall, 1982; Latou et al., 2014). Similarly, the increase in the a* values (redness) could be related to the myoglobin content inside the chicken breast (Latou et al., 2014). The addition of chitosan increased the *b** values (yellowness), suggesting the natural chitosan color affected the surface color of this meat product.

Table 2 shows the effects of treatment on the exudate loss, where the initial values were 3.38, 1.74, 1.86 and 3.84 for the T1, T2, T3 and T4 treatments, respectively. These results clearly indicate increases that reached 5.12 (T1), 5.66 (T2) and 5.28 (T3) by the end of the storage period, whereas controls reached a value of 5.35. Young et al. (2004) evaluated the effects of feed supplemented with creatine and pyruvate. In this study, the authors obtained values ranging from 4-20%. The values obtained for the treatments and the control differed such that supplementation significantly decreased the values. In contrast, these changes are a practical indicator of myofibrillar protein structure changes, where decreases indicate protein denaturalization. The liberation of drops from the muscle seems to be independent of the contraction state after rigor instauration. This finding could be due to the filamental space and cellular membrane changes that cause water liberation in the extracellular space (Young et al., 2004).

Figure 1 shows the effects of the different treatments on the WRC of fresh (Figure 1a) and cooked (Figure 1b) chicken slices, where the initial values of the fresh slices were 94.55, 91.2, 91.09 and 90.58 for T4, T1 T2 and T3, respectively. The values decreased during the storage period (81.35, 86.78 and 90.62 for T1, T2 and T3, respectively); the treatment values were higher than the control value (77.42). Qin et al. (2015) evaluated the effects of the application of L-arginine and a soluble salt gel with meat proteins on the WRC of chicken breast. The values ranged from 80-95%, and higher concentrations resulted in better WRC. These results were similar to those observed in the current study: as time advanced, the extract treatments (T2 and T3) exhibited better WRC. The behavior of the cooked chicken throughout the storage period was variable between treatments. The initial values were 79.63, 73.81, 70.21 and 75.87 for the T1, T2, T3 and T4 treatments, respectively. The T3 treatment exhibited better WRC on day 8 (82.34), followed by T2 (76.56) and T1 (69.18), and the control reached 80.08 on the final day of shelf life day (day 4). At the end of the storage period the WRC values of

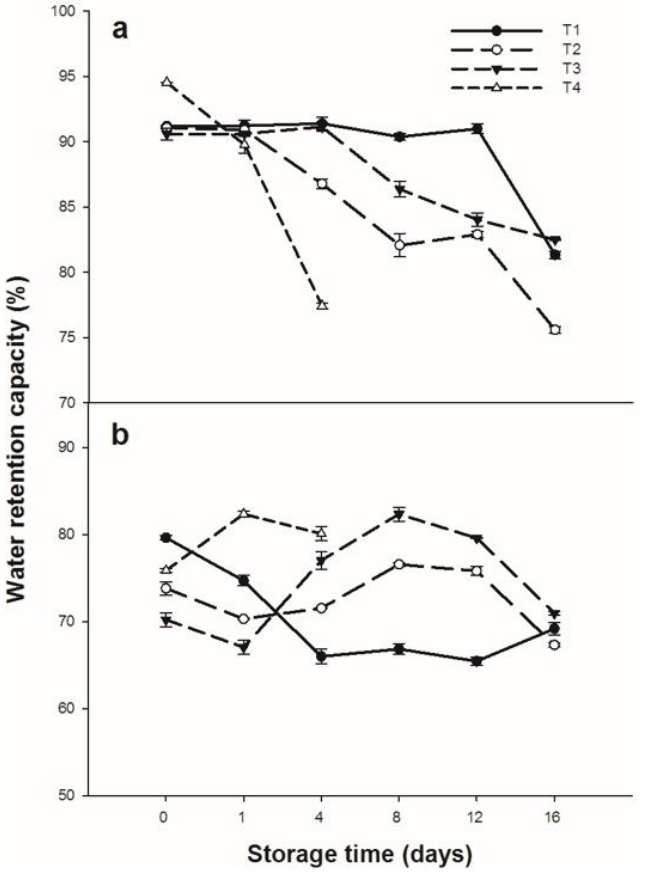

Figure 1. Effects of chitosan-tomato plant extract coatings on WRC in raw (a) and cooked (b) chicken during refrigerated storage.

the treatments reached 66.84 (T1), 67.30 (T2) and 70.96 (T3); T3 exhibited the best WRC. Kiliç et al. (2014) evaluated the effects of encapsulated phosphates in cooked chicken meat and obtained values ranging from 82-92%. The values obtained using encapsulated phosphates were higher than those reported in the current study. These differences could be attributed to the meat preparation methods used for the analysis (they used meat ground); however, the values decreased with some of the treatments. This behavior could be due to processes related to the WRC in meat, such as protein denaturalization and cellular structure disintegration during cooking (Bertram et al., 2003). It has been suggested that pH differences in the meat protein isoelectric point (higher values avoid denaturalization) can increase the WRC (Kiliç et al., 2014), but the type of fiber, species, oxidative stability, cooking and temperature could also be related factors (Kristensen & Purslow, 2001; Kiliç et al., 2014).

The texture of the fresh chicken breast (Figure 2a) decreased on day 4 and then increased until the final day of storage. T1 and T2 (12.11 and 10.56 N) yielded the highest results, and T3 yielded the lowest (8.68 N); the textures differed significantly ($p > 0.05$) between treatments. In contrast, cooked slices (Figure 2b) presented a variable behavior such that the values decreased on day 1 with the T1, T2 and T4 treatments and then progressively increased until day 16 (final storage day), reaching a maximum of 15.35, 18.84 and 16.85 for the T1, T2 and T3 treatments, respectively. Rodríguez-Calleja et al. (2012) evaluated the application of antimicrobial edible coatings on chicken quality using hydrostatic high pressure and did not observe any significant differences between treatments in the initial values, which suggested this behavior is related to the protein system, temperature, pressure and duration of storage. Soysal et al. (2015) evaluated the effects of antimicrobial packing on chicken strips during storage and obtained values ranging from 2.7 N to 2.4 N. The authors concluded that over long storage periods, the use of antimicrobial packing does not have an undesirable effect on the chicken breast texture. The values reported in their study were lower than those reported in the current study. Treatment 3 produced lower values in both presentations (fresh and cooked chicken), followed by T2 and T1. These results could be explained by decreases in the gelation capacity caused by extract concentration increases in the chitosan emulsion that may affect the adherence of the edible coating in food. Similarly, changes in these values may be due to the degree of water drop loss in the meat during storage.

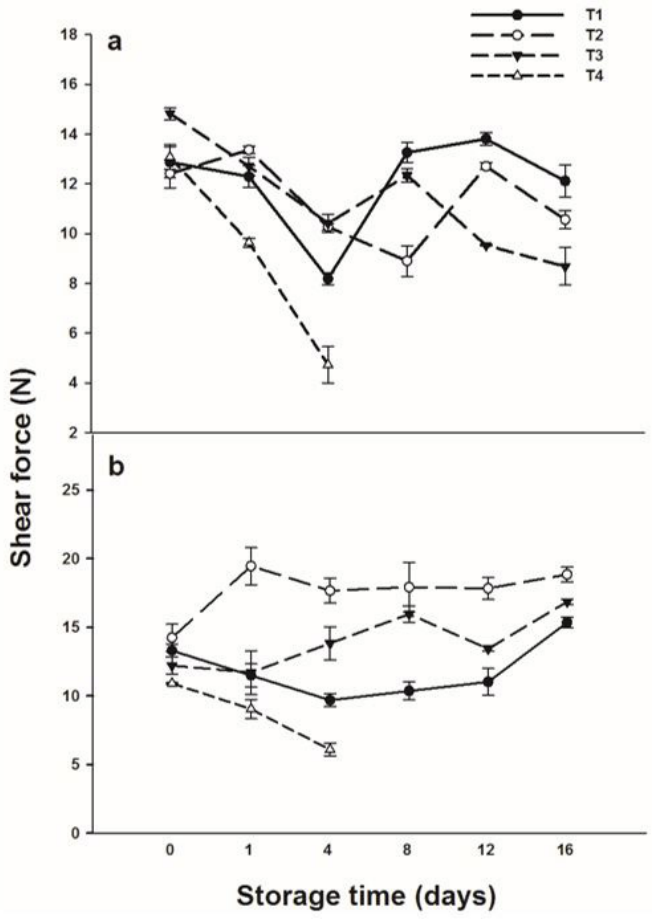

Figure 2. Effects of chitosan-tomato plant extract coatings on texture in raw (a) and cooked (b) chicken during refrigerated storage.

3.3 Microbiological analysis

The different treatments reduced the population of aerobic mesophilic bacteria by 1 Log CFU/g (Figure 3a); the T3 treatment produced the best results. In contrast, the effect (Figure 3b) decreased the total coliform population in the T2 and T3 treatments on day 1 and increased the population on day 4, maintaining growth over time and reducing by 1 Log CFU/g. These results are similar to those reported by Higueras et al. (2013), who evaluated the effects of an edible coating in fresh chicken over an 8-day period. This study observed the same behavior observed in the current study and the population of aerobic mesophilic bacteria reached 3 and 2 Log CFU/g in the total coliforms with the treatments applied. These results indicated a positive effect such that both populations were reduced by 3 Log CFU/g. In contrast, Olaimat & Holley (2015) evaluated the effects of an edible coating of chitosan with mustard extract applied to fresh chicken breast and observed that the aerobic mesophilic bacteria population was reduced by 1 Log CFU/g during the storage period. The positive effects increased with longer exposure times. Fernández-Pan et al. (2014) evaluated the antimicrobial effects of edible coating applied to chicken over a 13-day period and observed that the natural extract produced better results in chicken, reducing the bacterial population by 1 Log CFU/g. The positive effects increased with higher extract concentrations, thus indicating the importance of concentration on the antimicrobial effect.

For the psycrophilic bacteria (Figure 3c), the initial values were 1.9 Log CFU/g in the treated samples, and the control had a higher value of 2.4 Log CFU/g. On day 1, the values decreased and then progressively increased during storage, showing a reduction by 1 Log CFU/g compared to the control. Higueras et al. (2013) evaluated the effects of chitosan edible coating with an alcoholic compound in chicken and observed growth starting on day 2 and a 4 Log CFU/g reduction. The authors suggested that the preservative effects of the edible coating could be due

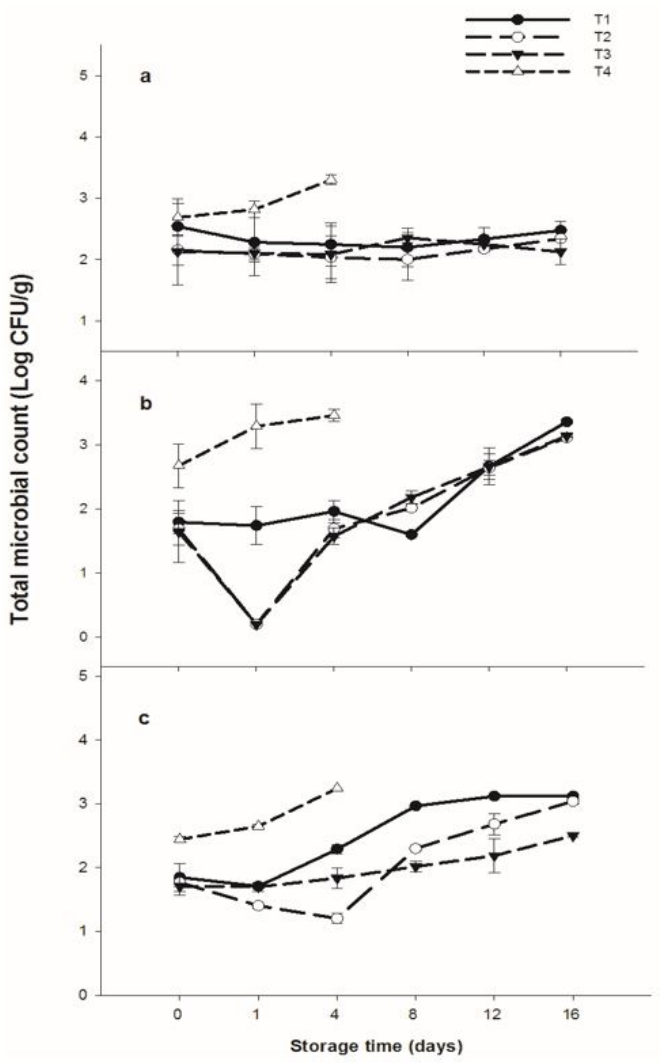

Figure 3. Effects of chitosan-tomato plant extract coatings on the total aerobic mesophilic (a), total coliform (b) and psychrophilic bacteria (c) in chicken during refrigerated storage.

to the addition of antimicrobial compounds that improve the preservation of the meat products.

3.4 Antioxidant capacity

The T2 treatment produced better ABTS (Figure 4a) and DPPH (Figure 4b) results, with values of 0.440 and 0.387 mmol TE/g of meat, respectively. Huang et al. (2011) reported similar antioxidant capacities in fresh and cooked mutton and pork treated with *Nelumbo nucífera* root and leaf extracts. The antioxidant capacity of the treated meat was significantly higher than that of the control (T4).

The T3 treatment had a higher TPC content with an initial value of 29 mg GAE/g of meat and a final value of 21 mg GAE/g of meat, followed by T2 and T1 (Figure 5). A significant difference ($p < 0.05$) was observed between treatments with edible coatings with or without tomato extracts and the control; the behavior was

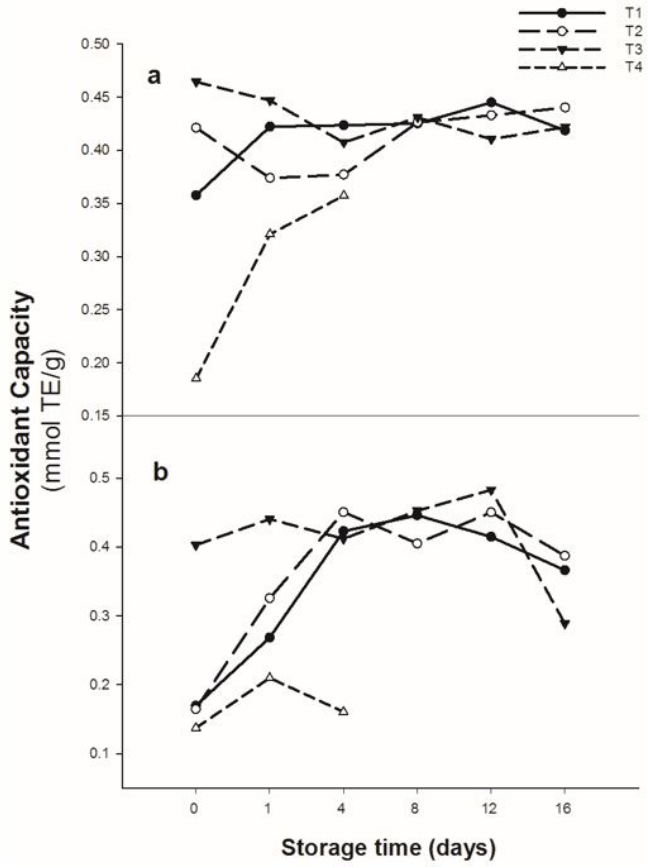

Figure 4. Effects of chitosan-tomato plant extract on the antioxidant capacity evaluated by the ABTS (a) and DPPH (b) methods in chicken during refrigerated storage.

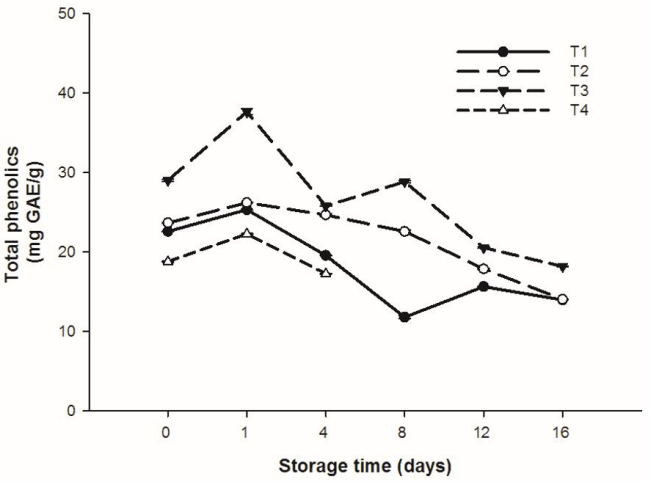

Figure 5. Effects of chitosan-tomato plant extract on the total phenolics in chicken during refrigerated storage.

variable during the storage period. Some studies have evaluated the antioxidant capacity and the total phenolic compounds in extracts used in meat preservation (Lahucky et al., 2010; Chang et al., 2011; Huang et al., 2011; Biswas et al., 2012) with edible coatings; however, analyses of the different treatments

with extracts were not shown. The authors related the higher antioxidant capacity of the treatments to their TPC, which enables the treatments to decrease the principal deterioration problems.

4 Conclusions

Therefore, chitosan-based edible coatings with tomato plant extract added can be used to increase the shelf life while maintaining some of the quality parameters and improve the microbial safety of chicken during refrigerated storage.

Acknowledgements

The authors acknowledge the financial support from the Instituto Tecnológico de Sonora (project PROFAPI 00500 and 2017-0049) and PFCE.

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