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Effect of ulluco starch coating on the preservation of harvested goldenberries (*Physalis peruviana* L.)

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Abstract

This study aimed to determine an alternative to extend the shelf life of goldenberries by using an edible ulluco starch-based coating (USBC). For this purpose, USBCs were prepared at different starch concentrations, namely S1 (2.0% w/v), S2 (2.5% w/v), and S3 (3.0% w/v). Then, ripe goldenberries were divided into four groups and coated with S1, S2, S3, and water as a control thus obtaining the S1G, S2G, and SG3 groups. The coated fruits were stored and analyzed with respect to their physicochemical and microbiological parameters. Results demonstrated that the use of the USBC did not affect sugar and total soluble solids, pH, titratable acidity, and color in the fruits. Moreover, a reduction in respiration rate and water loss as well as an improvement in fruit firmness were observed. Microbiological analysis revealed that the coating delayed the growth of microorganisms by at least one week. The use of ulluco starch for edible coating preparation is a potential alternative for the improvement of the shelf life of goldenberries, and it can be a strategy to add value to the ulluco crop.

Novelty impact statement: This research shows an extension of the shelf life of goldenberries using an edible coating based on ulluco starch. Edible coatings decreased respiration rate and weight loss in goldenberries. The use of ulluco starch can help in meeting the industrial demand for starch as a raw material without compromising on food security.

1 | INTRODUCTION

Physalis peruviana L. is a perennial plant belonging to the Solanaceae family native to South American Andes and is cultivated primarily at altitudes between 1,700 and 2,900 m above sea level (m a.s.l.), particularly in Colombia, Peru, and Ecuador (Bernal et al., 2018; Maruenda et al., 2018). *P. peruviana* fruit, also known as goldenberry or cape gooseberry, is a climacteric edible yellow–orange waxy skin berry with juicy pulp characterized for being protected by a papery husk (calyx) and contains between 150 and 300 small seeds (Fischer et al., 2011). This fruit is recognized as having high nutritional value, the reports in the literature establish protein contents of 2.6%, lipids 0.5%, carbohydrates 19.6%, and crude fiber 4.9% in wet basis, and an energy intake of 76.8 cal (Puente et al., 2011, 2020). Goldenberries, are a valuable source of minerals such as Potassium (467 mg per 100 g of pulp) and Iron (1.24 mg per 100 g of pulp) (Leterme et al., 2006; Puente et al., 2011), and provide a medium to low level of Sodium (6 mg per 100 g of pulp), Calcium (28 mg per 100 g of pulp), Magnesium (19 mg per 100 g of pulp), Phosphorus (55 mg per 100 g of pulp), and Zinc (0.40 mg per 100 g of pulp) (Puente et al., 2011). In addition, the presence of vitamins such as vitamin C, E, B3, and B6; provitamin A; polyphenols, carotenoids, withanolides and physalins A, B, D, and F has been reported in the pulp, and their presence has been linked to promoting consumer health benefits (Etzbach et al., 2018; Olivares-Tenorio et al., 2016; Puente et al., 2011). As a

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consequence, this crop has received increased interest worldwide, thus, increasing its demand in different countries, such as the Netherlands, Germany, France, United Kingdom, Spain, Belgium, Switzerland, Canada, United States, Italy, and Brazil (Fischer et al., 2011).

Despite its potential benefits, goldenberry consumption is limited owing to its short shelf life, which is influenced by different parameters, such as moisture content, ripeness state, respiration rate, ethylene production, and the presence or absence of calyx. For commercialization and exportation purposes, some countries demand calyx removal from the fruits to avoid phytosanitary problems (Licodiedoff et al., 2016), thereby increasing the respiration rate and probability of surface rupture and microorganism proliferation, with a significant decay in the fruit quality. İzli et al. (2014) reported that the shelf life of goldenberries with calyx is approximately 1 month, whereas in the absence of the calyx, shelf life can be reduced to 1 week or less. Consequently, different studies have evaluated the conditions for optimal storage and transportation of goldenberry fruits (Alvarado et al., 2004; Olivares-Tenorio et al., 2017) as well as the use of alternative processes, such as dehydration by convective and microwave methods (Izli et al., 2014), osmotic dehydration (Luchese et al., 2015), and more recently, application of edible coatings (Licodiedoff et al., 2016), for conservation. However, information differs primarily owing to agronomic characteristics, genetic differences, and the ripeness state of the samples analyzed. Among the alternative methods employed for extending the shelf life of goldenberry fruits, the application of edible coatings appears as a suitable method for industrial and commercialization purposes. Previous studies have successfully demonstrated the extension of shelf life with the application of edible coating on Red Crimson grapes (Fakhouri et al., 2015), strawberries (Peretto et al., 2014), oranges (Saberi et al., 2018), and bananas (Thakur et al., 2019) as the edible coating forms a barrier between the fruit and the external environment and delays biochemical processes during fruit ripeness (Thakur et al., 2019). However, there is not enough evidence regarding the application of edible coatings on goldenberry.

Starch is a low cost, biodegradable, nontoxic, and abundant renewable resource, allowing it to be used as a raw material for edible coating preparation (Fakhouri et al., 2015). Different advantages of starch-based coatings and films include transparency, odorless, tasteless, and low permeability to oxygen (Galindez et al., 2019) as well as decreasing costs and increasing benefits due to the low cost of the manufacturing and application process. Starches from various botanical sources have been used for coating different food materials. Thakur et al. (2019) used a coating of rice starch mixed with sucrose esters to increase shelf life during postharvest ripening of Cavendish banana, and the results showed a delay in ethylene biosynthesis and a reduction in the respiration rate, which were evident with an increase in the shelf life of coated Cavendish banana of 12 days compared with the control. The dynamic behavior of starch coatings on plums was evaluated. The authors showed that although wheat starch-based coatings have a hydrophilic character, their application on plums increased the resistance to water vapor permeability by 60% in fruits exposed to conditions of high transpiration potential (Basiak et al., 2019). Ulluco (*Ullucus tuberosus* Caldas) starch is a potential raw material for edible film preparation owing to its high amylose content, which confers a proper barrier and mechanical properties (Daza et al., 2018; Galindez et al., 2019). Moreover, the use of ulluco starch can help in meeting the industrial demand of starch as a raw material without compromising on food security. This work aimed to produce ulluco starch-based edible coating and evaluated the effects of its application on the shelf life of goldenberry fruits at the ripening stage and commercial storage conditions. For this purpose, the fruits were evaluated with respect to their physicochemical and microbiological characteristics.

2 | MATERIALS AND METHODS

2.1 | Raw material and starch extraction

Ulluco starch (amylose content of 35.7%) was extracted according to a previous report (Galindez et al., 2019). Goldenberries of commercial ripeness according to the NTC 4580 (ICONTEC, 1999) were kindly supplied by Colombia Paradise S.A.S (Silvania, Cundinamarca, Colombia). The fruits were selected and washed with tap water, and samples with mechanical surface damage were discarded. The initial moisture, total soluble solid (TSS), titratable acidity (TA) of the fruits was 80.46%, 11.67 °Brix, and 1.53% of citric acid, respectively.

2.2 | Coating preparation and application

Starch was dissolved in distilled water at concentrations of 2.0% (S1), 2.5% (S2), and 3.0% (S3) (w/v) with magnetic stirring for 5 min. The mixture was heated to 95°C and maintained at this temperature until a clear and viscous gel was obtained (about 5 min). Then, the mixture was cooled to 50°C, and glycerol was added at a fixed concentration of 1.0% (w/v), followed by the addition of Tween 80 (0.1% w/v; density at 20°C, 1,060 kg/m^3; Merck, Darmstadt, Germany) as an adjuvant ingredient between the coating solution and the oily surface of the fruits. All the components were mixed for 10 min. Finally, the solution was allowed to cool at room temperature (approximately 25°C) with agitation. Solutions were prepared on the same day of its use.

Goldenberries were immersed in 0.02% w/v Timsen (Food grade, Cimpa S.A.S., Colombia) solution for 10 min, followed by washing with distilled water, and then allowed to dry for 30 min (25 ± 2°C). Timsen is a commercial sanitizer, and the concentration was adjusted according to the manufacturer's instructions. For the coating application, fruits were divided into four groups (control group, CG; goldenberries coated with solution S1, S1G; goldenberries coated with solution S2, S2G; and goldenberries coated with solution S3, S3G), immersed into the respective coating solution for 1 min (in a ratio of 1:1 goldenberries:coating solution), the excess of coating solution was drained for

5 min, and then fruits were placed in a stainless steel net (mesh 2, with a filament thickness of 0.45 mm) and allowed to dry for 20 min at 25 ± 2°C. In the CG (uncoated), the fruits were immersed in water instead of the coating solution. The coated samples were then placed in polyethylene terephthalate (PET) trays with cover (250 g of samples per tray) and stored in a climate chamber (ICH, Memmert GmbH + Co, Schwabach, Germany) for 17 days at 8 ± 1°C and 90 ± 2% relative humidity. Each coating formulation was made in duplicate, and the experiments involving each parameter were performed at least in triplicate.

2.3 | Physicochemical analysis

2.3.1 | Weight loss

The percentage of weight loss (WL) for coated and uncoated samples of goldenberries was calculated using the following formula: $\mathrm{WL} = 100 \times \left(w_{\mathrm{d0}} - w_{\mathrm{dn}}\right) / w_{\mathrm{d0}}$

where w_{d0} is the mass at day zero, and w_{dn} is the mass on the day of analysis.

2.3.2 | TA, TSS, pH, and reducing sugars

Juice from goldenberry samples (24 g) was extracted using a ground blender (Black & Decker, Colombia). TA was evaluated using the 942.15 AOAC method (AOAC, 1995) and expressed as % citric acid. TSS content was determined using a portable refractometer (PAL–1, ATAGO, Fukaya-shi, Japan) according to the 932.12 AOAC method (AOAC, 1995) and expressed as °Brix. For pH determination, the electrode of a pH meter (pH Basic+, Sartorius, Gotinga, Germany) was immersed in the juice extract. Reducing sugar content was evaluated according to the method reported by Miller (1959).

2.3.3 | Fruit color

Color parameters of coated and uncoated fruits were evaluated on the surface using a colorimeter (CR-410 Chroma Meter, Konica Minolta, Japan). Results were expressed according to the CIELAB color system (*L**, lightness; *a**, redness; and *b**, greenness).

2.3.4 | Textural analysis

Textural analysis was performed using a texturometer (LS1, Lloyd Ltd., Largo, FL, USA) equipped with a load cell of 1 kN. Each fruit was placed in the center of a steel plate, and a puncture was made in the equatorial zone of the sample using a cylindrical prove (2 mm) at a compression rate of 40 mm/min. The results correspond to the average of six repetitions per treatment.

2.3.5 | Respiration rate

Respiration rate of goldenberries was measured using the closed system method as described by Banda et al. (2015) with some modifications. Briefly, 150 g of CG and coated goldenberries (stored at 8°C) were placed into a glass jar (capacity 1 L) and hermetically sealed. A gas analyzer (Checkmate 3, PBI Dansensor, Ringstead, Denmark) was used to monitor the CO_2 concentration at 30-min intervals for 3 hr. The respiration rate was calculated using Equation (1):

$$y_{\mathrm{CO_2}} = y^{i}_{\mathrm{CO_2}} + \frac{R_{\mathrm{CO_2}} W}{V_{\mathrm{f}}}(t - t_0) \tag{1}$$

where $y_{\mathrm{CO_2}}$ and $y^{i}_{\mathrm{CO_2}}$ are CO_2 concentration (%) at time t and at time zero t_0 (initial time), respectively; $R_{\mathrm{CO_2}}$ is the respiration rate in ml/kg h; W is the total weight of the product (kg); and V_{f} is the free volume inside the glass jar (ml).

2.4 | Phenolic compounds and antioxidant capacity

The samples (1 g, dry basis d.b.) were extracted with 70% aqueous ethanol (20 ml) using a homogenizer (Ultra-Turrax T25; IKA, Staufen, Germany) for 3 min at 10,000 rpm. The homogenized extract was centrifuged at room temperature for 10 min at 5,600 *g*, and the supernatant was transferred to a volumetric flask and filled up to the mark using the same solvent. Extracts were maintained at −18°C until subsequent analysis (for no more than three days). All extractions were done in triplicate.

2.4.1 | Total phenolic content

The total phenolic content (TPC) was determined using the methodology reported by Singleton et al. (1999), with some modifications (Daza et al., 2017). A 0.25-ml aliquot of the extract was mixed with 0.25 ml of Folin–Ciocalteu reagent (Sigma Aldrich, St Louis, MO, USA) and 2 ml of distilled water. After maintaining for 3 min at room temperature (25 ± 2°C), saturated sodium carbonate (Na_2CO_3; 0.25 ml) solution was added. The mixture was placed in a water bath at 37°C for 30 min. Absorbance at 750 nm was read using a spectrophotometer (Genesys 10S UV-VIS, Thermo Fisher Scientific, Waltham, MA, USA). Gallic acid (Sigma Aldrich) was used as the standard for the calibration curve (0–40 μg/ml). Results were expressed as mg of gallic acid equivalents per gram of sample on a dry weight basis (mg GAE/g d.b.).

2.4.2 | DPPH radical scavenging ability

Antioxidant capacity was determined using the 2,2-diphenyl-1-picrylhydrazyl (DPPH·) radical scavenging method, according to Brand-Williams et al. (1995). A 540-μl aliquot of the extract, previously diluted, was mixed with 2.6 ml of a methanolic solution of DPPH· (0.5 mM) and incubated in the dark at room temperature (25°C) for 25 min. Then, absorbance of the samples was measured at 517 nm using a spectrophotometer. A calibration curve was prepared using Trolox (Sigma Aldrich) at different concentrations (20–80 μM). Results were expressed as μmol of Trolox equivalents per gram of sample on a dry weight basis (μmol TE/g d.b.).

2.4.3 | Ferric-reducing antioxidant power

Ferric-reducing antioxidant power (FRAP) of the fruit samples was measured according to the method of Benzie and Strain (1996). Briefly, 320 μl of the previously diluted extract and 2.4 ml of the FRAP reagent were mixed and then incubated for 4 min at 37°C. Absorbance was measured at 593 nm using a spectrophotometer. Trolox was used as standard for calibration curve preparation (0.1–0.8 mmol/L). Results were expressed as mmol Trolox equivalents per gram of sample on a dry weight basis (mmol TE/g d.b.).

2.5 | Microbiological analysis

The counting of yeast and molds was performed according to the method of Hashemi et al. (2017). The quantitation of psychrophilic microorganisms was conducted according to the method of Olivas et al. (2007). Goldenberries (10 g) were homogenized for 2 min with 90 ml of sterilized peptone water (0.1% w/v). Then, 10-fold dilutions were prepared in 0.1% peptone water and pour plated in plate count agar (PCA; Oxoid, Basingstoke, UK). The Petri dishes were incubated at 10°C for 10 days to count psychrotrophic colonies. For molds and yeast, the same dilutions were cultured in potato dextrose agar (PDA; Oxoid) and incubated for 5 days at 25°C.

2.6 | Statistical analysis

Analysis of variance at 95% confidence level was performed to determine significant differences in the properties between samples and storage time. Multiple range tests, using the Tukey–Kramer range test, were used to determine significant difference between groups, and between the days of analysis for each sample. Statistical analysis was performed using the MATLAB R2017b software (The MathWorks Inc., Natick, MA, USA).

3 | RESULTS AND DISCUSSION

3.1 | WL

Weight loss of goldenberries, primarily due to water loss, involves mechanical, textural, visual, and chemical changes, which result in a decrease in quality and shortening of the product shelf life.

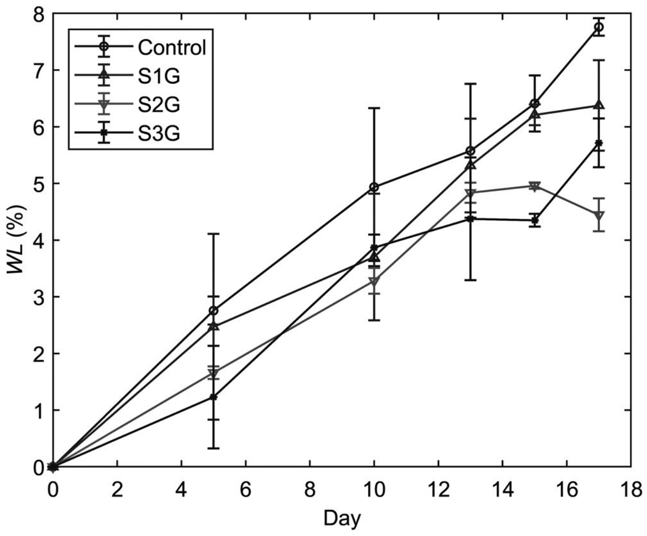

FIGURE 1 Weight loss of uncoated (control) and coated goldenberries stored for 17 days

Therefore, overcoming this issue is a challenge for commercialization purposes (Thakur et al., 2019). The use of edible coatings of different concentrations (S2G and S3G) of ulluco starch on goldenberries significantly reduced WL at the final day of storage (day 17) compared to that in the CG ($p < .05$) (Figure 1 and Table 1).

In general, all treatments exhibited WL during the entire storage period with a maximum loss of mass of 7.76%, 6.37%, 4.44%, and 5.71% for CG, S1G, S2G, and S3G, respectively. S2G and S3G were the most effective treatments in the prevention of WL, which is due to the starch concentration as higher the concentration of polymer, greater is the interaction between the chains of the coating formed on the fruit surface or between the starch and water molecules, hence limiting the exchange of gases, water evaporation, and solute migration. Results obtained in this study corroborate with the results obtained for the reduction of WL of tomato using coating prepared with mango kernel starch (Nawab et al., 2017) and for goldenberries coated with a gelatin–calcium chloride solution (Licodiedoff et al., 2016).

3.2 | TA, TSS, pH, and reducing sugars

Table 1 shows the TA, TSS, and pH values for uncoated and coated goldenberries under storage conditions (8°C). TA, TSS, and pH values ranged from 1.26% to 1.61% of citric acid, 10.7% to 15.5%, and 3.64 to 4.00, respectively. These results agree with previous reports for goldenberries (Etzbach et al., 2019; Licodiedoff et al., 2016; Luchese et al., 2015). Differences between the treatments with regard to TA, TSS, and pH values ($p > .05$) were not observed. However, in all cases, a decrease in TA with an increase in storage time was observed, which is related to the ripening process as organic acids can be converted into sugars or are more probably used as respiratory substrates (Batista-Silva et al., 2018).

TABLE 1 Physicochemical properties of uncoated (control) and coated goldenberries

Sample	Storage time (days)					
	0	5	10	13	15	17
WL (%)						
Control	–	2.75 ± 0.25^{aBC}	4.93 ± 1.39^{Aab}	5.57 ± 1.18^{aAB}	6.41 ± 0.49^{aA}	7.76 ± 0.16^{aA}
S1G	–	2.47 ± 1.64^{aBC}	3.70 ± 1.12^{aABC}	5.31 ± 0.83^{aAB}	6.21 ± 0.18^{aA}	6.37 ± 0.80^{abA}
S2G	–	1.66 ± 0.11^{aC}	3.28 ± 0.23^{aB}	4.83 ± 0.18^{aA}	4.96 ± 0.06^{bA}	4.44 ± 0.29^{bA}
S3G	–	1.23 ± 0.90^{aB}	3.86 ± 0.23^{aA}	4.37 ± 1.08^{aA}	4.35 ± 0.11^{bA}	5.71 ± 0.43^{bA}
Total Soluble solids (°Brix)						
Control	13.44 ± 0.80^{aA}	15.15 ± 0.44^{aA}	14.44 ± 0.54^{aA}	14.98 ± 0.59^{aA}	14.97 ± 2.09^{aA}	14.54 ± 0.83^{aA}
S1G	10.91 ± 1.46^{aB}	11.25 ± 0.12^{bB}	12.11 ± 1.29^{aAB}	14.12 ± 0.08^{aAB}	14.85 ± 0.58^{aA}	12.90 ± 0.11^{aAB}
S2G	11.30 ± 1.07^{aA}	10.77 ± 0.99^{bA}	13.80 ± 2.35^{aA}	12.76 ± 2.23^{aA}	15.25 ± 0.86^{aA}	13.41 ± 0.70^{aA}
S3G	11.02 ± 1.92^{aA}	12.69 ± 0.19^{bA}	13.54 ± 0.73^{aA}	14.07 ± 0.50^{aA}	14.62 ± 0.71^{aA}	14.01 ± 0.32 ^{aA}
Titratable acidity (TA) (% citric acid)						
Control	1.59 ± 0.07^{aA}	1.55 ± 0.03^{aAB}	1.51 ± 0.02^{aAB}	1.54 ± 0.00^{aAB}	1.47 ± 0.03^{aAB}	1.43 ± 0.08^{aB}
S1G	1.61 ± 0.28^{aA}	1.57 ± 0.25^{aA}	1.51 ± 0.21^{aA}	1.60 ± 0.27^{aA}	1.55 ± 0.29^{aA}	1.41 ± 0.18^{aA}
S2G	1.46 ± 0.03^{aA}	1.39 ± 0.03^{aA}	1.29 ± 0.11^{aA}	1.41 ± 0.02^{aA}	1.35 ± 0.05^{aA}	1.28 ± 0.01^{aA}
S3G	1.46 ± 0.19^{aA}	1.43 ± 0.13^{aA}	1.49 ± 0.03^{aA}	1.42 ± 0.16^{aA}	1.30 ± 0.01^{aA}	1.26 ± 0.01^{aA}
pH						
Control	3.67 ± 0.05^{aB}	3.64 ± 0.03^{aB}	3.75 ± 0.07^{aB}	3.65 ± 0.02^{bB}	3.72 ± 0.03^{aB}	4.00 ± 0.06^{aA}
S1G	3.68 ± 0.07^{aA}	3.69 ± 0.07^{aA}	3.64 ± 0.05^{aA}	3.73 ± 0.02^{abA}	3.73 ± 0.04^{aA}	3.84 ± 0.05^{aA}
S2G	3.66 ± 0.04^{aA}	3.71 ± 0.01^{aA}	3.72 ± 0.01^{aA}	3.81 ± 0.01^{aA}	3.67 ± 0.03^{aA}	3.81 ± 0.12^{aA}
S3G	3.65 ± 0.02^{aA}	3.66 ± 0.04^{aA}	3.71 ± 0.1^{aA}	3.76 ± 0.04^{abA}	3.67 ± 0.01^{aA}	3.87 ± 0.16^{aA}
Reducing sugars (g Glu/100 g)						
Control	8.56 ± 0.58^{aA}	7.79 ± 0.18^{abAB}	6.50 ± 0.15^{aBC}	7.02 ± 0.98^{aAB}	5.88 ± 0.33^{aBC}	4.72 ± 0.30^{aC}
S1G	6.11 ± 0.14^{bAB}	7.16 ± 0.25^{bA}	7.23 ± 1.03^{aA}	7.15 ± 0.15^{aA}	6.91 ± 0.33^{aAB}	5.08 ± 0.05^{aB}
S2G	7.26 ± 0.26^{abAB}	7.03 ± 0.24^{bAB}	7.65 ± 0.28^{aA}	7.12 ± 0.25^{aAB}	8.21 ± 1.31^{aA}	5.06 ± 0.06^{aB}
S3G	6.46 ± 1.0^{abA}	8.22 ± 0.11^{aA}	8.01 ± 0.60^{aA}	7.49 ± 0.1^{aA}	7.33 ± 3.10^{aA}	4.58 ± 0.14^{aA}
Firmness (N)						
Control	2.17 ± 0.23^{aA}	1.85 ± 0.23^{bA}	1.71 ± 0.11^{aA}	2.01 ± 0.41^{aA}	1.82 ± 0.23^{aA}	1.36 ± 0.13^{bA}
S1G	2.04 ± 0.22^{aA}	2.59 ± 0.21^{aA}	2.43 ± 0.72^{aA}	2.15 ± 0.08^{aA}	2.26 ± 0.13^{aA}	2.31 ± 0.32^{abA}
S2G	1.75 ± 0.07^{aA}	2.13 ± 0.04^{abA}	2.41 ± 0.27^{aA}	2.03 ± 0.07^{aA}	2.04 ± 0.22^{aA}	2.06 ± 0.24^{abA}
S3G	2.01 ± 0.03^{aA}	1.87 ± 0.02^{bA}	2.19 ± 0.31^{aA}	2.0 ± 0.06^{aA}	2.25 ± 0.41^{aA}	2.69 ± 0.28^{aA}

Note: Values are expressed as means ± standard deviation. Different lowercase letters in the same column indicate significant differences between samples, and different capital letters in the same row indicate significant differences between the days of analysis of the same sample ($p \le .05$).

In contrast, an overall increase in TSS from day 0 to day 15 with a subsequent decay between days 15 and 17 was observed. The TSS content from day 0 to 15 was due to the conversion of starch into simple sugars by hydrolysis. As well as organic acids, sugars are used in the respiration process, which led to a decrease in their concentration between days 15 and 17. Similar results have been observed for *Prunus salicina* fruits coated using a rice starch-based edible coating (Thakur et al., 2018); this can be related to the fact that in all treatments, the reducing sugar content decreased with an increase in storage time. As expected, the pH of coated and uncoated goldenberries increased during postharvest storage, which is related to the degradation of starch and the consumption of organic acids for the respiration process. The above is an indication that the ulluco starch-based edible coating did not affect the biochemical processes related to these parameters in goldenberries.

3.3 | Color

Table 2 shows the values of L^*, a^*, and b^* for the coated and uncoated goldenberries during the analysis period. With regard to a^* and b^* values, all the fruits presented positive values, which was expected as the fruits used in this study were of commercial ripeness stage wherein green coloration has entirely disappeared and turned to a reddish yellow coloration. However, the use of edible coating did not show a significant effect in comparison to the CG ($p < .05$) during the

TABLE 2 Color parameters of uncoated (control) and coated goldenberries

Sample	Storage time (days) 0	5	10	13	15	17
*L**						
Control	45.52 ± 0.08^{aA}	43.98 ± 0.12^{aAB}	43.21 ± 0.44^{aB}	43.04 ± 0.40^{aB}	43.88 ± 1.11^{aAB}	42.25 ± 0.54^{aB}
S1G	44.17 ± 0.42^{aA}	42.75 ± 0.25^{aA}	43.02 ± 0.37^{aA}	43.78 ± 0.13^{aA}	43.18 ± 0.67^{aA}	43.69 ± 0.29^{aA}
S2G	44.43 ± 0.42^{aA}	43.77 ± 2.35^{aA}	42.72 ± 0.75^{aA}	43.56 ± 0.38^{aA}	42.95 ± 0.13^{aA}	43.74 ± 2.06^{aA}
S3G	45.16 ± 0.45^{aA}	43.51 ± 2.09^{aA}	42.10 ± 1.55^{aA}	43.64 ± 0.57^{aA}	41.13 ± 0.42^{aA}	44.30 ± 3.44^{aA}
*a**						
Control	23.02 ± 0.06^{aA}	22.84 ± 0.97^{aA}	23.66 ± 1.20^{aA}	22.50 ± 0.16^{aA}	21.40 ± 0.48^{aAB}	19.81 ± 0.02^{aB}
S1G	20.89 ± 0.17^{aA}	21.35 ± 1.24^{aA}	21.26 ± 0.37^{aA}	17.09 ± 3.61^{aA}	21.19 ± 0.70^{aA}	21.19 ± 2.19^{aA}
S2G	21.81 ± 0.51^{aA}	20.37 ± 1.76^{aA}	22.86 ± 0.48^{aA}	20.65 ± 0.52^{aA}	20.62 ± 0.42^{aA}	21.50 ± 0.62^{aA}
S3G	22.23 ± 1.00^{aA}	18.38 ± 4.67^{aA}	22.36 ± 0.53^{aA}	21.65 ± 0.29^{aA}	19.93 ± 0.47^{bA}	21.71 ± 0.23^{aA}
*b**						
Control	44.23 ± 1.16^{aA}	43.35 ± 0.34^{aA}	45.02 ± 0.71^{aA}	43.31 ± 2.23^{aA}	42.62 ± 1.42^{aA}	43.37 ± 1.33^{aA}
S1G	38.65 ± 0.25^{cA}	39.90 ± 2.31^{aA}	42.18 ± 0.31^{aA}	38.05 ± 0.42^{aA}	42.62 ± 1.18^{aA}	43.71 ± 4.54^{aA}
S2G	39.65 ± 0.90^{bcA}	39.03 ± 0.18^{aA}	44.96 ± 2.56^{aA}	39.70 ± 2.09^{aA}	38.51 ± 0.44^{bA}	42.32 ± 3.56^{aA}
S3G	42.20 ± 0.77^{abABC}	39.39 ± 1.91^{aABC}	45.54 ± 1.76^{aA}	38.78 ± 2.02^{aBC}	36.34 ± 0.29^{bC}	43.95 ± 1.78^{aAB}

Note: Values are expressed as means ± standard deviation. Different lowercase letters in the same column indicate significant differences between samples, and different capital letters in the same row indicate significant differences between the days of analysis of the same sample ($p \le .05$).

storage period. Similar results have been obtained for goldenberries analyzed in the maximum ripeness stage (Yıldız et al., 2015). Similar to parameters *a** and *b**, the values obtained for *L** of goldenberries did not show significant differences between the treatments. These results indicated that the use of ulluco-based edible coating did not affect the natural appearance of the fruit.

3.4 | Firmness analysis

Firmness is an important quality attribute for commercialization purposes, which depends on several parameters related to biochemical processes, such as content and water loss, wall composition of the fruit, and enzyme activity (Nawab et al., 2017). No significant changes ($p > .05$) in fruit firmness were observed after the application of the ulluco-based coating at the beginning of storage. During the first 13 days of storage, firmness of coated and uncoated fruits remained stable without significant differences between the groups ($p > .05$) (Table 1). However, from day 13 until the last day of storage (day 17), a significant decay in the firmness of fruits from the CG was observed ($p < .05$), decreasing from 2.01 N (day 13) to 1.36 N (day 17). The final firmness of S1G, S2G, and S3G was 2.31 N, 2.10 N, and 2.70 N, respectively. The most effective treatment for the maintenance of fruit firmness was S3G. Loss in the firmness of the CG is associated with the highest WL of uncoated fruits (Section 3.1). Moreover, normal decomposition of the fruit wall components is primarily due to the action of polygalacturonase, β-galactosidase, and pectin methylesterase (Thakur et al., 2018). The maintenance of the firmness of the coated fruits is evidence that the application of ulluco-based edible coating on goldenberries delays the metabolic activity of fruits. Similar results have been reported for fruits coated with starch-based coatings using rice (Thakur et al., 2018), mango kernel (Nawab et al., 2017), and pea starch (Saberi et al., 2018). Thakur et al. (2018) related the retention of firmness of plum fruits coated with a rice starch-based edible coating to the slowdown in the metabolic activity of enzymes due to the restricted gas exchange through the coating barrier.

3.5 | Respiration rate

Modification in the atmosphere can delay the normal physiology and biochemistry processes of the fruits, leading to the extension of the shelf life, primarily by the reduction of the respiration rate, which is involved in the oxidative decomposition of sugars, lipids, and organic acids (Balaguera-López et al., 2014). Figure 2 shows the production rate of CO_2 for uncoated and coated goldenberries. As expected, CG showed the highest production rate of CO_2 due to the lack of the barrier formed by the coating present in S1G, S2G, and S3G ($p < .05$), indicating a normal decomposition of different components of the fruits. The low production of CO_2 in fruits coated was due to the well-known low permeability of the coatings prepared with starch to oxygen (Farahnaky et al., 2013). Similar results have been reported for oranges coated using a film made from pea starch and guar gum (Saberi et al., 2018) and for apple slices treated with a cassava starch coating (Oriani et al., 2014). Although the degradation of sugars and organic acids cannot be related to the decrease in respiration rate due to the use of ulluco starch-based coating (Section 3.2), we

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can relate the reduction in CO_2 production with the fact that the coated fruits exhibited lower loss of firmness, associated with a reduction in the activity of enzymes, such as polygalacturonase (Silva et al., 2013).

3.6 | Phenolic compounds and antioxidant capacity

Table 3 shows the TPC of coated and uncoated goldenberries throughout the storage period. TPC values for coated and uncoated goldenberries at days 0 and 5 were not significantly different between the different treatments ($p > .05$). However, a significant reduction in TPC of the CG at day 10 of storage was observed relative to the S1G- and S2G-coated groups ($p < .05$). In all cases, there was an increase in TPC between days 10 and 13, with a subsequent decay until the final day of storage (day 17). The increase in TPC values was also observed during the storage of coated plum fruits using edible coatings based on rice starch and Arabic gum and added with essential oils (Andrade et al., 2017; Thakur et al., 2018). This behavior was attributed to the fact that phenolic compounds are synthesized during the ripening and storage processes of the fruit. However, the reduction in TPC after day 13 in all the treatments can be associated with the degradation by different enzymes, such as polyphenol oxidase, peroxidase, laccase, and lipoxygenase, present in the fruit (De la Rosa et al., 2019). All the treatments showed higher TPC than that of the CG on the last storage day (day 17); however, no statistically significant differences were observed between the fruits in the CG and treated fruits ($p > .05$).

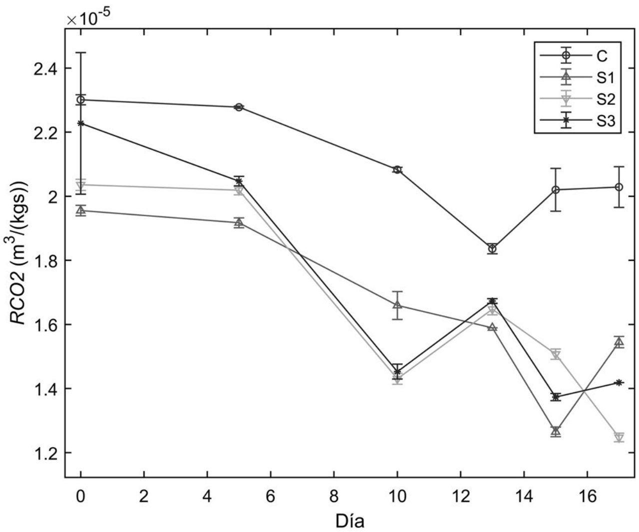

FIGURE 2 Production of CO_2 in uncoated (control) and coated goldenberries stored for 17 days

Antioxidant capacity was evaluated as a stability indicator of the functional properties of uncoated and coated goldenberries. Concerning the FRAP of the fruits, no significant differences were observed between treatments ($p > .05$) on the final day of the storage. However, in the DPPH analysis, significant differences were observed between S1G and S2G compared with the CG at the end of the storage time, indicating that coating the goldenberries helped in retaining the antioxidant capacity of the fruit, however, for treatment one, which was prepared with the highest concentration of starch, no significant differences were observed. The retention of antioxidant capacity can be related to TPC and less WL of the coated fruits as the relationship between antioxidant capacity and TPC is well known (Daza et al., 2017; Izli et al., 2014). Additionally, more

TABLE 3 Total phenolic content (TPC) and antioxidant capacity of uncoated (control) and coated goldenberries

	Storage time (days)					
Sample	0	5	10	13	15	17
TPC (mg GAE/g d.b.)						
Control	3.22 ± 0.38^{aA}	3.66 ± 0.47^{aA}	2.92 ± 0.13^{bA}	3.56 ± 0.31^{aA}	3.23 ± 0.45^{aA}	3.01 ± 0.42^{aA}
S1G	3.26 ± 0.06^{aA}	3.45 ± 0.11^{aA}	3.60 ± 0.29^{aA}	3.78 ± 0.46^{aA}	3.49 ± 0.54^{aA}	3.10 ± 0.32^{aA}
S2G	3.47 ± 0.33^{aA}	3.42 ± 0.35^{aA}	3.59 ± 0.02^{aA}	3.81 ± 0.27^{aA}	3.36 ± 0.37^{aA}	3.42 ± 0.09^{aA}
S3G	3.26 ± 0.13^{aBC}	3.08 ± 0.06^{aC}	3.32 ± 0.02^{abBC}	3.89 ± 0.01^{aA}	3.44 ± 0.04^{aB}	3.27 ± 0.08^{aBC}
DPPH (μmol TE/g d.b.)						
Control	11.07 ± 0.31^{aA}	10.20 ± 0.37^{bAB}	6.89 ± 0.23^{bD}	9.67 ± 0.27^{bBC}	8.61 ± 0.20^{bC}	8.79 ± 0.33^{bC}
S1G	10.06 ± 0.19^{bB}	8.22 ± 0.24^{cD}	8.88 ± 0.17^{aD}	8.97 ± 0.30^{bCD}	9.88 ± 0.27^{aBC}	11.08 ± 0.29^{aA}
S2G	10.67 ± 0.23^{abA}	11.67 ± 0.00^{aA}	8.38 ± 0.21^{aC}	9.53 ± 0.38^{bB}	9.04 ± 0.26^{abBC}	9.64 ± 0.25^{bB}
S3G	11.06 ± 0.02^{aA}	10.01 ± 0.19^{bB}	8.75 ± 0.26^{aC}	11.13 ± 0.13^{aA}	9.41 ± 0.3^{abBC}	8.83 ± 0.21^{Bc}
FRAP (mmol TE/g d.b.)						
Control	0.87 ± 0.10^{aA}	0.71 ± 0.17^{aA}	0.63 ± 0.01^{aA}	0.66 ± 0.08^{aA}	0.95 ± 0.15^{aA}	0.91 ± 0.01^{aA}
S1G	0.80 ± 0.22^{aA}	0.80 ± 0.02^{aA}	0.75 ± 0.02^{aA}	0.71 ± 0.0^{aA}	0.83 ± 0.16^{aA}	0.92 ± 0.05^{aA}
S2G	0.80 ± 0.01^{aA}	0.74 ± 0.07^{aA}	0.88 ± 0.07^{aA}	0.61 ± 0.15^{aA}	0.84 ± 0.22^{aA}	0.79 ± 0.1^{aA}
S3G	0.90 ± 0.18^{aA}	0.78 ± 0.13^{aA}	0.91 ± 0.33^{aA}	1.02 ± 0.24^{aA}	0.87 ± 0.16^{aA}	0.85 ± 0.11^{aA}

Note: Values are expressed as means ± standard deviation. Different lowercase letters in the same column indicate significant differences between samples, and different capital letters in the same row indicate significant differences between the days of analysis of the same sample ($p \leq .05$).

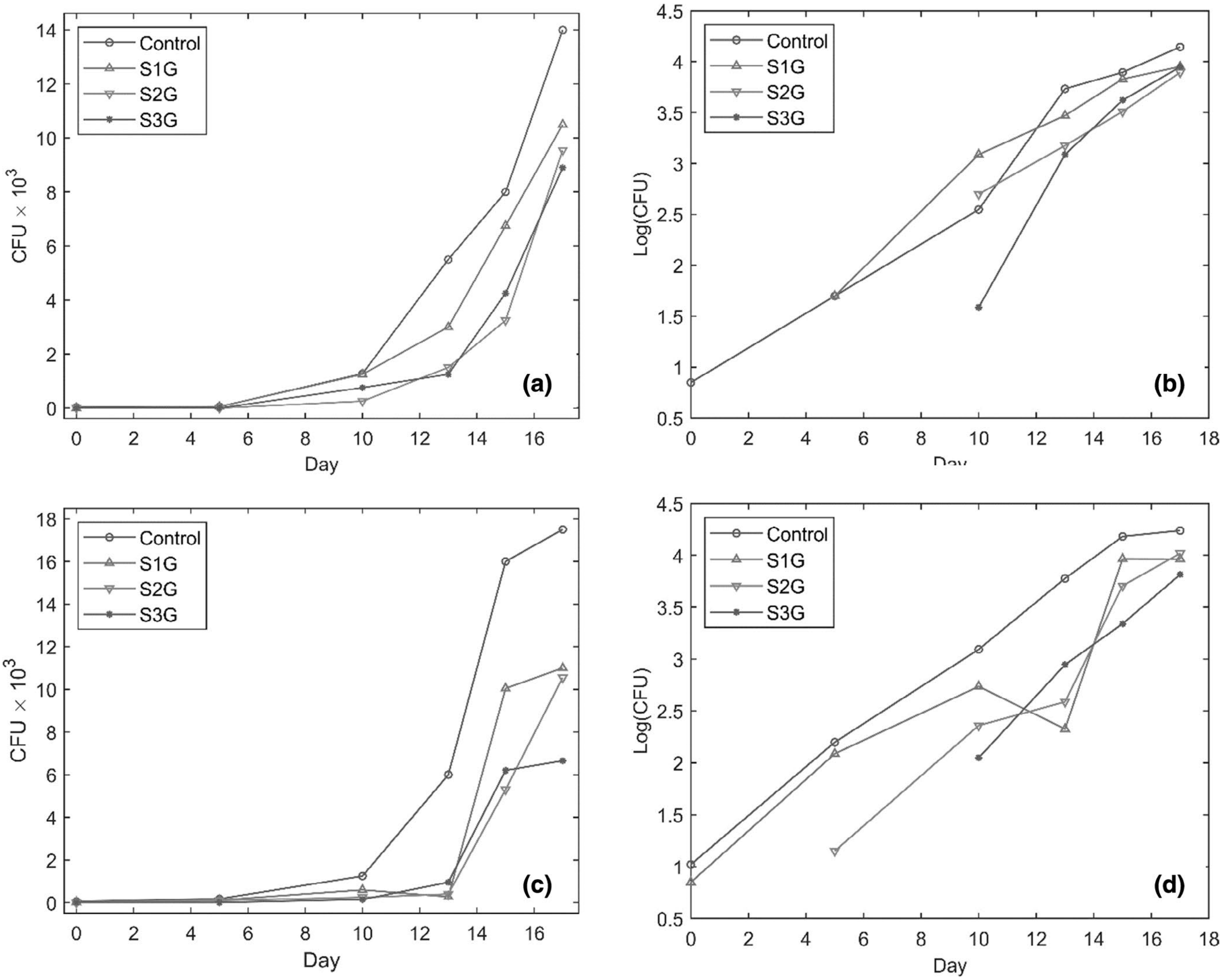

FIGURE 3 Microbial growth on uncoated (control) and coated goldenberries stored for 17 days. Yeast and molds (a and b); psychrophilic microorganism (c and d)

significant WL in the CG may be related to a loss of compounds with antioxidant capacity, thus, explaining the lower antioxidant capacity shown by uncoated fruits.

3.7 | Microbiological test

The use of ulluco starch-based edible coating on goldenberries controlled the growth of yeast and molds and psychrophilic microorganisms (Figure 3a,b). Although microbial growth was observed on day 17 in all treatments, S2G and S3G treatments enhanced the control of fruit spoilage and delayed the growth of yeasts and molds during the first 10 days in contrast to CG and S1G treatments, which showed higher microorganism growth from day 5. With regard to psychrophilic microorganisms, all the treatments, S1G, S2G, and S3G, showed a growth-retarding effect during the first 13 days of storage. Although growth was observed from day 13 to day 17, the final colony-forming units (CFU)/g was lower compared to that of CG. The growth-retarding effect of the starch-based coating is possibly due to the reduction in the rate of respiration as a consequence of the low permeability to oxygen (Guynot et al., 2003). The effectiveness of starch-based coatings in retarding the growth of microorganisms has been previously reported (Garcia et al., 2012; Sapper & Chiralt, 2018).

4 | CONCLUSIONS

The application of ulluco starch-based edible coating to goldenberries did not affect sugar production, pH and acidity development, and the final concentration of solids in the fruit. Furthermore, the use of this coating did not affect color parameters, which are associated with consumer perception. Moreover, with the use of edible ulluco-based coating, a reduction in the respiration rate of the goldenberries was achieved, which was evidenced by the improvement of parameters such as water loss and firmness. Additionally, the use of coatings delayed microbial growth on the fruits relative to the CG, demonstrating that the use of this type of coating is an alternative to reduce postharvest losses and to protect and extend the shelf life, by at least 1 week, of goldenberries in the commercialization process in markets requiring the separation of the calyx from the fruits. This study also demonstrated the potential of ulluco starch for alternative uses in the food industry.

CONFLICT OF INTEREST

The authors have declared no conflicts of interest for this article.

AUTHOR CONTRIBUTIONS

Andres Galindez: Conceptualization; Formal analysis; Investigation; Methodology; Writing-original draft. **Luis Daniel Daza:** Conceptualization; Formal analysis; Investigation; Methodology; Writing-original draft. **Angie Homez-Jara:** Investigation; Writing-original draft. **Angelica Sandoval-Aldana:** Resources; Writing-original draft. **Henry Alexander Váquiro:** Conceptualization; Methodology; Writing-original draft; Project administration; Supervision.

DATA AVAILABILITY STATEMENT

Data available on request from the authors.

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