

## Development of a whey protein concentrate/apple pomace extract edible coating for shelf life extension of fresh-cut apple

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### Abstract

The present work aimed to develop a novel edible coating using whey protein concentrate (WPC) and apple pomace extract (APE) to extend the shelf life of fresh-cut apple. Apple slices were coated with a mixture of WPC and APE at concentrations of 0.5, 1.0, and 1.5%, and were stored at 5°C for 12 d. The total phenolic content and DPPH radical scavenging activity of APE were determined. The weight loss, colour, browning index, microbiological analysis, and sensory evaluation of coated and uncoated apple slices were estimated. A total phenolic content of ethanolic APE was  $6.77 \pm 0.339$  mg gallic acid equivalent/g dry apple pomace. Apple pomace extract contained a total of 15 phenolic compounds. Also, a significant antioxidant activity was observed for APE using the DPPH method, and the inhibitory concentration ( $IC_{50}$ ) was  $51.97 \pm 1.576$   $\mu$ g gallic acid equivalent/mL extract compared with BHT ( $21.80 \pm 0.424$   $\mu$ g/mL). Coating apple slices with WPC/APE decreased the weight loss as compared to the uncoated and apple slices coated with WPC only. The coated apple slices with WPC/1.5% APE had the highest lightness as compared to other coated and uncoated apple slices after 12 d of storage. In addition, the coated apple slices with WPC/1.0 and 1.5% APE exhibited the lowest browning index as compared to the uncoated apple slices. Using WPC and APE as coating agents showed antimicrobial activity, and it had little effect on the sensory evaluation of apple slices.

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### Keywords

whey protein,  
apple pomace,  
edible coating,  
fresh-cut apple

## Introduction

Fresh-cut fruits and vegetables are the most preferable foods for consumers because they are highly nutritious and convenient. However, their market is still limited due to rapid damage / spoilage during storage and distribution. In recent years, there has been an increasing interest in developing novel strategies to enhance storage ability, shelf life, and the microbiological safety of fresh-cut products. To this end, edible coatings and films have been considered as prospective strategies. Edible coatings constitute a thin layer of edible agent (Kuorwel *et al.*, 2015; Tavassoli-Kafrani *et al.*, 2016). Edible coatings can preserve vegetables and fruits in fresh form by enhancing the retention of flavour, sugars, acids, and colour to prolong shelf life and retain nutritional characteristics (Fakhouri *et al.*, 2015; Kerch, 2015). Edible coatings are also used to prevent undesirable mass transports (moisture, oxygen, and flavour), improve visual properties, and act as carriers to deliver active components such as antimicrobial, antioxidant, and nutraceuticals agents (Reinoso *et al.*, 2008).

Lipids, proteins, and polysaccharides can be used as biopolymers in edible coating production (Schmid

*et al.*, 2015; Jahed *et al.*, 2017; Martelli *et al.*, 2017; Niamlang *et al.*, 2017). Proteins are of great interest in edible coating technology due to their abundance as by-products of food processing. Also, the reactive amino acids enable the proteins to be modified and cross-linked through chemical and physical treatments to form new polymeric structures (Gennadios, 2002). Whey protein isolates have excellent barrier function for gas, aroma compounds, and oil as compared to the films made with polysaccharides and lipids (Krochta, 2002; Feng *et al.*, 2018). Commercially, whey proteins are available as whey protein concentrates (WPC) or whey protein isolates (WPI), with protein contents of 20 - 85 and > 90%, respectively (Khwaldia *et al.*, 2004). Since whey protein coatings are edible, they are perfect carriers for nutraceuticals to improve the nutritional value of the coated food product. The applications of whey protein films are mainly as antimicrobial agents and as protective barrier coatings to increase the shelf life of food products (Seydim and Sarikus, 2006).

Apple pomace is an industrial solid waste of apple manufacturing, and it represents around 30% of the original fruit. Wet pomace, generated by cider pressing, represents up to 25% of the fresh fruit weight, and its

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moisture content is about 70 - 85% after being pressed. Apple pomace is a heterogeneous mixture consisting of apple peels, leftover flesh, and core with seeds and stems (Jung *et al.*, 2015; Kara and Doymaz, 2015). It has been proved that apple pomace affects pharmacological targets. Nutraceutically, apple pomace has various pharmacological benefits, where preliminary studies have reported promising anti-inflammatory, antiviral, antioxidative, and antibacterial activities (Waldbauer *et al.*, 2017). Many studies aiming to developed value-added products have used apple pomace to produce protein-enriched feeds, ethanol, enzymes, and natural antioxidants (Shrikot *et al.*, 2004; Paganini *et al.*, 2005; Medeiros *et al.*, 2006; Albuquerque *et al.*, 2006; Vendruscolo *et al.*, 2008). The polyphenols content of apple pomace and its ability to scavenge DPPH radicals have been reported (Cetkovic *et al.*, 2008; Rana *et al.*, 2014; Gharedaghi *et al.*, 2019).

Based on the previously mentioned information, the present work thus aimed to develop whey protein-based coating incorporating apple pomace extract as an anti-browning, antimicrobial, and antioxidative agent for apple slices under cold storage.

## Materials and methods

### Materials

Whey protein concentrate (WPC, 80%), glycerol (99.5%), 1,1-diphenyl-2-picrylhydrazyl (DPPH), and butylated hydroxytoluene (BHT) were purchased from CP Kelco (Georgia, USA) and Sigma-Aldrich (St. Louis, USA). Apples (*Malus domestica* var. *Anna*) were purchased from a local supermarket in January 2019.

### Preparation of apple pomace extract

A total of 10 kg of apple fruits were washed and cut into small pieces and then squeezed in a domestic food processor (Moulinex, Compact Kitchen Machine, Egypt), and finally filtered through muslin cloth. Apple pomace was oven-dried at 50°C, milled, and sieved at 50 mesh. About 200 g apple pomace powder was extracted by ethanol 80% at a ratio of 1:20 (w/v) using a homogeniser for 30 min. The extract was passed through a filter paper (Whatman No. 1). The filtrate was concentrated by rotary evaporator at 40°C. The concentrate was lyophilised and stored at 5°C before coating application.

### Coating preparation

The apple fruits were cut into similar thick slices (2 cm). The pieces were divided into five parts.

The first part was dipped in distilled water, and served as a control. The second part was dipped in an aqueous solution of 10% (w/w) WPC and 3% (w/w) glycerol. The third, fourth, and fifth parts were coated with the same solution incorporated with 0.5, 1.0 and 1.5% of APE, respectively. Dipping process was performed for 2 min. The excess of the immersion solutions on the apple slices was drained off for 5 min. Then these apple slices were placed in polypropylene packages, and thermally sealed by stretch film before storage at 2 - 5°C and 80% RH for 12 d for analyses. Three batches for each treatment were performed.

### Total phenolic content and antioxidant activity of apple pomace extract

The total phenolic compounds of ethanolic APE were determined using the Folin-Ciocalteu reagent, and gallic acid was used as a standard. The results were expressed as mg gallic acid equivalent/g dry matter according to Khalifa *et al.* (2017). The ability of APE to scavenge DPPH radicals was measured according to Marquez *et al.* (2017).

### Phenolic compounds of apple pomace extract

The phenolic compounds of ethanolic APE was determined using high-performance liquid chromatography (HPLC). Samples were analysed using an Agilent 1260 series HPLC system. The separation was carried out using Agilent Zorbax C<sub>18</sub> column (4.6 × 250 mm, 5 µm i.d., Agilent Technologies Co. Ltd., USA). The mobile phase consisted of water (A) and acetonitrile (B) at a flow rate of 1 mL/min. The mobile phase was programmed consecutively in a linear gradient as follows: 0 - 5 min (80% A); 5 - 8 min (40% A); 8 - 12 min (50% A); and 12 - 16 min (80% A). The multi-wavelength detector was monitored at 280 nm. Each sample was injected at 10 µL. The column temperature was maintained at 35°C.

### Determination of weight loss

Weight loss of different apple slices was estimated in triplicate after 1, 4, 8, and 12 d of storage using Eq. 1:

$$\text{Weight loss (\%)} = \frac{(\text{initial weight} - \text{final weight})}{(\text{initial weight})} \times 100 \quad (\text{Eq. 1})$$

### Measurement of colour

The colour of apple slices was measured by a chromameter Minolta CR-400 (Minolta, Inc., Tokyo, Japan) using the CIE colour parameters L\*, a\*, and b\*. The samples were measured after 1, 4, 8, and 12 d of storage. The browning index (BI) was calculated according to Olivas *et al.* (2007) using Eqs. 2 and 3:

$$BI = \frac{100(x-0.31)}{0.172} \quad (\text{Eq. 2})$$

$$x = \frac{(a^* + 1.75L^*)}{(5.646L^* + a^* - 5.646b^*)} \quad (\text{Eq. 3})$$

#### Antimicrobial activity of apple pomace extract

The antimicrobial activity of APE was determined using agar well diffusion method against Gram-positive bacteria (*Staphylococcus aureus* and *Bacillus subtilis* NRRL B-543), Gram-negative bacteria (*Escherichia coli* ATCC 25955 and *Proteus vulgaris* ATCC13315), mould (*Aspergillus fumigatus*) and yeast (*Candida albicans* ATCC 10231) as described by Boyanova *et al.* (2005).

#### Microbiological examination

Each sample of apple slice (10 g) was aseptically homogenised with 90 mL of Ringer's solution as described by International Commission on Microbiological Specifications for Foods (1978). Serial dilutions were made using Ringer's solution, and they were poured onto sterile plate count agar plates. Inoculated plates were incubated at 32°C for 48 h for the enumeration of total bacterial count, or at 7°C for 5 d for the enumeration of psychrotrophic bacteria. Following incubation, colonies were counted, and results were expressed as log CFU/g of the sample.

#### Sensory evaluation

Ten panellists from the staff members of the Department of Food Science, Faculty of Agriculture, Cairo University, Egypt were recruited. A quality rating scorecard was used for the evaluation of treated apple slices for taste, odour, texture, and overall acceptability. Based on their preference and liking, panellists were required to classify the

samples on a ten-point hedonic scale; 1 = unacceptable, and 10 = very much like.

#### Statistical analysis

The results were expressed as mean  $\pm$  standard deviation. All data were analysed in three replications for each parameter. Statistical analysis was performed using XLSTAT 2014 (5.03) software (USA). Significant differences ( $p < 0.05$ ) between means were determined by Tukey's test.

## Results and discussion

#### Total phenolic content and phenolic composition

The phenolic compounds are responsible for most of the antioxidant activity as well as the health benefits of apple consumption (Feng *et al.*, 2018). Total phenolic content of ethanolic APE was  $6.77 \pm 0.339$  mg gallic acid equivalent/g dry apple pomace, while it was  $14.969 \pm 0.359$  mg gallic acid equivalent/g dry lyophilised extract. Suárez *et al.* (2010) found that the total phenolic content of apple pomace methanolic and acetonetic extracts was 3.63 and 6.48 mg gallic acid equivalent/g of dry wt. pomace, respectively.

Apple pomace extract was subjected to HPLC analysis, and the total identified phenolic compounds were 15 (Figure 1). The major polyphenols of APE were ellagic acid (2494.93 mg/L), salicylic acid (174.83 mg/L), quinol (138.65 mg/L), gallic acid (73.39 mg/L), benzoic acid (70.95 mg/L), rosmarinic acid (50.51 mg/L), syringic acid (16.05 mg/L), chlorogenic acid (12.13 mg/L), *o*-coumaric acid (9.39 mg/L), and vanillin (9.18 mg/L); while the main identified flavonoids were myricetin (3184.31 mg/L), naringin (94.93 mg/L), kaempferol (57.62 mg/L), quercetin (12.79 mg/L), and rutin (7.90 mg/L). Suárez *et al.* (2010) indicated

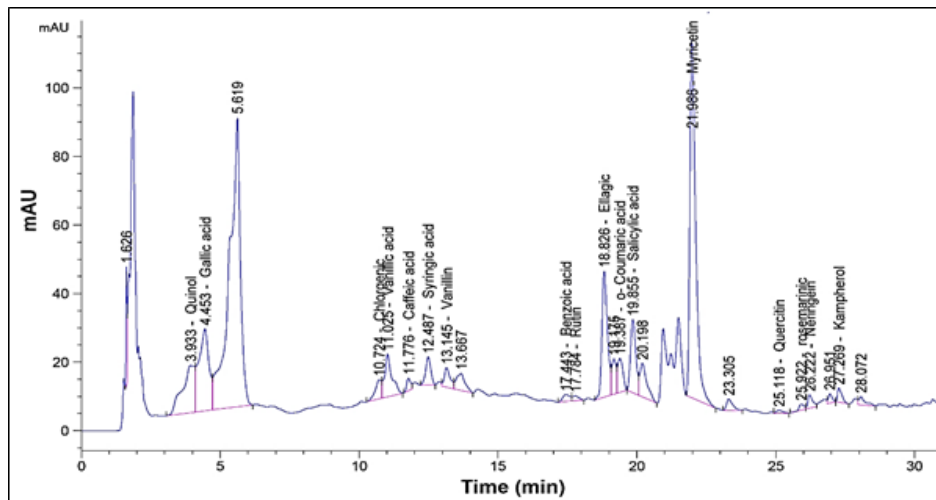


Figure 1. HPLC profile of phenolic compounds in apple pomace extract.

the presence of chlorogenic acid, (-)-epicatechin, quercetin, protocatechuic acid, and caffeic acid in apple pomace methanol extract.

#### Free radical scavenging capacity of apple pomace extract

The obtained results showed that the antioxidant activity of APE increased as polyphenol concentration increased. The  $IC_{50}$  (concentration of APE that is required to inhibit 50% of DPPH free radicals) value of APE was  $51.97 \pm 1.576 \mu\text{g}$  gallic acid equivalent/ mL, whereas the  $IC_{50}$  value of BHT was  $21.80 \pm 0.424 \mu\text{g/mL}$ . The radical scavenging capacity of APE could be attributed to the presence of ellagic acid which is the main phenolic compound in apple pomace (Hayes *et al.*, 2011). Cetkovic *et al.* (2008) found that  $IC_{50}$  value of DPPH radical scavenging activity of apple pomace methanol extract ranged from 6.33 to 15.72 mg/mL from five apple varieties. Rana *et al.* (2014) found that the  $IC_{50}$  value of DPPH of ethyl acetate fraction of APE was 7.37 mg/mL.

#### Weight loss of apple slices

The effect of WPC/APE coating on the weight loss of apple slices during cold storage is shown in Figure 2. The weight loss of WPC/APE coated samples was  $< 0.25\%$  after 4 d of storage, instead of  $> 2\%$  in the case of uncoated and WPC-coated apple slices. After 12 d of cold storage, uncoated apple slices showed the highest weight loss ( $3.07 \pm 0.042\%$ ). However, the weight loss of WPC-coated apple slices incorporated with APE at concentrations of 0.5, 1.0, and 1.5% significantly decreased ( $p < 0.05$ ) to  $1.06 \pm 0.021$ ,  $0.98 \pm 0.014$ , and  $0.58 \pm 0.028\%$ , respectively, as compared to the uncoated and WPC-coated apple slices. Increasing APE concentration in the coating mixture to 1.5% was significantly ( $p < 0.05$ ) effective in reducing the weight loss of apples. This could be due to the high sugar content of the dried apple pomace as reported by O'Shea *et al.* (2015).

Weight loss of uncoated apple slices varied from 0.53 to 1.29% after 12 d of cold storage at  $2^\circ\text{C}$  according to the investigated cultivars (Kim *et al.*, 1993). Khalifa *et al.* (2017) found that the weight loss of uncoated apple samples reached 3.03 and 8.50% after 21 and 35 d of storage, respectively. Marquez *et al.* (2017) reported that coating apple slices with WPC decreased the weight loss from 10 to 8% after 10 d of storage at 4 -  $6^\circ\text{C}$ . McHugh and Krochta (2014) concluded that protein-based films have high sensitivity to moisture and poor water vapour barrier properties due to their hydrophilic nature. Umaraw

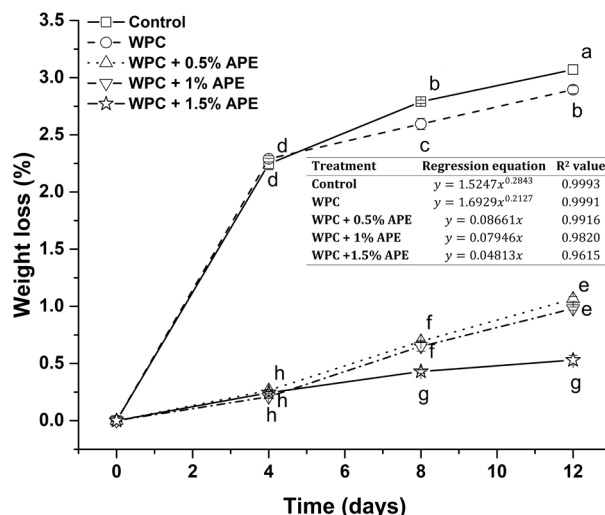


Figure 2. Weight loss of apples treated with different coating formulations during cold storage.

and Verma (2017) reported that WPI have high water vapour permeability owing to the high degree of hydrophilic amino acids in their structure. In addition, Alves *et al.* (2017) found that coating formula containing sodium ascorbate (10 g/L) was more effective in controlling weight loss of apple slices than that without antioxidants. This result may be due to the additional protective effect provided by the interactions of the antioxidants with compounds at the surface of the apples.

#### Colour changes and browning assessment of apple slices

The extension of storage period of apple slices was accompanied by an increase in the enzymatic browning as indicated by an increase in  $a^*$  and  $b^*$  values, and a decrease in lightness ( $L^*$ ) and hue values (Perez-Gago *et al.*, 2006). In Figure 3a, results indicated that the uncoated apple slices and those coated with WPC significantly ( $p < 0.05$ ) recorded the lowest lightness after 12 d of storage. The  $L^*$  values of apple slices coated with WPC/APE were not significantly ( $p > 0.05$ ) different at the end of storage, regardless of the level of APE used in the coating formula. Coating apple slices with WPC/APE retained its  $L^*$  values for 12 d, not significantly ( $p > 0.05$ ) different from those of WPC-coated apple slices stored for 4 d.

A significant ( $p < 0.05$ ) increase in ( $a^*$ ) value of all treatments was observed during the cold storage (Figure 3b). The lowest increase of  $a^*$  value after 12 d of storage was recorded for apple slices coated with WPC/APE (1.5%). The highest ( $+b^*$ ) value ( $33.81 \pm 0.168$ ) was recorded for the uncoated apple slices at the end of storage (Figure 3c). There



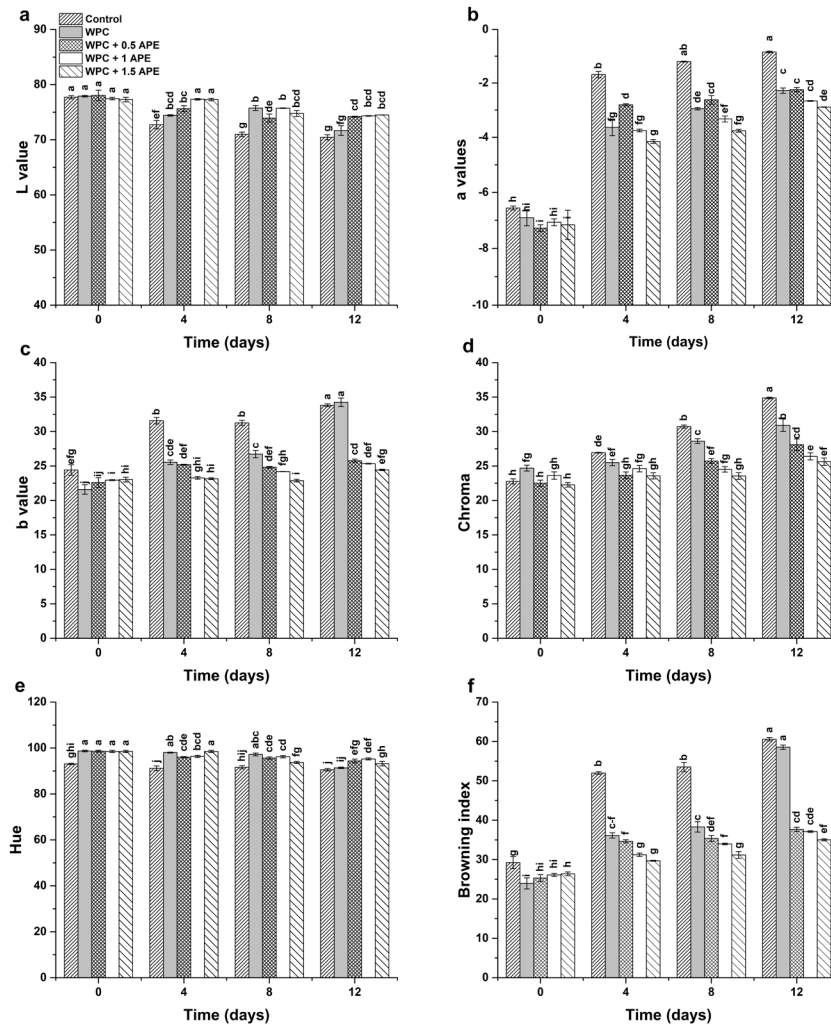


Figure 3. Colour changes and browning index of apples treated with different coating formulations during cold storage.

was no significant ( $p > 0.05$ ) change between (+b\*) value of apple slices coated with WPC/APE at 1.0 or 1.5% after 12 d of storage, and that of the freshly cut apple slices (uncoated).

The extension of storage time of all treatments to 12 d was accompanied by a significant ( $p < 0.05$ ) increase in the chroma ( $C^*$ ) values (Figure 3d). The chroma ( $C^*$ ) values of WPC/APE (1.0 or 1.5%) coated apple samples, at the end of storage period, was not significantly ( $p > 0.05$ ) different from those of the 4 d stored uncoated or WPC-coated apple slices.

Hue values slightly decreased during storage of the uncoated and coated apple slices (Figure 3e). After 12 d of storage, the hue value of the WPC/APE (1.5%) coated apple samples was not significantly ( $p > 0.05$ ) different from that of the uncoated slices at zero-time storage.

The browning index is an indicator for tissue decay. The results in Figure 3f show that browning index increased during the cold storage for all

treatments. The uncoated apple slices significantly ( $p < 0.05$ ) recorded the highest browning index ( $60.57 \pm 0.338$ ) at the end of the cold storage period. Meanwhile, browning index of apple slices coated with WPC only was  $58.54 \pm 0.453$ . On the other hand, incorporating the coating formula with APE at levels of 0.5, 1.0, and 1.5% significantly ( $p < 0.05$ ) reduced the increase of browning index to  $37.66 \pm 0.174$ ,  $37.10 \pm 0.425$ , and  $35.01 \pm 0.200$ , respectively. Coatings incorporated with antioxidants reduced oxygen permeability and affect polyphenol oxidase activity (Alves *et al.*, 2017). In this regard, Perez-Gago *et al.* (2006) found that apple slices coated with whey protein-based coatings had higher  $L^*$  and lower  $b^*$  and  $a^*$  values. They reported that browning index values of the coated apple slices were lower than those of the uncoated ones.

#### Microbiological examination of apple slices

The antimicrobial activity of APE (200 mg/mL) was determined against six species of

spoilage and pathogenic microorganisms, and the results showed that the APE showed large zone of inhibition (8.00 mm) for *S. aureus* NRRL B-543 and *E. coli* ATCC 25955. However, no inhibition zones were detected for the other investigated microorganisms. These results are consistent with those of Younis and Ahmad (2015). The growth inhibition property of apple pomace is attributed to the presence of polyphenols (Agourram *et al.*, 2013).

As shown in Table 1, coating apple slices with WPC or WPC/APE at 0.5 or 1.0% significantly ( $p < 0.05$ ) decreased the TBC during storage. Increasing APE concentration in the coating mixture from 0.5 to 1.0% significantly ( $p < 0.05$ ) decreased the TBC during storage of apple slices. The phenolic compounds of apple pomace have antimicrobial activity (Zhang *et al.*, 2016; Riaz *et al.*, 2018).

The lowest bacterial count was recorded for

Table 1. Total bacterial count (log CFU/g) of apples treated with different coating formulations during cold storage.

Treatment	Storage day			
	1	4	8	12
Control	2.17 ± 0.01 <sup>c</sup>	2.16 ± 0.01 <sup>c</sup>	2.26 ± 0.02 <sup>b</sup>	2.38 ± 0.01 <sup>a</sup>
WPC	1.55 ± 0.05 <sup>fg</sup>	1.97 ± 0.01 <sup>d</sup>	1.82 ± 0.05 <sup>e</sup>	1.52 ± 0.02 <sup>g</sup>
WPC + 0.5% APE	1.28 ± 0.02 <sup>h</sup>	2.10 ± 0.04 <sup>c</sup>	1.89 ± 0.01 <sup>e</sup>	1.49 ± 0.04 <sup>g</sup>
WPC + 1.0% APE	1.16 ± 0.02 <sup>i</sup>	1.21 ± 0.04 <sup>hi</sup>	1.18 ± 0.01 <sup>i</sup>	1.14 ± 0.04 <sup>i</sup>
WPC + 1.5% APE	2.17 ± 0.02 <sup>c</sup>	2.16 ± 0.03 <sup>c</sup>	2.13 ± 0.02 <sup>c</sup>	1.62 ± 0.03 <sup>f</sup>

Values are mean ± standard deviation. Means with different superscript letters differ significantly ( $p < 0.05$ ) by Tukey's test. Control = uncoated apple; WPC = whey protein concentrate; and APE = apple pomace extract. Psychrotrophic bacteria were not detected in all treatments at day 1 and during storage.

Table 2. Sensory evaluation of apples treated with different coating formulations during cold storage

Treatment	Storage day	Taste	Odour	Texture	Overall acceptability
Control	1	9.62 ± 0.45 <sup>a</sup>	9.87 ± 0.33 <sup>a</sup>	8.50 ± 0.50 <sup>cd</sup>	9.62 ± 0.48 <sup>abc</sup>
	4	8.03 ± 0.27 <sup>c</sup>	6.93 ± 0.24 <sup>g</sup>	7.81 ± 0.52 <sup>g</sup>	8.18 ± 0.52 <sup>cd</sup>
	8	5.62 ± 0.24 <sup>d</sup>	4.25 ± 0.82 <sup>j</sup>	5.62 ± 0.55 <sup>i</sup>	5.75 ± 0.24 <sup>g</sup>
	12	3.81 ± 0.94 <sup>f</sup>	3.37 ± 0.72 <sup>i</sup>	2.31 ± 0.59 <sup>j</sup>	3.87 ± 0.48 <sup>k</sup>
WPC	1	9.62 ± 0.45 <sup>a</sup>	9.80 ± 0.40 <sup>a</sup>	9.00 ± 0.36 <sup>b</sup>	9.86 ± 0.44 <sup>ab</sup>
	4	8.20 ± 0.24 <sup>c</sup>	8.46 ± 0.80 <sup>c</sup>	8.00 ± 0.36 <sup>c</sup>	8.66 ± 0.59 <sup>c</sup>
	8	6.20 ± 0.67 <sup>h</sup>	6.33 ± 0.69 <sup>e</sup>	6.80 ± 0.54 <sup>h</sup>	7.86 ± 0.24 <sup>c</sup>
WPC + 0.5% APE	12	4.86 ± 0.88 <sup>e</sup>	3.46 ± 0.74 <sup>k</sup>	5.00 ± 0.44 <sup>j</sup>	5.33 ± 0.59 <sup>h</sup>
	1	9.70 ± 0.40 <sup>a</sup>	9.73 ± 0.44 <sup>a</sup>	9.40 ± 0.48 <sup>cd</sup>	9.93 ± 0.24 <sup>a</sup>
	4	8.30 ± 0.52 <sup>bc</sup>	8.66 ± 0.47 <sup>bc</sup>	9.06 ± 0.85 <sup>de</sup>	9.13 ± 0.33 <sup>b</sup>
	8	8.00 ± 0.24 <sup>c</sup>	7.33 ± 0.73 <sup>c</sup>	7.93 ± 0.59 <sup>e</sup>	8.33 ± 0.57 <sup>f</sup>
WPC + 1.0% APE	12	5.33 ± 0.59 <sup>e</sup>	6.20 ± 0.40 <sup>f</sup>	5.73 ± 0.44 <sup>i</sup>	7.00 ± 0.36 <sup>h</sup>
	1	9.64 ± 0.23 <sup>a</sup>	10.00 ± 0.54 <sup>a</sup>	10.00 ± 0.33 <sup>a</sup>	10.00 ± 0.33 <sup>a</sup>
	4	8.16 ± 0.23 <sup>c</sup>	8.93 ± 0.24 <sup>b</sup>	9.26 ± 0.57 <sup>cd</sup>	9.60 ± 0.48 <sup>a</sup>
	8	8.80 ± 0.24 <sup>b</sup>	8.80 ± 0.40 <sup>bc</sup>	8.66 ± 0.33 <sup>ef</sup>	9.60 ± 0.40 <sup>a</sup>
WPC + 1.5% APE	12	5.53 ± 0.49 <sup>e</sup>	7.00 ± 0.24 <sup>f</sup>	7.13 ± 0.71 <sup>h</sup>	7.40 ± 0.71 <sup>f</sup>
	1	9.87 ± 0.21 <sup>a</sup>	9.75 ± 0.43 <sup>a</sup>	10.00 ± 0.33 <sup>a</sup>	10.00 ± 0.33 <sup>a</sup>
	4	9.62 ± 0.34 <sup>a</sup>	9.75 ± 0.42 <sup>a</sup>	9.62 ± 0.48 <sup>a</sup>	10.00 ± 0.49 <sup>a</sup>
	8	8.34 ± 0.24 <sup>bc</sup>	8.93 ± 0.74 <sup>b</sup>	9.43 ± 0.49 <sup>bcd</sup>	9.62 ± 0.39 <sup>a</sup>
	12	7.93 ± 0.82 <sup>c</sup>	8.81 ± 0.48 <sup>b</sup>	8.18 ± 0.88 <sup>de</sup>	10.00 ± 0.33 <sup>a</sup>

Values are mean ± standard deviation. Means for each parameter with different superscript letters differ significantly ( $p < 0.05$ ) by Tukey's test. Control = uncoated apple; WPC = whey protein concentrate; and APE = apple pomace extract.

the WPC/APE (1%) coated samples that was significantly ( $p < 0.05$ ) different from all other treatments. Extending storage time to 12 d did not significantly ( $p < 0.05$ ) affect the bacterial count of WPC/APE (1%) coated samples. On the other hand, coating apple slices with WPC/APE at 1.5% did not significantly ( $p < 0.05$ ) decrease TBC during the first 4 d of storage, after which the TBC significantly ( $p < 0.05$ ) decreased. These results indicated that WPC and APE may have antimicrobial activity. In this respect, Marquez *et al.* (2017) found that the whey protein/pectin/transglutaminase edible coating is efficacious to avoid fresh-cut apple spoilage during 10-d storage, as demonstrated by microbial growth prevention.

#### *Sensory evaluation of apple slices*

The utilisation of functional ingredients as coating agents to the fruits may alter the sensory attributes of the fruits, and might cause a decrease in consumer acceptability. Consequently, it is essential to study the changes in sensory attributes of apple slices as a result of using WPC and APE as coating agents. The sensory attributes of taste, odour, and texture of coated and uncoated apple slices are listed in Table 2. On day 1 of cold storage, no significant ( $p < 0.05$ ) differences were noted in all treatments for the taste and odour sensory attributes. The highest scores for texture and overall acceptability were recorded for WPC/APE (1.0 and 1.5%) coated samples at the first day of storage. During cold storage, it was observed that there was a gradual decrease in the sensory properties of all samples, except WPC/APE 1.5% coated samples, till the end of the storage period. Coating with WPC/APE 1.5% kept sensory attributes of apple slices during the first 4 d of storage without significant ( $p < 0.05$ ) difference from those of the freshly cut slices. Extending storage time to 12 d did not significantly affect the overall acceptability of the WPC/APE 1.5% coated samples.

Our findings pointed out that using WPC and APE as coating agents attained the sensory properties of apple slices during storage. In this regard, Javanmard (2011) found that WPC-gellan coating maintained the colour, firmness, glossiness, and overall acceptability of apple during storage. Hassani *et al.* (2012) reported that using a composite of WPC and rice bran oil as a coating agent was effective in the preservation of colour, firmness, taste, and overall acceptability of the kiwifruit during storage. Marquez *et al.* (2017) observed no significant differences in acceptability scores for the texture and flavour of the coated samples with whey

protein/pectin/transglutaminase edible coating after storage as compared to all samples tested before storage.

#### **Conclusion**

The present work revealed that the use of a mixture of whey protein concentrate and apple pomace extract as an edible coating was effective to avoid fresh apple slices damage or spoilage during the 12 d of cold storage. This edible coating led to the reduction of weight loss, colour changes, browning index, and microbial growth of fresh apple slices. Also, coating apple slices with whey protein concentrate and apple pomace extract did not have a negative effect on their sensory attributes. It can thus be concluded that a blend of whey protein concentrate and apple pomace extract can be used as coating agents for fresh-cut fruits without affecting their properties during the cold storage period.

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