



Research article

Effect of a multifunctional edible coating based on cassava starch on the shelf life of Andean blackberry

Misael Cortés Rodríguez^{a,*}, Camilo Villegas Yépez^a, Jesús Humberto Gil González^a, Rodrigo Ortega-Toro^b^a Universidad Nacional de Colombia, Facultad Ciencias Agrarias, Cra. 65 No. 59A – 110, Medellín, Colombia^b Universidad de Cartagena, Programa de Ingeniería de Alimentos, Research Group in Complex Fluids Engineering and Food Rheology (IFCRA), Food Packaging and Shelf Life Research Group (FP&SL), Avenida del Consulado Calle 30 No. 48 – 152, Cartagena de Indias D.T. y C., Colombia

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ABSTRACT

The blackberry is a fragile fruit with a high degree of decomposition, which limits its shelf life. The effect of an edible coating (EC) based on cassava starch, whey protein, beeswax, chitosan, glycerol, stearic acid, and glacial acetic acid on the shelf life of fruit stored at 4 °C was evaluated. The physical, chemical, physical, microbiological, and sensorial quality was evaluated, comparing with a fresh control fruit. The EC had a positive effect on the physicochemical and sensorial properties (mainly in texture, flavor, and aromas), due to the reduction of physiological processes, whereas the color changes are mainly due to anthocyanin losses. After 10 days of storage, weight losses were 39.6% lower and firmness was 81.4% higher; while chitosan reduced the mold and yeast count. The EC increased the useful life of the Andean blackberries by 100%.

1. Introduction

Andean blackberry (*Rubus glaucus* Benth) is a fruit native to tropical areas of South America, grown mainly in countries such as Colombia and Ecuador, and it is distinguished by being a non-climacteric fruit, rich in minerals (Ca, P, K, Mg, Fe) and vitamins A, C, E, K, B (Carvalho and Betancour, 2015; Ospina et al., 2019; Sinuco et al., 2013). Additionally, it is a juicy, dark red fruit with a pleasant aroma, characterized in the food industry as a fruit of versatile transformation (Arozarena et al., 2012; Kumar et al., 2017a,b; Dávila et al., 2017; Rojas-Llanes et al., 2014).

In recent years, the consumption of blackberries has increased, opening export markets mainly in North America and the European Union (Carvalho and Betancour, 2015), for its high nutritional value. It is an excellent natural source of antioxidant compounds such as benzoic acid, hydroxycinnamic acid, flavonoids, ellagic acid, tannins, ellagitannins, quercetin, gallic acid, anthocyanins, and cyanidins (Acosta-Montoya et al., 2010; Arozarena et al., 2012; Estupiñán et al., 2011; Kumar et al., 2017a,b; Mertz et al., 2007; Parada-Moreno et al., 2012; Rojas-Llanes et al., 2014; Romero and Yépez, 2015), which can

contribute to the prevention of degenerative diseases (Ali et al., 2011; Carvalho and Betancour, 2015).

However, blackberry is a fruit with a high-water content (90–91%), fragile morphological structure, and undergoes continuous physicochemical and firmness changes. This makes it a highly perishable fruit susceptible to fungal contamination and large post-harvest losses under inadequate management, giving it a shelf life of 3–5 days at refrigeration temperatures (Ayala et al., 2013; Ramírez et al., 2013; Rodríguez-Barona et al., 2012; Romero and Yépez, 2015; Villegas and Albarracín, 2016). To guarantee the quality and safety of the blackberry, thermal treatments have been used; however, these directly affect the antioxidant, nutritional, and sensorial properties (Romero and Yépez, 2015; Villegas and Albarracín, 2016).

In recent years, technological alternatives have been sought to reduce high energy consumption and environmental impact, as well as to ensure the quality of fresh products (Kaushik et al., 2014; São José et al., 2014; Villegas and Albarracín, 2016). In this context, edible coatings (EC) made from composite materials help to increase the shelf life of highly perishable fruits by forming a barrier capable of retaining water vapor, breathing gases (CO₂, O₂, ethylene) and aromas, and mitigating the

* Corresponding author.

E-mail address: mcortesro@unal.edu.co (M. Cortés Rodríguez).

physiological processes important to fruit (Bezerra-De Aquino et al., 2015; Boesso-Oriani et al., 2014; Silva et al., 2015; Thomas et al., 2016). On the other hand, ECs are considered vehicles for transporting bioactive compounds that serve to add value to fruits and protect them microbiologically (Boesso-Oriani et al., 2014; Zheng et al., 2019).

In Andean blackberries, the application of EC has been reported with formulation from different sources: Starch (Chen et al., 2019; Pajak et al., 2019; Galindez et al., 2019), aloe vera (Ramírez et al., 2013; Ortega-Toro et al., 2017; Gutiérrez and Álvarez, 2016), sodium alginate (Salama et al., 2018; Abdel-Aziz, Salama and Sabaa, 2018; Ruan et al., 2019), gellan gum (Du et al., 2019; Wei et al., 2017; Danalache et al., 2016), gelatin (Dou et al., 2018; Jridi et al., 2019; Soo and Sarbon, 2018), and casein (Chevalier et al., 2018a, b), and hydroxypropyl methylcellulose (Villegas and Albarracín, 2016), among others. These have increased the shelf life of the fruit while preserving its physical and chemical properties, as well as sensory and microbiological, with respect to the fresh blackberries. However, the application of ECs with compound matrices has not yet been reported in this fruit. In papaya, starch-based EC and commercial waxes were applied to improve firmness and texture. In mango, EC was applied based on cassava starch, pectin, and olive oil, increasing shelf life up to 12 days of storage (Estrada-Mesa et al., 2015). Strawberry was coated using an EC based on tara gum, beeswax, and shellac, reducing the physiological processes of the fruit (Pavón-Vargas and Valencia-Chamorro, 2016). On the other hand, multicomponent ECs have been formulated in order to increase the preservative properties of the EC applied in fruits, as verified in strawberries with cassava starch, isolated soy protein, and canola oil (Saavedra and Algecira, 2010) and in cape gooseberry with cassava starch, whey protein, and beeswax (López et al., 2016).

The aim of this work was to evaluate the effect of a multifunctional EC based on cassava starch (CS), whey protein (WP), beeswax (BW), chitosan (CH), glycerol (G), stearic acid (SA), and glacial acetic acid in the quality of fresh Andean blackberry during storage at 4 °C.

2. Materials and methods

2.1. Materials

Andean blackberries (*Rubus glaucus* Benth) from the municipality of Granada (Antioquia) with maturity degree 5 were selected with a uniform size without mechanical damage or visual fungal contamination and, then, underwent a process of washing and disinfection with 50 ppm NaClO solution (Villegas and Albarracín, 2016). This fruit without coating application was considered the control fruit. The EC was prepared from CS, WP, BW, CH, G, SA, and glacial acetic acid to dissolve the CH.

2.2. Preparation and application of the edible coating

A suspension of CS (3.5% w/w) and WP (1.16% w/w) in distilled water was initially prepared using an Ultra Turrax homogenizer (digital IKA T25) at 13000 rpm for 3 min. Then, the G suspension was added, according to the ratio of $G/(CS + WP) = 2$, and the system was homogenized again at 13000 rpm for 3 min. On the other hand, the total content of the CH (0.75% w/w) was dissolved in a solution of 1% v/v glacial acetic acid in distilled water at 40 °C for 2 h. Subsequently, both systems were mixed with constant stirring and heating in a water bath using a heating plate (IKA C-MAG HS 4). When 70 °C was reached, the BW (0.47% w/w) and the EA were added at a ratio of $BW/EA = 5$, and the heating was continued up to 85 °C. Finally, the formed emulsion was cooled to 35 °C and homogenized while cold at 21000 rpm for 1 min, then degassed in a vacuum chamber at 7.4 kPa for 45 min. Blackberry with the edible coating (B + EC) was obtained by immersing the fruit for 90 s, followed by a surface runoff for 90 s more before subsequent drying by forced convection at 30 °C for 1 h.

2.3. Characterization of the blackberry fruits

For measurement of the Andean blackberry physicochemical properties, the fruit was homogenized until a homogeneous pulp was obtained and, then, passed through qualitative filters of 90 mm at 65 g/m². The acidity was determined by potentiometric titration with NaOH until reaching a pH of 8.2 by diluting 5g in 50 mL of distilled water (Joo et al., 2011; Villegas and Albarracín, 2016), expressing the results as malic acid (%). The total soluble solids (TSS) were determined by reading with a refractometer (Colombian Technical Standard, 1997). The pH was determined with a pH-meter (Hanna pH 211) (Villegas and Albarracín, 2016). Moisture content was determined by the modified AOAC 930.15/1990 method, where drying was carried out in a vacuum oven (Memmert VO 200) at 60 °C and 1 kPa mbar for 24 h.

Weight loss (WL) was determined by the gravimetric method (Villegas and Albarracín, 2016; Mantilla et al., 2013), according to Eq. (1), where IW is the initial weight on day 0, and FW is the final weight on control days. The WL data were reported as a percentage.

$$WL = \frac{IW - FW}{IW} * 100 \quad (1)$$

For determination of total phenols, antioxidant activity, and anthocyanins, the extracts were obtained by weighing 0.3 g of pulp and 9 mL of methanol: water solution (70/30 v/v), mixing for 20 min, and centrifuging at 8000 rpm for 10 min and 20 °C (Hettich Universal 320 R centrifuge). Subsequently, the supernatant was filtered with 90 mm qualitative filters (65 g/m²), shaking for 20 min, and centrifuged again under the same conditions. The phenols content was determined according to the methodology of Horvitz et al. (2017), according to the following modifications: 20 µL of the methanolic extracts and 1250 µL of 20% Na₂CO₃ were mixed in 480 µL of distilled water, allowed to stand for 5 min, and then, it was mixed with 250 µL of the Folin-Ciocalteu reagent diluted in distilled water in a 1/1 ratio. Afterwards, it was kept in the dark for 2 h, and the absorbance was determined at 760 nm (Thermo Fisher Evo 60 spectrophotometer), expressing the results in mg of gallic acid/100 g db.

The antioxidant activity of the extracts was determined by the ABTS and DPPH methods according to the methodology described by Manozzi et al. (2018) with some modifications: 20 µL of methanolic extract and 2 mL of ABTS solution were mixed for 1 min, left in the dark for 7 min, and then absorbance was read at 734 nm. On the other hand, 20 µL of the extract were mixed with 1.98 mL of the DPPH solution, left at rest for 30 min, and the absorbance was read at 517 nm. The results were expressed in mg of Trolox/100 g db. The anthocyanins content was determined by the pH difference method (Kuskoski et al., 2005), preparing a buffer solution of 0.025 M at pH 1 with hydrochloric acid and potassium chloride and also pH 4.5 to 0.4 M with acetic acid and sodium acetate. 200 µL of extract was mixed with 1800 µL of the corresponding buffer solution, and the absorbance was measured against a blank at 510 and 700 nm. The final absorbance (F_A) was calculated with Eq. (2) and the content of anthocyanins with Eq. (3), where MW is the molecular weight (449.2 g/mol), DF is the dilution factor, ε is the molar absorptivity (26900). The data were expressed in mg of Cyanidine 3-glucoside/100 g db.

$$F_A = (A_{510} - A_{700})_{pH 1} - (A_{510} - A_{700})_{pH 4.5} \quad (2)$$

$$Anthocyanins = \frac{A_F * MW * DF * 100}{\epsilon * l} \quad (3)$$

The firmness was determined through penetration tests in the equatorial zone, according to the methodology described by Ramírez et al. (2013) with some modifications. A Stable Micro System texturometer TA.XT2i was used with accessory P/5 and with a penetration speed and distance of 2 mm/s and 15 mm, respectively. The color parameters were determined on the epicarp of the equatorial zone of the fruit, taking 4

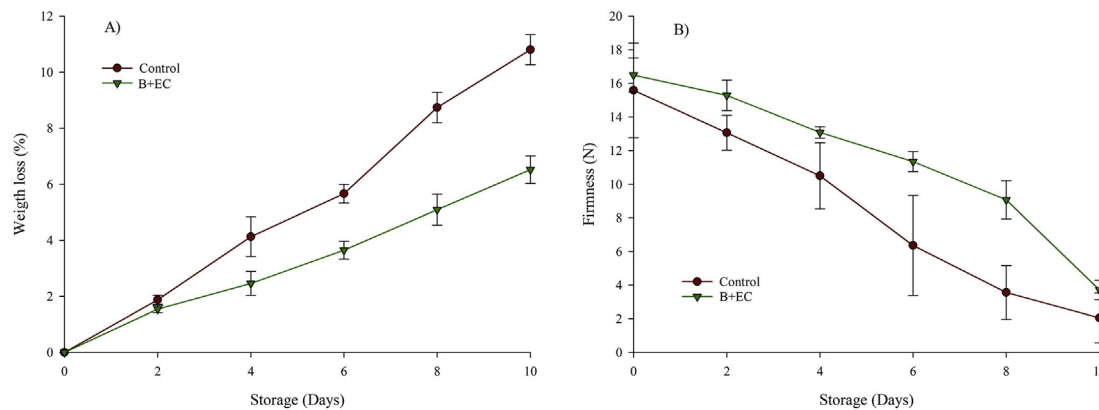


Figure 1. Weight loss (panel A) and firmness (panel B) of blackberry with the edible coating (B + EC) and blackberry without edible coating (Control) during storage at 4 °C.

readings at 90°. An X-Rite model SP62 spectrophotometer, D65 illuminant, 10° observer, specular component included was used, obtaining the CIE-Lab color coordinates and the color changes (ΔE) from the reflection spectra (equation 4) (Ramírez et al., 2013). ΔL , Δa , and Δb represent the differences in brightness and chromaticity a (red - green) and b (yellow - blue) respectively, between the parameter evaluated in the control time t and the time 0, both for the B + EC and for the control fruit.

$$\Delta E = \sqrt{(\Delta L)^2 + (\Delta a)^2 + (\Delta b)^2} \quad (4)$$

The sensory evaluation was carried out after 0, 6, 10 days of storage, evaluating acceptance tests of color, smell/aroma, flavor, and texture, using a hedonic scale of 5 points: 1 (I dislike it a lot) and 5 (I like it very much) with 30 consumer panelists (García-Mogollón et al., 2010). On the

other hand, the microbiological evaluation was performed based on the count of molds and yeasts (AOAC 17.2/2002), as well as total and fecal coliforms (AOAC 966.24/1998), expressed as colony forming units/g (CFU/g).

2.4. Storage

The B + EC and the control fruit were packed in perforated polypropylene boxes and stored at 4 °C for 0, 2, 4, 6, 8, and 10 days.

2.5. Statistical analysis

Determination of the dependent variables was performed in triplicate for each control time, and the results were analyzed from ANOVA, using

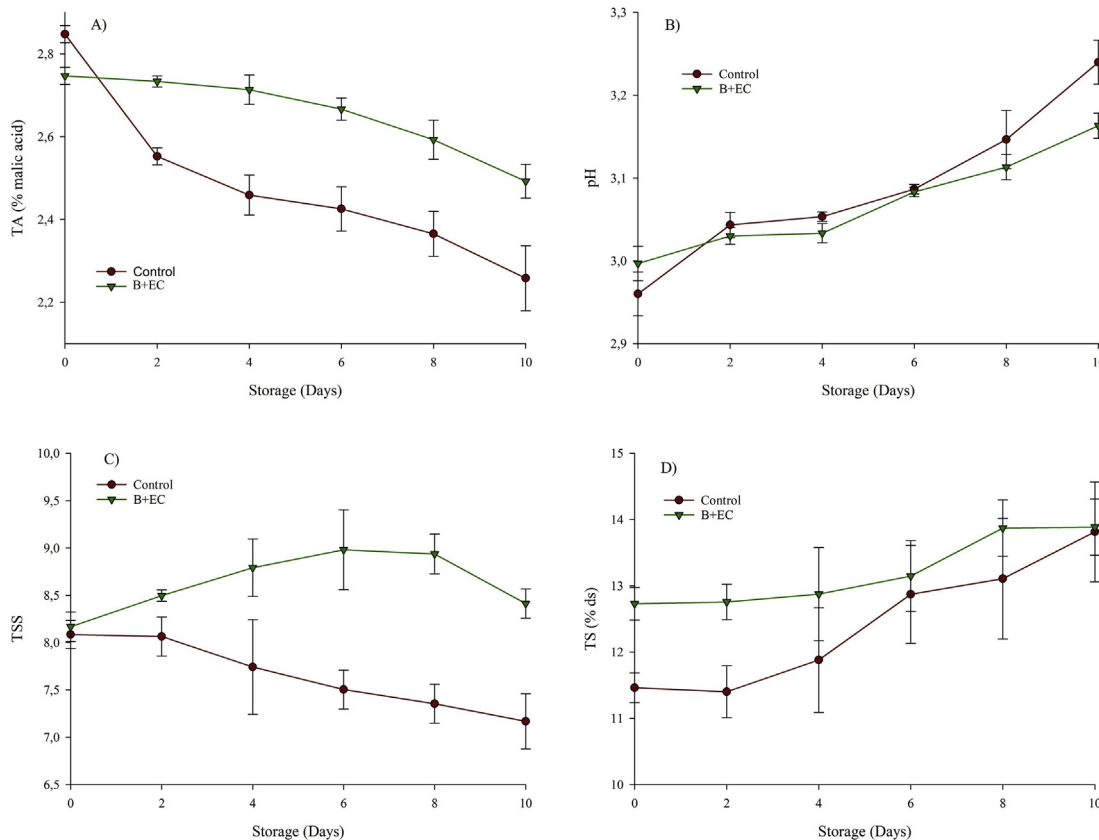


Figure 2. Titratable acidity (panel A), pH (panel B), total soluble solids (panel C), and total solids (panel D) of blackberry with the edible coating (B + EC) and blackberry without edible coating (Control) during storage at 4 °C.

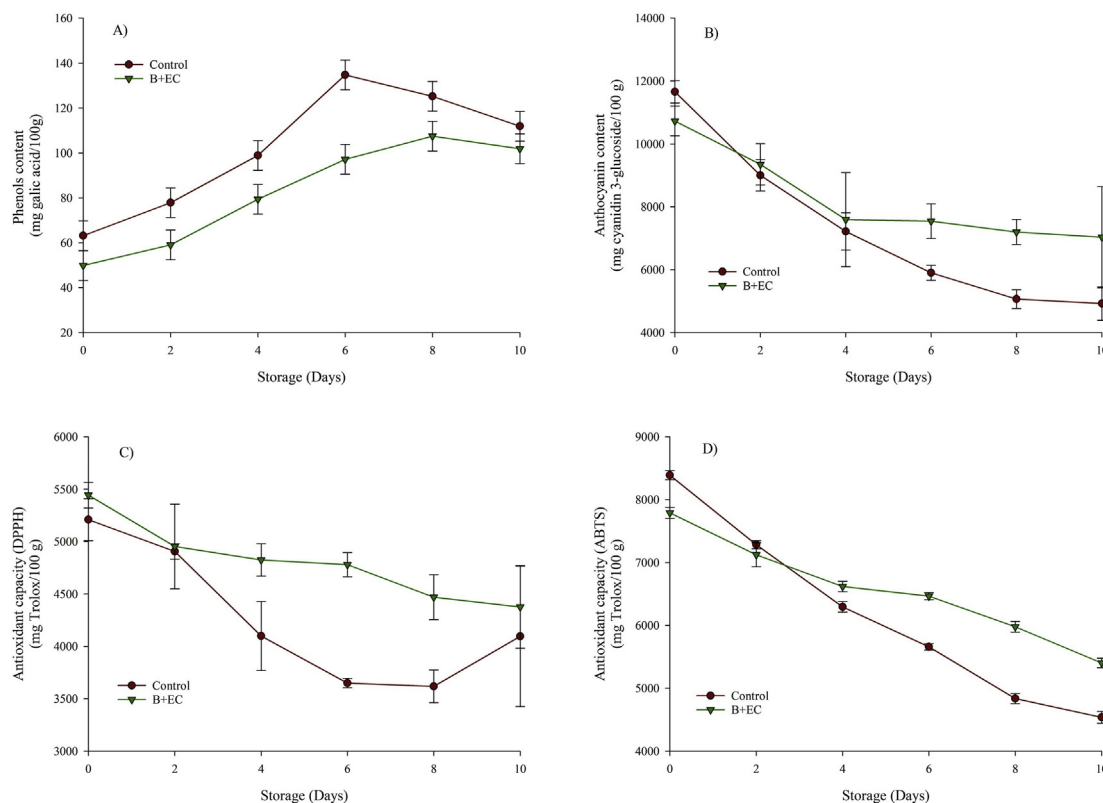


Figure 3. Phenols content (panel A), anthocyanin content (panel B), DPPH antioxidant capacity (panel C) and ABTS antioxidant capacity (panel D) of blackberry with the edible coating (B + EC) and blackberry without edible coating (Control) during storage at 4 °C.

the LSD method (least significant differences) of multiple comparisons with a confidence level of 95%. For the statistical analysis, the statistical package Statgraphics Centurion XVI was used.

3. Results and discussions

3.1. Water loss and firmness

Figure 1 shows the behavior of the WF and the firmness of the B + EC and the control fruit during storage at 4 °C. The ANOVA showed significant statistical differences ($p < 0.05$) between the WF and the firmness with respect to the time and treatment factors. The WL showed an upward trend in both treatments, being approximately 6 and 11% at the end of storage for B + EC and fruit control, respectively, (WL in B + EC is 39.6% < control fruit), which is attributed to the mass transport and diffusion of water vapor that happens during the physiological processes of Andean blackberries (transpiration and respiration) (Ramírez et al., 2013; Villegas and Albarracín, 2016). On the other hand, the use of EC exerts a barrier to gases (O_2 , CO_2 , among others), as has been described by some authors (Ortega-Toro et al., 2014; Ayala et al., 2014), and helps reduce the respiration rate of the fruit. The incorporation of BW into the formulation increased the water vapor barrier thanks to the hydrophobic nature of this compound and the increased tortuosity it exerts on the material when the water vapor molecules pass through (Velickova et al., 2013).

Because of its plasticizing characteristics, glycerol (G) does not contribute to improving the barrier properties and increases the molecular mobility and the free volume of the material, facilitating the permeation of the molecules (Ortega-Toro et al., 2017). However, the inclusion of EA could improve the properties of barrier against water vapor due to its hydrophobic nature (Perez-Gago et al., 2005). The reduction of the WL has also been described by Villegas and Albarracín (2016) in Andean blackberries with EC based on hydroxypropyl

methylcellulose and BW, as well as by Mannozi et al. (2018) in cranberry coated with CH.

The firmness showed a decreasing trend in both treatments for all storage periods, and the surface rigidity of B + EC was greater than the control fruit (81.4% after 10 days of storage); however, the speed of change was similar. The firmness of the blackberry is linked to the respiration and transpiration processes of the fruit, occurring as enzymatic degradations cause changes in its cell wall (Horvitz et al., 2017). The application of the EC formulation acted as a barrier and reduced the physiological processes of the blackberry, and this retards the degradation of polymers present in the cell wall that adhere to pectic acids avoiding tissue softening, due to the loss of cellular turgor and the loss of extracellular and vascular air (Auras et al., 2004; Joo et al., 2011; Ramírez et al., 2013; Valle and Rodríguez, 2011). The CS-based EC provided a more elastic surface that when interacting with the fruit and resulted in reducing the loss of surface firmness. A similar situation has been reported in several dietary matrices with CS-based EC: hartón plantain (Márquez-Cardozo et al., 2015); guavas (Bezerra-De Aquino et al., 2015); peppers (Ordoñez-Bolaños et al., 2014); and blackberry (Menezes-Oliveira et al., 2013). On the other hand, the results found are also similar to those reported in blackberries covered with aloe vera mucilage (Ramírez et al., 2013), strawberries with CH-calcium-based EC (Hernández-Muñoz et al., 2008), and blueberries with CH-based EC (Mannozi et al., 2018).

3.2. Acidity, pH, soluble solids, and total solids

Figure 2 shows the behavior of the physicochemical properties titratable acidity (TA), pH, TSS, and total solids (TS) of B + EC and control fruit during storage at 4 °C. The maturation and the physiological processes of the blackberry affect the physicochemical properties, presenting significant statistical differences ($p < 0.05$) in all the parameters regarding the time and treatment factors.

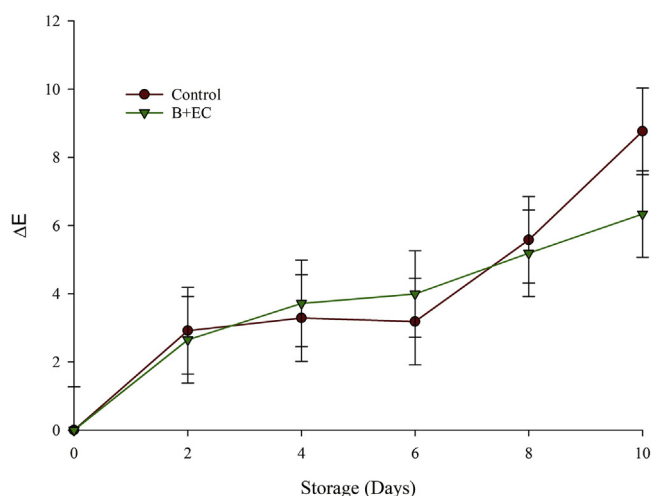


Figure 4. Color changes (ΔE) of blackberry with the edible coating (B + EC) and blackberry without edible coating (Control) during storage at 4 °C.

During the first days of storage, the TA of the control fruit had a higher rate of change than the B + EC, varying from 2.85 to 2.26%. However, the B + EC presented an approximately constant rate of change for this parameter until day 8, observing a total decrease of 7.41%. The decrease of the TA is attributed to the oxidation of the organic acids present, which are substrates in the respiration process (Ramírez et al., 2013; Villegas and Albarracín, 2016). The behavior of the pH in both treatments was similar and consistent with the TA, increasing with the storage time. The pH was affected by the reduction in acidity. In addition, it could also be affected by the union of pectin fragments with polyphenols during the maturation process (Joo et al., 2011; Villegas and Albarracín, 2016).

The EC decreased the changes in acidity and pH, due to the effect on the physiological processes that these exert on the fruit. This behavior has been observed in several fruits with EC: blackberries with EC based on hydroxypropyl methylcellulose (Villegas and Albarracín, 2016), blackberries with EC based on mucilage from aloe vera (Ramírez et al., 2013), mango with EC to base of native and oxidized cassava starch (Figuerola and Salcedo, 2013), among others.

The TSS of the B + EC showed an increasing behavior until day 8 (8.17% → 8.94%) and an unexpected decrease to 8.4% on day 10. This increase in the TSS was consistent with the WL observed and attributable to the evaporation caused by the difference of chemical potential of the water (motive force to the transfer of mass) between the fruit and the environment (Gol et al., 2013; Ramírez et al., 2013; Velickova et al., 2013; Villegas and Albarracín, 2016); in addition, to the conversion of organic acids into sugars during the physiological processes of blackberry. However, the control fruit did not have a consistent behavior for WL, presenting a downward trend over time. This could be attributed to the consumption of sugars and organic acids in the respiration process, which is accelerated by the senescence of fruit and the weight loss due to leaching caused by the enzymatic reactions that develop in physiological

processes (Gol et al., 2013; Velickova et al., 2013). This decreasing behavior was also observed by Menezes-Oliveira et al. (2013), where the blackberry control fruit had an TSS loss from 10.13 to 8.43. The opposite occurred in research presented by Ramírez et al. (2013) and Villegas and Albarracín (2016), where the blackberry control fruits increased the TSS over time.

In the case of TS, their behavior was consistent with the WL in both products, increasing over time and observing the greatest differences between the treatments in the first 4 days of storage because the driving force to the WL is greater. Some authors have attributed the increase of TS to the presence of EC on the surface of the fruit (Lopes-Carvalho et al., 2016; Mannozi et al., 2018).

3.3. Total phenols, anthocyanins, and antioxidant activity

Figure 3 shows the behavior of the total phenols, anthocyanins, and the DPPH and ABTS antioxidant activity of the B + EC and the control fruit during storage at 4 °C. All these parameters presented significant statistical differences ($p < 0.05$) regarding the time and treatment factors.

The total phenols content presented a similar behavior in both treatments, with an increasing trend, but it was always higher in the control fruit than in the B + EC. The control fruit reached a maximum value at 6 days (13475.2 ± 656.7 mg gallic acid/100 g db) and subsequently decreased to 11191.2 ± 825.0 mg gallic acid/100 g db. Also, the B + EC reached its maximum value at 8 days and then was steady until day 10 (10188.8 ± 663.6 mg gallic acid/100 g db). This increase in phenolic content is attributed to the possible synthesis of compounds with antioxidant capacity during the physiological processes of the fruit, which has been also observed in plums with EC + CH (Kumar et al., 2017a,b). However, some authors have observed phenolic compounds obtained by Folin-Ciocalteu and are assumed to be compounds such as ascorbic acid, reducing sugars, soluble proteins among others (Oms-Oliu et al., 2008), which can explain their increase during storage. The reduction of phenolic compounds over the last days of storage can be attributed to the decomposition of the cellular structure during senescence (Gol et al., 2013).

The content of monomeric anthocyanins in both treatments presented a similar behavior and a faster change during the first 4 days. Subsequently, the B + EC showed asymptotic behavior until the 10th day, reaching 73.4 ± 10.1 mg Cyanidin 3-glucoside/100 g db and a total degradation of 31.6%. The control fruit reached the asymptotic behavior on day 8 reaching 49.9 mg Cyanidin 3-glucoside/100 g db with a total degradation of 57.2%. The decrease of anthocyanins in the blackberry was attributed to the instability of the pigment during processing and storage, generating colorless and insoluble derivatives (Ayala et al., 2012; Da Silva et al., 2014). The results obtained had a behavior similar to that reported in strawberries with EC based on CS and propolis extract (Thomas et al., 2016). On the other hand, strawberry with EC based on CH anthocyanins presented the opposite behavior and increased over time, attributed to the synthesis of anthocyanins during the physiological processes of the fruit (Gol et al., 2013).

Table 1. Microbiological counts for B + EC and control fruit during storage at 4 °C.

Time	Total coliforms		Fecal coliforms		Yeast		Mold	
	Control	B + EC	Control	B + EC	Control	B + EC	Control	B + EC
0	20–110	<10	<10	<10	200–250	<10–280	70–140	<10–20
2	20–30	20	<10	<10	180–200	140–300	30–50	<10–190
4	<10	<10	<10	<10	<10–300	190–280	<10–90	<10–60
6	<10–100	10–20	<10	<10	300–380	130–230	<10–200	60–120
8	<10–110	<10	<10	<10	190–250	<10	80–1200	20–130
10	20–2100	40–70	<10	<10	2000–4000	180–280	140–3000	160–430

Data expressed in CFU/g.

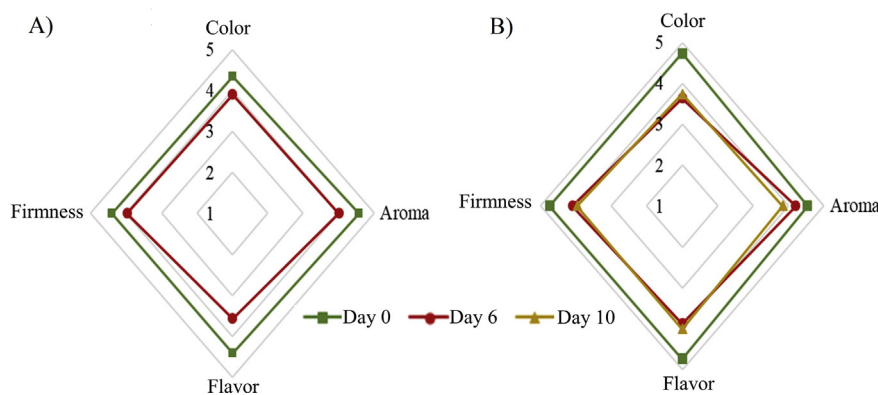


Figure 5. Sensory profile of blackberry without edible coating (panel A) and blackberry with the edible coating (panel B) during storage at 4 °C.

For the control fruit and the B + EC, the mean DPPH values fluctuated between (5209.5–4095.6) and (5443.7–4376.7) mg of Trolox per 100 g db, while the ABTS was between (8389.6–4536.9) and (7790.9–5402.5) mg of Trolox per 100 g db respectively. This demonstrated that the ABTS technique is more sensitive to the determination of phenolic compounds in aqueous media, as reported by Kuskoski et al. (2005). The antioxidant capacity decreased with the increase of storage time, observing a positive effect of the EC on the protection of the Andean blackberry, which contributed to lower loss of its antioxidant activity. This can be due to the high barrier against the O₂ of the EC based on CS and the decrease in the interaction with light. This decrease in antioxidant capacity is mainly associated with the loss of anthocyanins present in the fruit, which are the most important in this food matrix (Mannozi et al., 2018; Bernal et al., 2014). However, some authors have reported an increase in antioxidant capacity due to the synthesis of secondary metabolites such as polyphenols (Ayala et al., 2014).

3.4. Color changes

Figure 4 shows the color change (ΔE) of the B + EC and the control fruit during storage at 4 °C. The ANOVA showed significant differences ($p < 0.05$) in the ΔE with respect to time, whereas there were no significant differences ($p > 0.05$) with respect to the treatment factor. Both the B + EC and control fruit showed a tendency to increase ΔE over time, a behavior that has also been reported in aloe vera-coated blackberries (Ramírez et al., 2013).

This situation could be attributed to various physicochemical and physical phenomena that both systems experience during storage: A) Anthocyanins that are structurally polyphenolic can be oxidized by the action of polyphenoloxides, B) co-pigmentation process that promotes the formation of polymers from condensation reactions of anthocyanins and other phenolic compounds, C) formation of adducts or complexes between anthocyanins and quinones generated during the oxidation of polyphenols and D) weight loss (WL) that occur during storage, caused by loss of water, especially on the fruits' surface (Mannozi et al., 2018; Kumar et al., 2017a,b; Ramírez et al., 2013; Fang et al., 2007).

3.5. Microbiological analysis

Table 1 presents the counts for total coliforms, fecal coliforms, yeast, and mold of the B + EC and the control fruit during storage at 4 °C. The results obtained for allow inferring that the B + EC has a greater antimicrobial capacity than the control fruit, which is mainly due to the bactericidal characteristics of the CH present in the EC (Gol et al., 2013; Kumar et al., 2017a,b; Simonaitiene et al., 2015). Some researchers have reported that there is CH control over the growth of pathogenic fungi, as well as coliforms and aerobic microorganisms during the storage of blackberries (Campos et al., 2011). This control is possibly attributed to the fact that this biopolymer produces chitinase, which adheres to the

cell walls of microorganisms causing severe cell damage in fungi and interfering with the secretion of enzymes that increase the senescence of the fruit (Gol et al., 2013; Hernández-Muñoz et al., 2008; Velickova et al., 2013). Some authors reported similar behaviors in strawberries coated with CH and lemon essential oil (Perdones et al., 2012), strawberries with CH (Wang and Gao, 2013), blueberries coated with CH and pro-cyanidins (Mannozi et al., 2018), and blueberries treated with Sem-perfresh™, CH, calcium caseinate, and sodium alginate (Duan et al., 2011).

On the other hand, it was observed that the control fruit values for the total coliforms and the count of molds and yeasts do not comply with the allowable requirements in Colombian regulations (150 and 3000 CFU/g respectively), whereas fecal coliforms kept the same values throughout storage. Similar results have been reported by some investigators in Andean blackberries stored at different temperatures (8 and 18 °C) (Horvitz et al., 2017). It was noted that the counts of molds and yeasts in the B + EC over the 10 days of storage maintained at values lower than 430 and 300 CFU/g, which could be due to the first instance of EC application to the fruit, which generates a barrier capable of inhibiting the growth of fungi (Velickova et al., 2013). In strawberries coated with carboxymethylcellulose-CH, hydroxypropyl methylcellulose-CH (Gol et al., 2013) and with CH-BW (Velickova et al., 2013) a reduction in the fungal growth was observed concerning the control fruit.

3.6. Sensorial analysis

Figure 5 presents the sensory profile of the control fruit and B + EC after 0, 6, and 10 days of storage at 4 °C. In both products, it was observed that the assessment of the attributes of sensory quality such as color, aroma, taste, and texture decreased as storage days increased. It is noted that the control fruit was not evaluated on day 10, due to the presence of visual fungal contamination. However, the B + EC trends to maintain its sensorial values after 6 and 10 days, being the mean values and their standard deviation for color, aroma, flavor, and texture of 3.65 ± 1.05 , 4.02 ± 0.91 , 3.97 ± 1.06 , 4.03 ± 0.97 respectively.

In blackberries covered with aloe vera gel and carnauba wax, better sensory properties were observed with respect to the control fruits during the storage period. This is because the applied ECs delayed the physiological processes of the fruit and reduced the loss of quality by microbiological effects (Ramírez et al., 2013).

4. Conclusions

The application of the EC to Andean blackberries had a positive effect on the physicochemical properties such as pH, acidity, soluble solids, total solids, antioxidant capacity, phenolic compounds, and anthocyanins, due to the decrease of the physiological processes of the fruit such as perspiration and respiration. The color changes found are mainly due to the loss of anthocyanins that the fruit experiences during storage. The

applied EC slowed the microbial growth of the fruit and conserved the sensory quality, mainly for texture, flavor, and aroma retention during 10 days of storage at 4 °C. The EC based on CS, WP, BW, CH, G, SA, and glacial acetic acid applied to the Andean blackberry is an effective alternative for its conservation, increasing its useful life up to 10 days at 4 °C, corresponding to an increase of approximately 100% when compared to what was found in the control fruit and with that reported with other researchers.

Declarations

Author contribution statement

Misael Cortés Rodríguez: Conceived and designed the experiments; Analyzed and interpreted the data; Contributed reagents, materials, analysis tools or data; Wrote the paper.

Camilo Villegas Yépez: Performed the experiments; Wrote the paper.

Jesús Humberto Gil G: Performed the experiments; Analyzed and interpreted the data.

Rodrigo Ortega Toro: Analyzed and interpreted the data; Wrote the paper.

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Competing interest statement

The authors declare no conflict of interest.

Additional information

No additional information is available for this paper.

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