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ORIGINAL PAPER

A Potential Application of Mango (*Mangifera indica* L. cv Manila) Peel Powder to Increase the Total Phenolic Compounds and Antioxidant Capacity of Edible Films and Coatings

M. Rojas-Bravo[1] · E. G. Rojas-Zenteno[1] · P. Hernández-Carranza[1] · R. Ávila-Sosa[1] · R. Aguilar-Sánchez[2] · I. I. Ruiz-López[3] · C. E. Ochoa-Velasco[1]

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Abstract
Study of fruit by-products is increasing because they contain several bioactive compounds which can add value to food products. In this study, the effect of mango peel powder addition (0, 2, and 4%) on physical, structural, and antioxidant properties of starch edible films and their effectiveness as edible coatings on apple slices during storage (4 °C) were evaluated. The addition of mango peel powder increased the penetration resistance and a^* and b^* color parameters of edible films and reduced the numbers of holes in them. The higher antioxidant properties were obtained with the highest amount of mango peel added. For example, increases in 178.4 and 830.7% for total phenolic compounds (TPC) and antioxidant capacity (AC) were obtained, respectively. Suspensions (0, 2, and 4% of mango peel powder) applied as edible coating increased the firmness, browning index (BI), TPC, and AC of apple slices. In storage, the edible coating application did not inhibit the increase of BI and decrease of firmness of apple slices. However, the bioactive compounds and antioxidant capacity remained constant. Although further studies have to be conducted, mango peel powder may be used to improve the mechanical, physical, and antioxidant properties of edible films, and these could be used as an edible coating on apple slices.

Keywords Mango peel · Apple slices · Antioxidant compounds · Edible coating · Storage life

Introduction

Nowadays, consumers are concerned about their health and the relationship between food consumption and developing chronic diseases (De Ridder et al. 2017). Therefore, they are not only demanding food products with high nutritional and sensory quality, ready-to-eat, fresh, free of chemical preservatives, or synthetic additives but also food with high content of health-promoting compounds such as fiber, vitamins, pigments, minerals, terpenoids, and phenolic compounds (Asioli et al. 2017). The constant intake of these compounds, generally present in fruit and vegetables, has been associated with the reduction of chronic disease appearances (Martins et al. 2017). For example, the World Health Organization (WHO 2018) guidelines recommend eating > 400 g (five portions) of fruit and vegetables per day. These could be consumed fresh, minimally processed, or processed, including frozen, canned, dried, juices, nectar, among other products. However, during their processing, several by-products such as peel, seed, core, and pomace are obtained, which in many cases contains several health-promoting compounds, even with higher amounts of those present in the fruit or vegetable (Silva et al. 2014).

Mango is a potential source of polyphenolic compounds with antioxidant capacity that may help to protect the human body against oxidative stress (Aziz et al. 2012). It is a fruit greatly exploited to produce juices, nectars, and jams, but its seed and peel are usually discarded, being the peel its major by-

✉ C. E. Ochoa-Velasco
carlosenriqueov@hotmail.com

[1] Departamento de Bioquímica-Alimentos, Facultad de Ciencias Químicas, Benemérita Universidad Autónoma de Puebla, 14 Sur y Av. San Claudio, Ciudad Universitaria, C.P. 72570 Puebla, Puebla, Mexico

[2] Departamento de Química Analítica, Facultad de Ciencias Químicas, Benemérita Universidad Autónoma de Puebla, 14 Sur y Av. San Claudio, Ciudad Universitaria, C.P. 72570 Puebla, Puebla, Mexico

[3] Facultad de Ingeniería Química, Benemérita Universidad Autónoma de Puebla, Av. San Claudio y 18 Sur, Ciudad Universitaria, C.P. 72570 Puebla, Puebla, Mexico

product (15–20% of the whole fruit) (Ajila and Prasada Rao 2013). Mango peel contains several bioactive compounds such as phenolic acids (gallic acid and hydroxybenzoic acid), flavonoids (mangiferin, quercetin, and anthocyanins), and carotenoids, among other compounds with antioxidant capacity (Ajila et al. 2007). Mango peel has been used for the formulation of edible coating applied to fruit such as papaya (Velderrain-Rodríguez et al. 2015) and peach (Torres-León et al. 2018).

Edible films and coatings could be defined as packaging based on edible components. They can be directly applied as a thin layer of edible material on food or formed into a film and be used as a food wrap without changing the original ingredients or the processing method (Galus and Kadzińska 2015). Edible films and coatings have been used to protect food products from mechanical, physical, chemical, and microbial damages, to improve gas and moisture barriers, and to add bioactive compounds such as antimicrobial and antioxidant compounds, which enhance functional attributes of the formulation, therefore extending the shelf life of various food products such as fresh fruit and vegetables, whether whole or fresh-cut (Arnon-Rips and Poverenov 2018).

Apple is one of the leading fruit produced worldwide. It is widely consumed due to its firmness, flavor, appearance, and nutritional characteristics (Gul et al. 2018). The last characteristic is gaining importance because apple is an important source of health-promoting compounds, and several epidemiological studies have reported that these compounds have protective health effects (Rago et al. 2013). Moreover, since apple consumer tendencies are changing (Nicklas et al. 2015) and fresh-cut apples are more difficult to preserve because the cutting operation increases the respiration rate, softening, microbial growth, and enzymatic activity (Song et al. 2013), the application of minimal processing for its preservation is on the rise. Therefore, the aim of this research was to evaluate the effect of mango peel addition to starch edible films and assess their effect as an edible coating on apple slices during storage. To achieve this purpose, the following topics were covered: (i) characterization of physical, structural, and antioxidant properties of starch edible film formulated with 0, 2, and 4% of mango peel powder, and (ii) evaluate the effect of the application of edible coatings formulated with mango peel on the physicochemical, color, texture, and antioxidant characteristics of apple slices stored for 12 days at 4 °C.

Materials and Methods

Plant Material

Mango (*Mangifera indica* L. cv Manila) and apple (*Malus domestica* Borkh. cv Granny Smith) were acquired from a local market of Puebla, Puebla, Mexico. Both fruits were obtained in their edible maturity stage according to the color references proposed by the United States Department of Agriculture (2005, 2006), free from physical and microbiological damages. They were transported to the Facultad de Ciencias Quimicas laboratory and immediately used for processing. Fruits were washed with tap water and disinfected using a sodium hypochlorite solution (150 mg/L), and dried with absorbent paper. Mango peel was manually obtained using a stainless-steel knife, then cut in squares (1 cm^2) and dried at 50 °C until constant weight (24 h approximately). Dried peel was grinded and sieved to obtain a fine powder (180 μm), and stored in darkness until its use.

Chemical Reagents and Solvents

Gallic acid, trolox, DPPH (2,2-diphenyl1-picrylhydrazyl) radical, sorbitol, sodium hydroxide, corn starch, Folin-Ciocalteu reagent, and sodium carbonate were obtained from Sigma-Aldrich Inc. (Toluca, Mexico). Distilled water, ethanol, and phosphoric acid were obtained from J.T. Baker (Mexico City, Mexico).

Film Characterization

Edible Film Preparation

Film suspensions were prepared by mixing starch from corn (5%), sorbitol (2%), mango peel (0, 2, or 4%), and 0.125 mol/L aqueous NaOH solution (to sum 100%). Briefly, 5 g of starch was solubilized in NaOH solution, then sorbitol (2 g) was added, and the mixture was acidified with concentrated phosphoric acid until the pH was set to 4.0; next, the mango peel powder was added, and the homogenization was made at constant stirring (Isotemp, Fisher Scientific, USA) at 700 rpm for 5 min at room temperature. Peel powder percentage was established according to its maximum homogenization in sodium hydroxide solution. Edible film without mango peel was used as control. In order to eliminate air bubbles, suspensions were set aside at room temperature and protected from the light (4 h). Films were prepared by the casting method; 12 mL of suspensions was poured into 60 × 15-mm glass Petri dishes and dried in a conventional oven (FE-293AD, Felisa, Mexico) at 38 ± 2 °C for 24 h.

Color, Mechanical, and Structural Properties of Films

Color The L^* (luminosity), a^* (+ red, − green), and b^* (+ yellow, − blue) color parameters of the CIELab scale were measured using a Precise Colorimeter Reader (TCR 200, TIME High Technology, Beijing). Color parameters were evaluated in three different points on edible films surface. Hue and Chroma were calculated following Eqs. 1 and 2, respectively:

$$\text{Hue} = \tan^{-1}\left(\frac{b^*}{a^*}\right) \quad (1)$$

$$\text{Chroma} = \sqrt{a^{*2} + b^{*2}} \quad (2)$$

where L^*, a^*, and b^* are the color parameters of the edible films.

Tensile Test Tensile strength (TS) and elongation at break (EAB) were studied using a texture analyzer (EZ-test, EZ-SX, Shimadzu corp., Japan). Film discs of 50-mm diameter each were held tightly between mechanical grips. Force (N/mm^2) and deformation (mm) were recorded during extension at 60 mm/min. Tensile strength and elongation at break were determined using the interface software TRAPEZIUM X Material Testing Operation Software V 1.4.0 (Shimadzu corp., Japan).

Penetration Test Penetration force (PF) was determined using a texture analyzer. Film discs of 50-mm diameter each were fixed on the plate of the equipment with a hole of 10-mm diameter. A cylindrical probe of 3-mm diameter was moved perpendicular to the film surface at a constant speed of 1 mm/s until the probe passed through the film. The force-displacement curves were plotted, and at rupture point, the force (N) was recorded using the interface software described in the "Tensile Test" section.

Atomic Force Microscopy Structural analysis was carried out by atomic force microscopy (AFM), using a Naio-AFM microscope (Nanosurf, Liestal, Switzerland) provided with silicon carbide tips. The measurements were done in contact mode. The acquisition and analysis data were performed with the Naio Control Software Version 3.1 c (Nanosurf, Liestal, Switzerland). All measurements were done in air, under static force operating mode with a set point of 55 nN. The pore size and surface roughness were estimated by performing an analysis of at least four samples.

Antioxidant Characterization of Mango Peel Powder and Edible Films

Total phenolic compounds and antioxidant capacity of mango peel and edible films were made as follow: Mango peel extract was obtained by mixing 1 g of mango peel powder with 20 mL of distilled water for 1 h at 230–240 rpm (Isotemp, Fisher Scientific, USA) (Hernández-Carranza et al. 2016). To obtain the extract from the film, 1 g of edible film was homogenized (1 min) with 60 mL of distilled water using a domestic blender (Black and Dekker, MD, USA) (Aparicio-Fernández et al. 2018). All the extracts were centrifuged (Eppendorf AG, 5810R, Germany) at 2000 rpm for 20 min and immediately used for the determination of total phenolic compounds and antioxidant capacity (DPPH reagent).

Total Phenolic Compounds Total phenolic compounds (TPC) were evaluated according to the methodology proposed by Hernández-Carranza et al. (2016). One milliliter of an adequate dilution of the sample was mixed with 1 mL of Folin-Ciocalteu reagent (0.1 mol/L) and 1 mL of Na_2CO_3 (0.5% *w*/*v*) solution (3 min later). Then, the mixture was incubated for 30 min in darkness at room temperature. Absorbance was read at 765 nm using a Jenway UV-Vis spectrophotometer (model 6405, Staffordshire, UK). To quantify the total phenolic compounds, a standard curve of gallic acid was done (0–25 mg/L, slope 0.0126, intercept − 0.0481, R^2 0.991). Results were expressed as milligram of gallic acid equivalents (GAE) per 100 g of sample.

Antioxidant Capacity Antioxidant capacity (AC) was determined according to the methodology proposed by Hernández-Carranza et al. (2016) with modifications. Briefly, 1 mL of extract was placed in an amber glass tube, and 1 mL of DPPH solution (0.004%) was added. Tubes were mixed and incubated for 30 min in darkness at room temperature. Absorbance was read at 517 nm using a UV-Vis spectrophotometer. Results were expressed as milligram of trolox per 100 g of sample using a standard curve of trolox (0–10 mg/L, slope 9.2811, intercept − 0.7289, R^2 0.989).

Evaluation of Apple Slices During the Storage

Application of Edible Coating on Apple Slice

Edible coating was prepared according to the methodology described previously for film suspension. Apple transversal slices (1 cm of thickness) were divided into four batches: control (no coating), coating without mango peel, and coating with mango peel (2 or 4%). Apple slices without peel were immersed twice in the suspensions for 5 min. Apple slices were placed in a food dehydrator (Excalibur 3500, CA, USA) at 25 °C for 30 min, to eliminate the moisture excess. Then, apple slices were collocated into clear polyethylene boxes (0.15 m × 0.15 m × 0.10 m) and stored at 4 ± 1 °C (85 ± 5% of relative humidity). Physicochemical, texture, and antioxidant analyses were done every 30 days for 12 days. The experiment was performed in triplicate.

Physicochemical Analysis

One slice (10 g approximately) of each sample was blended with 50 mL of distilled water for 1 min using a domestic food blender. The extract was used for evaluating the total soluble solids (%) and pH following the 932.12 and 981.12 methods of the AOAC (2000), respectively.

Physical Analysis

Penetration Test The penetration force (PF) of apple slices was determined using a texture analyzer. The force necessary to penetrate 5 mm of apple slices using a cylindrical probe of 3-mm diameter at a speed of 1 mm/s was measured. The force-displacement curves were plotted and, at rupture point, the force (N) was recorded using the interface software described above.

Color The L^* (luminosity), a^* (+ red, − green), and b^* (+ yellow, − blue) color parameters of the CIELab scale were measured using a colorimeter. The color parameters were evaluated in three different points on the surface of the apple slices. With color parameters, the browning index (BI) of apple slices during storage was calculated following Eqs. 3 and 4:

$$BI = \frac{[100(X-0.31)]}{0.172} \quad (3)$$

$$X = \frac{(a^* + 1.75L^*)}{(5.645L^* + a^* - 3.02b^*)} \quad (4)$$

where L^*, a^*, and b^* are the color parameters of the apple slices.

Bioactive Compounds and Antioxidant Capacity of Apple Slices

To obtain the apple extract, 10 g of each sample was homogenized with 50 mL of distilled water using a food domestic blender. The extract was centrifuged at 2000 rpm, for 20 min, and immediately used for the determination of total phenolic compounds and antioxidant capacity. Total phenolic compounds and antioxidant capacity were quantified as mentioned before.

Statistical Analysis

All results were analyzed by one-way analysis of variance (ANOVA) using the Minitab 14 program (Minitab Inc., State College, PA, USA). A p value of 0.05 was used for deciding significant differences among averages using Tukey's test.

Results and Discussion

Edible Film Characterization

Mechanical and Color Characterization

Table 1 shows the mechanical properties of starch edible films formulated with and without mango peel powder. Results indicated that by increasing the amount of mango peel powder in the film formulation, the mechanical properties increased. However, only the penetration force was significantly improved by the addition of mango peel powder ($p < 0.05$). The increase in the mechanical properties of edible films by the addition of mango peel powder may be due to the polysaccharides that it contains, which strengthen the starch matrix through the intermolecular hydrogen bond formation (Sanyang et al. 2016). Moreover, according to Vieira et al. (2011), polymers from agro-resources may fill the space

Table 1 Mechanical, color, and antioxidant properties of starch edible film with different amounts of mango peel

Characteristic	Edible film	EFMP[a] (2%)	EFMP[a] (4%)
PF[b] (N)	$0.07 \pm 0.02_a$	$0.15 \pm 0.02_b$	$0.16 \pm 0.01_b$
TS[c] (N/mm^2)	$10.17 \pm 2.66_a$	$15.2 \pm 0.05_a$	$13.45 \pm 1.85_a$
EAB[d] (mm)	$2.75 \pm 1.15_a$	$5.53 \pm 1.00_a$	$6.69 \pm 0.93_a$
Deformation (%)	$18.30 \pm 7.68_a$	$36.90 \pm 6.65_a$	$44.60 \pm 6.23_a$
L^*	$86.69 \pm 0.15_a$	$80.03 \pm 0.4_b$	$67.26 \pm 0.20_c$
a^*	$1.79 \pm 0.03_c$	$5.88 \pm 1.00_a$	$7.29 \pm 0.50_a$
b^*	$-4.51 \pm 0.26_c$	$30.72 \pm 1.88_b$	$44.53 \pm 1.96_a$
Hue	$291.69 \pm 0.83_a$	$79.21 \pm 1.15_b$	$80.71 \pm 0.23_b$
Chroma	$4.85 \pm 0.25_c$	$31.28 \pm 2.03_b$	$45.12 \pm 2.01_a$
TPC[e] (mg GAE/100 g)	$107.30 \pm 6.10_d$	$247.70 \pm 25.30_c$	$298.70 \pm 13.00_b$
AC[f] (mg trolox/100 g)	$0.88 \pm 0.10_d$	$6.39 \pm 0.11_c$	$8.19 \pm 0.33_b$

Average ± standard deviation. Different subscript letters within the same line are significantly different ($p < 0.05$)

[a] Edible film with mango peel

[b] Penetration force

[c] Tensile strength

[d] Elongation at break

[e] Total phenolic compounds

[f] Antioxidant capacity

between the polysaccharide (starch) and plasticizer (sorbitol), improving the flexibility and strength of the edible films. In this sense, mechanical properties of films are influenced by the satisfactory cohesion of the polymer matrix compounds; thus, the formation of strong and numerous bonds between polymeric chains results in strong cohesion, which hinders their separation (Iahnke et al. 2015).

Mechanical properties may be also explained by structural analysis obtained from atomic force microscopy (Fig. 1). Figure 1 a (control) shows a uniform film with a high density of deep depressions that are evenly distributed in the film. These pores are of approximately 0.5 ± 0.05-μm depth and 1.7 ± 0.3-μm diameter as estimated from height profiles. Figure 1 b shows the edible film added with mango peel powder at 4%. As observed, the addition of mango peel to the edible film generates a more compact surface with less density of depressions and smaller diameters, probably due to mango peel powder may be hosted in the pores of the starch film, increasing its plasticity and flexibility (Rahman and Brazel 2004).

Table 1 shows the color parameters of edible film formulated with and without mango peel powder. As can be seen, an increase in the amount of mango peel powder decreases the L^* and increases the a^* and b^* color parameters. This indicates

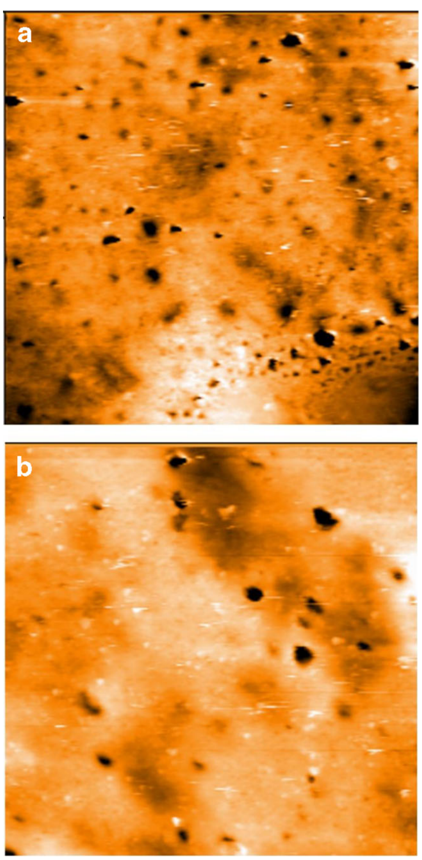

Fig. 1 Atomic force microscopy images of **a** starch film (control), **b** starch film added with 4% of mango peel powder. Conditions: static force, set point 55 nN. Area, 50 × 50 μm

that edible films formulated with mango peel powder tend to orange-yellow color. The color change was more evident with the calculation of the hue and chroma parameters. The first one indicates the color angle, which is near to the yellow color (90°) and no effect of the mango peel amount was observed ($p > 0.05$). However, the chroma parameter, which indicates the intensity of the color, was higher at the highest concentration of mango peel powder. The mango peel color, provided by the carotenoid and flavonoid compounds, gives the edible films a pleasant orange-yellow color (Nambi et al. 2016). Similar results were reported by other authors. They used fruit by-products for the formulation of edible films. For example, Iahnke et al. (2015) indicated that edible films formulated with carrot bagasse presented an orange color due to the carotenoids and flavonoids that it contains. While prickly pear peel provided the edible films a red color due to its betalain content (Aparicio-Fernández et al. 2018).

Total Phenolic Compounds and Antioxidant Capacity of Edible Films

Total phenolic compounds and antioxidant capacity of mango peel powder and edible films are presented in Table 1. The results obtained for TPC and AC values were lower and higher, respectively, to those obtained by Sogi et al. (2013) for mango peel (cv. Tommy Atkins) dried by different methods. They informed values of 2.0–3.2 g GAE/100 g and 4.4–5.5 g/100 g for TPC and AC, respectively. It is well known that several factors which include cultivar or variety, climatic condition, agronomic management, fruit maturity, storage temperature, relative humidity, and processes applied, among others may affect the bioactive compounds and antioxidant capacity of fruit, vegetables, and their by-products (Pérez-Ambrocio et al. 2018). On the other hand, the addition of mango peel at different percentages to starch edible films significantly improved their TPC and AC ($p < 0.05$). Increases of 191.4 mg GAE/100 g and 7.31 mg trolox/100 g for TPC and AC, respectively, were observed with the addition of 4% of mango peel powder.

Until now, many studies about the application of essential oil or extracts from fruit, vegetables, and their by-products to edible films to increase the bioactive compounds and antioxidant capacity have been conducted (Dou et al. 2018; Mushtaq et al. 2018). However, only a few works have been done about the direct addition of by-products to the edible film or coating formulation. In this aspect, the use of by-products as natural as possible, to avoid the use of many pretreatments such as extraction, concentration, and purification, is increasing (Mushtaq et al. 2018). For example, the addition of prickly pear peel powder and its extract significantly increased the total betalains (107.2 mg total betalains/100 g), phenolic compounds (435 mg GAE/100 g), and antioxidant capacity

(138 mg trolox/100 g) of edible films based on carboxymethyl cellulose (Aparicio-Fernández et al. 2018). A similar result was obtained by Iahnke et al. (2016), who used beetroot residue in the formulation of films based on residues of gelatin capsules.

Evaluation of Apple Slices Added with Edible Coating During the Storage

Physicochemical Characteristics of Apple Slices

Table 2 shows the total soluble solids (%) and pH of apple slices with and without edible coating. The edible coating significantly increased the total soluble solids of apple slices, especially when mango peel was added because of the total soluble solids of mango peel (Reddy et al. 2011). After 12 days of storage, total soluble solids remain constant without significant effect of the storage time ($p > 0.05$). On the other hand, pH was significantly increased by the addition of mango peel powder at 4% ($p < 0.05$). In storage, pH values increased from 3.61 to 3.66, 3.58 to 3.65, 3.60 to 3.62, and 3.74 to 3.75 in control apple slices and in those coated with 0, 2, and 4% of mango peel, respectively. This behavior may be associated with the metabolic processes of apples, which cause degradation of organic acids, increasing the pH (Fagundes et al. 2013).

Color of Apple Slices

Color is one of the most important factors that consumers consider to select fruit and vegetables. Apple slices' color with and without edible coating was evaluated (Table 2). Results obtained for color parameters were similar to those observed in edible films; the addition of mango peel to the edible coating formulation decreased the L^* and increased the a^* and b^* color parameters. However, only in apple slices formulated with 4% of mango peel, the a^* color parameter was significantly affected ($p < 0.05$). On the other hand, the hue parameter indicates that apple slices show an orange-yellow color (83.1 ± 1.5°); nevertheless, a significant reduction of hue was observed in apple slices added with edible coating formulated with 4% of mango peel powder ($p < 0.05$). Chroma values were also increased by the addition of the edible coating, but no significant effect was observed ($p > 0.05$). The slight effect of the application of edible coating formulated with mango peel powder on the color characteristics may be associated with a similar color between edible coating suspensions and apple slices.

The color change of apple slices during the storage was evaluated by the browning index (BI). At the beginning of the storage, BI was lower in apple slices added with edible coating without mango peel (Fig. 2a), which is caused by the whitish color of the suspension. In storage, BI increased in all samples, showing a quick increase in the first 3 days of storage in control apple slices and coated with mango peel. This result may be associated with the polyphenol oxidase activity, which causes the oxidation of phenolic compounds producing *o*-quinones, molecules highly reactive electrophilic that can quickly react with themselves and with amino acids, producing melanin (black pigment) (Holderbaum et al. 2010). In contrast, apple slices with edible coating without mango peel did not present any significant change during the first days of storage.

At the end of the storage, significant increases in BI values of 9.0, 14.6, 6.0, and 22.3 for control apple slices and for coated apple slices with 0, 2, and 4% of mango peel, respectively, were observed ($p < 0.05$). The highest BI was presented in apple slices added with edible coating formulated with 4% of mango peel powder. In contrast, the lowest BI occurred in apple slices added with edible coating formulated with 2% of mango peel powder. In this regard, mango peel contains bioactive

Table 2 Physicochemical and antioxidant characterization of apple slices with starch edible coating

Characteristics	Control	Coated slices	CAMP[a] (2%)	CAMP[a] (4%)
TSS[b] (%)	$12.00 \pm 0.85_c$	$14.40 \pm 1.27_b$	$16.50 \pm 0.42_a$	$16.80 \pm 0.00_a$
pH	$3.61 \pm 0.04_b$	$3.58 \pm 0.03_b$	$3.60 \pm 0.01_b$	$3.74 \pm 0.01_a$
L^*	$69.75 \pm 0.65_a$	$65.57 \pm 0.14_a$	$66.11 \pm 0.9_a$	$64.12 \pm 3.64_a$
a^*	$2.75 \pm 0.70_b$	$3.10 \pm 0.65_b$	$2.66 \pm 0.33_b$	$5.73 \pm 0.77_a$
b^*	$22.71 \pm 0.68_a$	$25.45 \pm 4.10_a$	$25.17 \pm 0.83_a$	$29.23 \pm 0.52_a$
Hue	$83.13 \pm 1.54_{ab}$	$83.08 \pm 0.34_{ab}$	$83.98 \pm 0.53_a$	$78.91 \pm 1.65_b$
Chroma	$22.88 \pm 0.76_a$	$25.64 \pm 4.1_a$	$25.31 \pm 0.86_a$	$29.79 \pm 0.36_a$
TPC[c] (mg GAE/100 g)	$33.65 \pm 1.33_c$	$39.73 \pm 8.93_c$	$56.44 \pm 1.99_b$	$75.78 \pm 3.10_a$
AC[d] (mg Trolox/100 g)	$78.90 \pm 1.31_c$	$87.61 \pm 11.33_c$	$141.64 \pm 4.00_b$	$193.6\ 4 \pm 7.47_a$

Average ± standard deviation. Different subscript letters within the same line are significantly different ($p < 0.05$)

[a] Apple slices coated with mango peel powder

[b] Total soluble solids

[c] Total phenolic compounds

[d] Antioxidant capacity

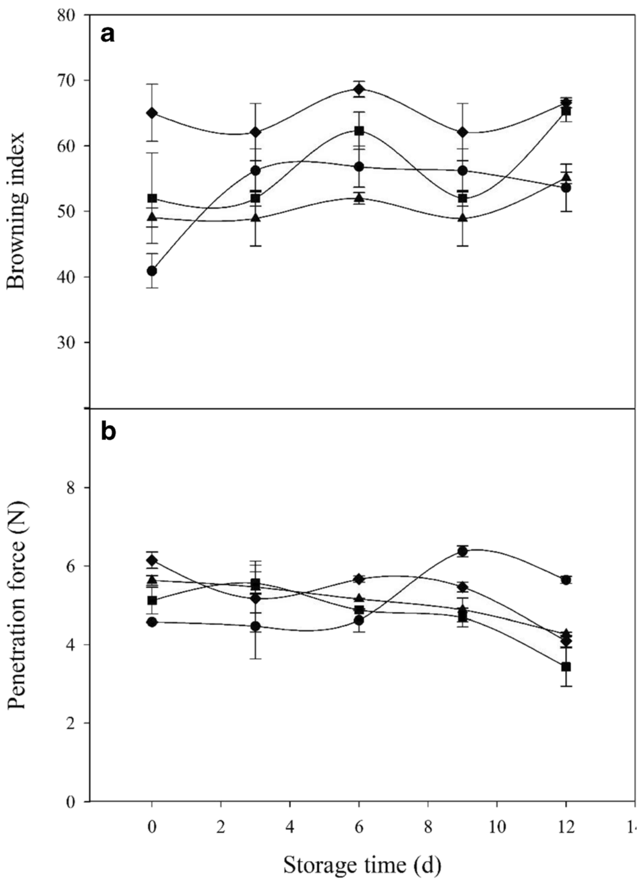

Fig. 2 Browning index (**a**) and penetration force (**b**) of control apple slices (●), coated apple slices (■), and apple slices coated with 2% (▲) and 4% (♦) of mango peel during the storage. Bars indicate standard deviation

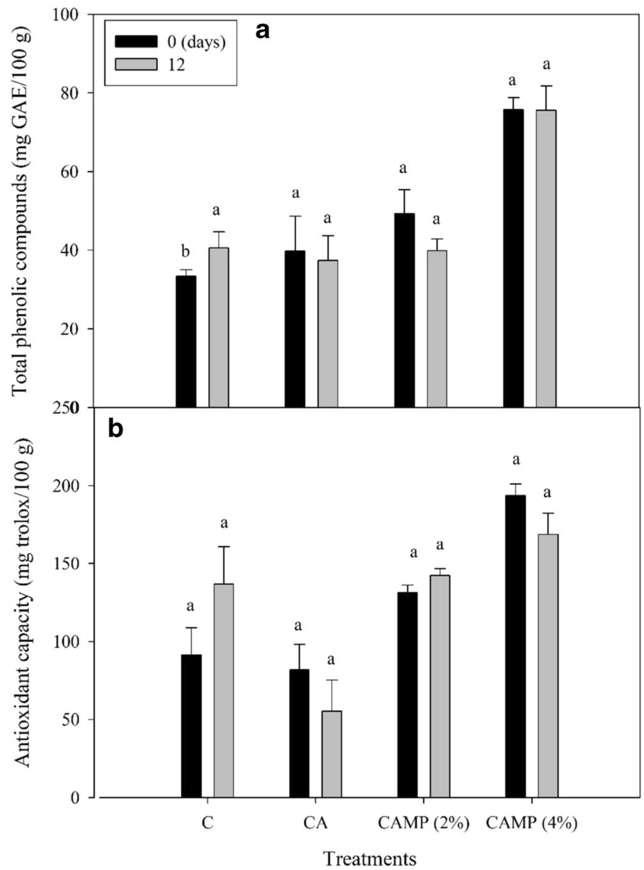

Fig. 3 Total phenolic compounds (**a**) and antioxidant capacity (**b**) of control apple slices (C), coated apple slices (CA), and apple slices coated with 2% (CAMP 2%) and 4% (CAMP 4%) of mango peel during the storage. Bars indicate standard deviation

compounds that may act as antioxidants (Fig. 3). However, it is possible that at higher concentration of mango peel, polyphenol oxidase may cause higher browning (previously discussed).

Resistance to Penetration of Apple Slices

The resistant to penetration of apple slices with and without edible coating was measured (Fig. 2b). At the beginning of the storage, the use of edible coating significantly increased the penetration resistant ($p < 0.05$), showing values of 4.6 ± 0.1, 5.1 ± 0.3, 5.6 ± 0.1, and 6.1 ± 0.2 N for control apple slices and for those coated with 0, 2, and 4% of mango peel powder, respectively. The increase in the resistant to penetration is very important because one of the main concerns of minimally processed apples is tissue softening, which can reduce their shelf-life (Chiabrando and Giacalone 2013). The results obtained indicate that the mechanical properties provided by the mango peel powder to the edible films were satisfactorily reproduced in the apple slices. These results are in concordance with those obtained in this study to edible films and those obtained by Moreira et al. (2015), who applied an edible coating formulated with gellan gum plus dietary fiber to fresh-cut apples.

During storage, the firmness of apple slices added with edible coating were reduced probably due to the action of pectic enzymes such as the pectinesterase and polygalacturonase, which degrade the cell wall (Song et al. 2013). However, the resistant to penetration for control apple slices was increased after 6 days of storage. This phenomenon may be associated with the absence of a physical barrier which avoids the water interchanges, causing dehydration of the product, increasing its resistant to penetration (Rojas-Graü et al. 2008).

Bioactive Compounds and Antioxidant Capacity of Apple Slices

Apples contain phytochemical recognized for their health-promoting antioxidant properties. Among phenolic acids, chlorogenic, *p*-coumaric, and caffeic acids are the most important; while quercetin, epicatechin, catechin, rutin, and phlorizin are the main flavonoids present in apples (Heras-Ramírez et al. 2012). Table 2 shows the TPC and AC of apple slices with and without edible coating. Control apple slices show values of TPC and AC similar to the values reported to different varieties of apples (Khanizadeh et al. 2008). Apple slices added with edible coating formulated with mango peel powder (4%) presented an increase of 126.9 and 145.4% of TPC and AC, respectively. Therefore, one of the main purposes of this research was covered, since the TPC and AC of apple slices were improved by the addition of mango peel powder to the edible coating.

After 12 days of storage (Fig. 3), TPC and AC of almost all samples remained constant, only the TPC for control apple slices significantly increased ($p < 0.05$), which may be attributed to the water loss during the storage. The results obtained in this study were similar to those obtained by Aguayo et al. (2010), who informed that TPC and AC did not change in fresh-cut apple slices treated with calcium ascorbate solution (0, 2, and 6%). Besides, Kou et al. (2014) informed that TPC remained constant in both peel and flesh of apple stored at 0 ± 1 °C for 30 days.

Conclusion

Mango peel powder may be incorporated to starch edible films to improve their physical, structural, and phenolic compounds and antioxidant capacity. Moreover, these advantages can be observed when they are used as edible coating on apple slices. In storage, the edible coating did not avoid the increase of browning index and the decrease of firmness of apple slices. However, edible coating formulated with 2% of mango peel showed the lowest browning index; moreover, the increase in the phenolic compounds and antioxidant capacity provided by the mango peel remains constant. Although further studies should be conducted to validate the suitability of mango peel powder on the improvement of mechanical, physical, and microbiological properties of edible films and coatings, this study shows that it can be used for their antioxidant fortification.

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