Effects of pulsed light treatments and pectin edible coatings on the quality of fresh-cut apples: a hurdle technology approach

Running title: Pulsed light and pectin coatings to extend the shelf-life of fresh-cut apples

Authors' names:

María R Moreira[1,2]

María V Álvarez[2]

Olga Martín-Belloso[3]

Robert Soliva-Fortuny[3*]

[1] Universidad Nacional de Mar del Plata. Argentina

[2] Consejo Nacional de Investigaciones Científicas y Técnicas (CONICET). Argentina.

[3] Department of Food Technology, University of Lleida – Agrotecnio Center, Lleida, Spain.

*Corresponding author: rsoliva@tecal.udl.cat

Department of Food Technology, University of Lleida – Agrotecnio Center. Av. Alcalde Rovira Roure 191, 25198 Lleida, Spain. Phone: +34 973702678; Fax: +34 973 702593.

Abstract

BACKGROUND:

Pulsed light treatments (PL) stand as an alternative for the shelf-life extension of fresh-cut products. The antimicrobial effects of pulsed light are well known; however, influence on quality attributes needs to be assessed. This study was aimed at evaluating the application of PL treatments in combination with pectin-based edible coatings enriched with dietary fiber for the preservation of fresh-cut apples.

RESULTS:

Dipping of fresh-cut apples in ascorbic acid/chloride calcium solution, prior to pectin coating and PL treatments, was effective to minimize browning and softening in apple surfaces. Incorporation of fiber in the pectin coating did not cause any change in microbial loads and sensory acceptability of apple cubes. Pectin-coated PL-treated apple pieces exhibited significantly higher antioxidant activity values than fresh and PL-control samples. At the end of storage, the combination of both treatments resulted into almost a 2 log CFU g^{-1} reduction of microbial counts. Sensory attribute scores did not fall below the rejection limit throughout 14 days, although the presence of off-odors limited the acceptability of the pectin-coated samples.

CONCLUSIONS:

Results demonstrate that PL treatments applied to pectin-coated fresh-cut apples may be used to maintain quality attributes, thus conferring prebiotic potential and extending the shelf-life of the product.

Keywords: pulsed light, fresh-cut fruit, dietary fiber, edible coatings, quality parameters

Introduction

During the last two decades, the production and consumption of fresh-cut commodities in the developed countries has experienced a continuous increase. [1,2] This trend obeys the increase in the demand for food products with health-promoting properties beyond the general provision of essential nutrients. [3] While the fresh-cut vegetables industries have consolidated their position in both foodservice and retail markets, fresh-cut fruit processors are still trying to develop products that attract the consumers' interest because of their fresh-like quality. The shelf-life of fresh-cut fruits is dramatically reduced by the removal of the protective skin as well as by the deleterious effects of cutting and handling operations. [4,5] Microbial growth and mechanical damage are the main causes of quality decay.

Fruit derived products are commonly stabilized by thermal processes, which are detrimental to their sensorial characteristics and antioxidant content. Recently, several nonthermal food processing technologies have been proposed as an alternative for extending the shelf life of fresh-cut fruits. Pulsed light (PL) is a non-thermal technology based on the application of intense pulses of short duration to inactivate microorganisms found on food surfaces and food contact materials. Literature data show that pulsed light can be used to efficiently decontaminate fresh-cut fruit and vegetable commodities. [6-8] However, under abusive treatment conditions pulsed light technology may be detrimental to the quality and sensory properties of minimally processed products.

Edible coatings are another incipient technology with good prospects for extending the shelf-life of fresh-cut fruit commodities. Hydrocolloids such as proteins and long-chain polysaccharides are the most suitable to produce coatings with appropriate structural properties. [9-11] Polysaccharide coatings may serve as carriers of food additives such as antibrowning and antimicrobial agents, colorings, flavorings, nutrients, spices and nutraceuticals. [9,12,13] Pectin, a polysaccharide associated to the cells and intercellular walls of plants and fruits, is able to form strong gels in the presence of multivalent metal cations such as calcium. Some publications have documented the effectiveness of pectin edible coating to prolong the shelf-life of some fruit such as apple, pears and melon. [12,14-18] Edible coatings can be also a vehicle for the incorporation of dietary fiber in order to meet the dietary requirements. [19] Dietary fibre is one of the first ingredients with proven health benefits. Namely, dietary fibers obtained from apple fruits are of higher quality than those extracted from alternative sources such as cereals, highlighting the importance of their soluble fraction and antioxidant properties. [20-21] Nevertheless, fiber incorporation to edible coatings could modify their optical properties, thus limiting the sensory acceptability of the coated products or even decreasing the decontamination efficacy of PL treatments.

The concept of multi-target preservation of foods, by employing a combination of treatments to increase the product stability, hence extending shelf life, is highly applicable to fresh-cut fruits processing. This hurdle approach was introduced by Leistner [22] and is based on the assumption that different techniques applied in a food might not have just an additive preservation effect, but could act synergistically. Nevertheless, combination of techniques could also generate antagonistic effects. This is especially relevant when considering the combination of PL treatments and edible coatings. There is limited information regarding the antimicrobial effectiveness of PL as affected by edible coatings. Recently, Moreira et al. [23] evaluated the combined application of a PL treatment and a gellan gum-based coating on the shelf-life of fresh-cut apples, concluding that the blockage of a certain part of the UV radiation could result in a reduction of the decontaminating effect of PL. However, the results may differ for one coating to another. Therefore, the main objective of this work was to study the combined effect of a PL treatment and a pectin edible coating, with and without fiber addition, on quality attributes and of fresh-cut apples.

2. Experimental

2.1. Materials

'Golden' delicious apples were purchased at a wholesale distributor of local produce in Lleida (Spain). The fruits had a commercial maturity and were stored at 4±1 °C until processing. Low methoxyl pectin, esterified potassium salt from citrus fruit (Sigma-Aldrich Chemic, Steinhein, Germany) was the carbohydrate biopolymer used in the coating formulations. Glycerol (Merck, Whitehouse Station, NJ, USA) was added to the coatings as a plasticizer. Calcium chloride (Sigma-Aldrich Chemic, Steinhein, Germany) was used to induce crosslinkage between the polymer chains. Ascorbic acid (Sigma-Aldrich Chemic, Steinhein, Germany) was added as antibrowning agent, following the commercial practice for this commodity. The apple fiber extract incorporated to the coatings was kindly supplied by Indulleida S. L. (Lleida, Spain) and had a purity of 55,90% (w/w). The contents in soluble and insoluble dietetic fiber were 13.10% and 42.80% (w/w), respectively.

2.2. Preparation of the film forming and crosslinking solutions

The film-forming solutions were prepared by dissolving pectin powder in distilled water (20 g kg $^{-1}$) at 70 °C under stirring until it became clear. Apple fiber was incorporated to half of the formulations in the same step in a concentration of 7 g kg^{-1}. This concentration was selected in view of the modification of the organoleptical characteristics and film-forming properties observed in previous experiments. Once the solution was cooled down to room temperature, 15 g kg^{-1} glycerol was added. Aside, an aqueous crosslinking 20 g kg^{-1} calcium chloride solution was prepared. Ascorbic acid (10 g kg^{-1}) was added to the calcium solution to prevent apple surface browning phenomena. The concentrations of the ingredients used in these formulations were set up according to previously reported studies (Rojas-Graü et al., 2007).

2.3. Fruit coating

Apples were washed with chlorinated water, rinsed with tap water and dried with paper cloth prior to peeling and cutting. Apples were then peeled, cored and diced into cubes of 1 cm^3. The freshly cut fruit pieces were first dipped for 2 min into the pectin-based film-forming solution, either containing or not containing apple fiber. The excess of coating solution was allowed to drip off for 1 min before a subsequent 2 min immersion into the crosslinking dip. Fresh samples dipped into the crosslinking solution but not into the film-forming dip were prepared as a reference. Approximately 60 g of apple pieces were weighed and placed into transparent polypropylene trays of 500 cm^3 (Mcp Performance Plastic LTD, Kibbutz Hamaapil, Israel) avoiding overlapping. Each tray was sealed without atmosphere initial modification using a 64 µm-thick polypropylene film with a permeability to oxygen of 110 $cm^3\ O_2\ m^{-2}\ bar^{-1}\ day^{-1}$ at 23 °C and 0% RH (Tecnopack SRL, Mortara, Italy) operating a Foodpack Basic V/G thermosealing machine (Ilpra, Vigenovo, Italy). Once sealed, the trays were kept at 4 ± 1 °C in the dark until exposure to pulsed light.

2.4. Pulsed light treatment

Pulsed light (PL) treatments were carried out with a XeMaticA-2L lab bench system (SteriBeam Systems GmbH, Germany). The device is equipped with two lamps situated perpendicularly above and below the sample holder. Experiments were carried out at an overall charging voltage of 2.5 kV. The lamps were separated by 17 cm and the sample was placed right half-way. Each lamp emitted 30 pulses of 0.3 ms with a fluence of 0.4 J/cm^2 per pulse measured at the sample level, thus delivering an accumulated energy of 12 J/cm^2 per side. The wavelengths spectrum ranged from 180 to 1100 nm with 15–20% of the light in the UV region. Polypropylene film was highly transparent to both visible and UV wavelengths. Transparency of the foil in the UV region was evaluated with a photodiode coupled to an oscilloscope and was found to be above 97% of the total emitted energy. A cold air gun (Model MOD.610-BSP, ITW Vortec, Blue Ash, OH, USA) was coupled to the system ventilation to prevent excessive temperature increase inside the chamber. Temperature at the sample surface was monitored with a Testo thermometer (Cabrils, Spain) equipped with a type K thermocouple and never exceeded 30 °C. Each tray was individually treated. Untreated and uncoated apple cubes were used as a reference. Immediately after processing, the samples were stored at 4 °C in the dark. Analyses were carried out periodically through 14 days for randomly withdrawn pairs of trays, so each tray corresponded to a processing replicate.

2.5. Antioxidant capacity

The antioxidant capacity of the fruit samples was evaluated according to the method described by Odriozola-Serrano et al., [24] based on the determination of the free radical-scavenging effect of sample extracts on a solution containing the 1,1-diphenyl-2-picrylhydrazyl (DPPH) radical. Apple pieces were crushed and centrifuged at 10.000g for 15 min at 4 °C (Centrifuge Medigifer; Selecta, Barcelona, Spain) and 100 µL of the supernatant was added to 3.9 mL of methanolic DPPH solution (0.025 g kg^{-1}). The homogenate was shaken vigorously and kept in darkness for 30 min. Light absorbance at 515 nm was read with a spectrophotometer (CECIL CE 2021; Cecil Instruments Ltd., Cambridge, UK) against a blank of pure methanol. Antioxidant capacity was expressed as the percentage inhibition of the DPPH radical compared to the initial amount in the DPPH solution.

2.6. Color measurement

A Minolta colorimeter (Model CR-400, Minolta, Tokyo, Japan) was used to determine the surface color of fresh-cut apple. The equipment was set up for a D65 illuminant and a 10° observer angle. A white standard plate (Y=94.00, x=0.3158, y=0.3322) was used for calibration. The color was evaluated in five pieces from each tray. Three measurements of the CIE L*, a* and b* values were read per replicate by changing the position of the fruit piece. Color modification was evaluated through changes in lightness (L*) and hue (h^*). The hue was calculated from a^* (green-red) and b* (blue-yellow) chromatic values with the following expression: h^*= arctan (b*/a*).

2.7. Firmness measurements

A TA-XT2 Texture Analyzer (Stable Micro Systems Ltd., England, UK) equipped a 25 kg weight cell and a 4-mm diameter probe was used to evaluate apple firmness. The maximum force required for a rod to penetrate 5 mm into the geometric center of a 1 cm-high apple cube at a rate of 5 mm s^{-1} was recorded. Ten replicate measurements were obtained from ten apple cubes randomly withdrawn from two trays processed and stored under the same conditions.

2.8. Microbiological analysis

The growth of naturally-occurring microbial populations on fresh-cut apples was evaluated over refrigerated storage. Mesophilic and psychrophilic aerobic microorganisms, as well as yeasts and molds were counted separately. A portion of 10 g of apple taken from eight different apple cubes was aseptically removed from each tray and transferred into sterile plastic bags. Samples were homogenized with 90 mL of saline peptone water (1 g kg^{-1}, Biokar Diagnostics, Beauvais, France) for 1 min in a stomacher blender (IUL Instruments, Barcelona, Spain). Serial dilutions were plated on plate count agar (PCA) and chloramphenicol glucose agar (GCA) (Biokar Diagnostics, Beauvais, France). Plates were incubated for 48 h at 30 °C for mesophilic aerobic microorganisms, for 5-7 days at 5 °C for psychrophilic aerobic microorganisms, and for 3-5 days at 25 °C for yeasts and molds. The results of the counts were expressed as CFU g^{-1} of apple. Analyses were carried out periodically during 14 days from randomly sampled pairs of trays and two replicate counts were carried out for each tray.

2.9. Sensory acceptability

The sensory attributes of fresh-cut apple cubes were evaluated by 10 panelists, aged between 20 and 30 years old, who like and regularly consume apples using 5-point hedonic scales. The judges were recruited among the research staff of the Department of Food Technology, University of Lleida. They were trained to evaluate color, firmness, taste and overall preference. Apple samples were offered to the judges immediately after removal from cold storage and on a white plate with three-digit codes in individual booths under white light at ambient temperature. The order of the samples was randomized for each panelist. The judges were asked to evaluate the intensity of the attributes for each sample on non-structured line scales with anchor points at each end. The left end of each scale corresponded to a strongly undesired amount of the stimulus while the right end of the scale stood for a largely desired level of the stimulus. The judges' average response was calculated for each attribute. The limit of acceptance was 3; hence samples receiving scores above 3 for any of the evaluated attributes were catalogued as acceptable form a sensory point of view, whereas samples with scores below 3 were deemed unacceptable. Beyond the first week of storage, samples were not tasted by the judges owing to safety reasons.

2.10. Statistical analysis

The experimental design used in this study was completely randomized with two factors, treatment, including pulsed light treatments and pectin coatings alone or in combination, and storage time. Data were analyzed using SAS Version 9.0 (SAS Institute, Cary, NC, USA). The general linear model procedure (PROC GLM) was used for the analysis of variance (ANOVA). Differences between means were evaluated with a 95% confidence level. Tukey's multiple comparison tests were run wherever significant differences were reported.

3. Results and Discussion

3.1. Microbiological quality

The growth of naturally-occurring microorganisms as affected by PL and pectin-based coatings with or without added apple fiber is shown in figure 1.

The different treatments, either applied individually or combined, did not initially result in a reduction of the counts of mesophilic aerobic microorganisms on fresh-cut apples (Fig. 1A). No significant differences ($p<0.05$) were noticed between treatments during the first week of storage. However, over the second storage week, the counts on untreated fresh-cut apples rapidly increased, while the application of PL lead to significantly lower ($p<0.05$) mesophilic aerobic counts. Hence, over 14 days of storage, the growth of total aerobic counts on untreated fresh-cut apples was greater, thus reaching 7.28 log CFU g^{-1}, while in treated samples this increase was reduced by at least 1.0 log cycle. Namely, pectin-coated fresh-cut fruit exposed to PL exhibited a highest reduction in microbial growth, reaching 5.82 log CFU g^{-1} after 14 days of storage. The addition of apple fiber was not found to have any significant effect on the proliferation of aerobic microorganisms, as differences in microbial counts between similar treatments, with or without incorporation of fiber, were not observed.

The evolution of psychrotrophic aerobic bacteria on fresh-cut apple pieces is shown in Figure 1B. In this case, significant differences ($p<0.05$) were observed among treatments just after processing. Untreated fresh-cut apples exhibited the highest counts (3.25 log CFU g^{-1}), whereas slight but significant reductions were observed on samples treated with PL. The application of pectin coatings did not initially led to decreased psychrotrophic aerobic counts. Over storage, counts on untreated fruit increased at highest rate, while differences among treatments were small. Hence, differences between treated and untreated samples increased over time. Furthermore, after 14 days counts on treated samples were 0.8-1.6 log CFU g^{-1} lower than on those untreated. As in the case of mesophilic aerobic microorganisms, the lowest counts corresponded to apple pieces coated with pectin and exposed to PL.

Figure 1C displays the changes in yeast and mold counts on treated and untreated apple cubes over storage. In this case, none of the treatments caused a decrease in the yeast and mold counts just after processing. Those initial counts were maintained without much difference over the first week of storage regardless the applied treatment. However, as reported for other microbial groups, differences between treated and untreated fresh-cut apples became evident over the second storage week. As well, the lowest increase in mold and yeast counts was observed on apple cubes treated with a combination of pectin coating without fiber addition and PL. Furthermore, no significant difference in yeast and mold counts was observed regardless of fiber addition.

These results are in line with those reported by other authors on other fruits such as tomato, plums or strawberries. Aguiló-Aguayó et al. [25] found that PL treatments caused ca. 1.0 log reduction in the yeast and mold counts of PL-treated tomatoes stored at 5 °C during 15 days. Luksiene et al. [26] reported inactivations between 1.0 to 1.3 log CFU g^{-1} of naturally distributed mesophilic bacteria in different fruit and vegetables such as plums, cauliflowers, sweet peppers and strawberries, thus indicating the feasibility of PL to reduce contamination in food products with surface irregularities. Similar results have also been observed on other vegetable matrices such as spinach, carrot, cabbage or mushrooms. [2,27] A few of these works highlight the occurrence of sublethal injuries that may explain the low inactivation levels achieved with PL treatments. In the current study, shielding of microorganisms by rough apple surface and internalization into the apple tissue could have had an important influence on the inactivation pattern. [28] On the other hand, combination of PL treatment and pectin coating was not found to be antagonistic, as observed by Moreira et al. in a recent study [23] when a gellan-gum based coating was used in the same fruit matrix.

3.2. Antioxidant activity

Figure 2 shows the antioxidant activity of fresh-cut apples as affected by PL treatments and pectin coatings with or without incorporation of apple fiber. No significant differences ($p<0.05$) in the initial antioxidant activity were observed among samples, as any of them were treated with an antioxidant dip containing ascorbic acid. During the first week of storage, a dramatic decrease in the antioxidant capacity values was observed regardless the applied treatment. As a consequence, fresh-cut apples had lost more than a 90% of their initial antioxidant content by day 10 regardless the applied treatment. However, pectin coated apple cubes, and especially those incorporating apple fiber, exhibited slightly higher antioxidant activity values beyond that point. In line with these results, several studies have evaluated the functional properties of dietary fibers derived from fruits such as orange and apple, highlighting their antioxidant properties. [20,21,29,30] Indeed, our results confirm those reported by Moreira et al., [19] who found that a pectin coating enriched with apple fiber was effective to maintain the antioxidant capacity of fresh-cut apple. As well, Oms-Oliu et al. [12] reported that a pectin coating containing antibrowning agents noticeably increased the antioxidant capacity of fresh-cut pears.

Furthermore, no significant difference was observed between fresh and PL control samples. In accordance with our results, Oms-Oliu et al. [2] reported no significant differences between the antioxidant activity of untreated fresh-cut mushrooms and PL-treated fruit, stored at 4 °C over 15 days. Our results suggest that the decrease in antioxidant capacity values was caused by the oxidation of antioxidant compounds such as vitamin C and polyphenols, which are found commonly in apples and may be easily degraded in the presence of oxygen by enzyme-mediated reactions.

3.3. Color

Color parameters of apple cubes as affected by a PL treatment and a pectin edible coating are presented in Table 1. Lightness (L*) is the most indicative parameter associated with enzymatic browning of fruit and vegetables. PL treated fresh-cut apples initially exhibited a slight but significant ($p<0.05$) decrease of their L* values. In accordance with our results, Gómez et al. [6,31] found that exposure of cut apples to PL increased surface browning as compared with untreated apples. Pectin coatings, regardless the addition of apple fiber, were not found to have any significant effect on L*. The sign of these observations was maintained over the first 4 days of storage. Thereafter, significant differences between treatments vanished, indicating that the quality stabilizing dipping treatment successfully inhibited browning in any of the assayed conditions over the whole studied period. Consistently, h° values slightly decreased as a consequence of the application of PL treatments. No major differences among treatments were observed over storage although h° values generally declined, showing faint evidences of oxidation.

3.4. Firmness

Table 2 shows the firmness of fresh-cut apples treated with PL and pectin edible coating, with and without fiber addition, over refrigerated storage. Significant differences ($p<0.05$) in firmness were found between PL-treated and untreated fresh-cut apples just after processing; the values achieved were in the range of 8.5 to 10.5 N. Up to day 7 of storage, firmness values of PL-treated apple cubes were significantly lower compared with those of untreated fresh-cut apples. In accordance with our results, other authors have reported undesirable changes as a consequence of PL treatments, such as loss of firmness, development of strong off-odors and taste deterioration. [27] Ramos-Villarroel et al. [32] reported that firmness loss of fresh-cut fruits can occurs normally as a consequence of releasing calcium, potassium, and some pectic enzymes from fruits by cellular damages caused during its processing. Also, these authors reported that PL can affect the textural properties of fresh-cut avocado.

Firmness values were maintained or even increased over storage regardless the applied treatment. This fact could be attributed to the use of calcium chloride to cross-link the polymer matrix representing a beneficial effect for the coated apple by delaying softening. Pectin is one of the major components of cell wall materials. The changes of cell wall structures are most correlated with the textural breakdown of fruits. Degradation of cell wall polysaccharides especially pectin solubilisation and depolymerisation contributes to these textural changes. In this sense, other researchers have reported that, when incorporated into edible coatings, calcium chloride can maintain the firmness in fruits. [4,6,17,31,33-36] This effect has been related to the cross-linkage of the cell wall polysaccharides and, more specifically, to the ability of low methoxyl pectins to cross-link with divalent ions such as calcium cations. This cross-linking, which is expected to follow the so-called egg-box model, involves junction zones created by ordered, side-by-side associations of pectin chains where specific sequences of galacturonic acid monomers form cavities where calcium ions fit and link the chains together by electrostatic and ionic bonding. [37] Hence, in the current study, calcium ions could act both at the cell wall level and at the coating level, as pectins are important constituents of these two structures.

3.5. Sensory quality

Sensory tests were performed throughout the storage period to evaluate the effect of the different treatments on the organoleptical quality of fresh-cut apples. Figure 3 shows the changes in color, texture, odor, taste and overall visual quality scores of control and treated fresh-cut apples stored for 14 days at 4 °C. Initially, no significant differences ($p<0.05$) were observed in color, odor, taste and texture corresponding to treated and untreated apple cubes. However, untreated apple pieces initially presented higher overall quality scores than PL-treated and/or pectin-coated fresh-cut apples. However, in the latter case, the scores did not fall below the threshold of acceptability. Significant differences ($p<0.05$) appeared over storage between untreated and treated apple cubes, in all tested parameters. Although some authors observed that no permanent impairment of taste and odour attributes was caused by PL treatments, [27] our results indicate that off-odors in PL-treated samples remained over the entire storage period and limited the acceptability of pectin-coated PL-treated samples. Photophysical effects caused by sample heating are the most feasible explanation for the changes in the sensory attributes in PL-treated samples. Although temperatures in the treatment chamber and in the cut tissue did not exceed 30ºC in the macroscopic level, localized heating of the irradiated surface is known to be induced by pulsed light due to the differences in the heating/cooling rate and absorption characteristics of product matrix. Several examples of these undesirable thermal effects have been reported by several authors. [2,6,27] However, the most noticeable depletion of the sensory scores was observed in pectin-coated apple pieces, either PL-treated or not. Although the reasons for these modifications should be further studied, a plausible hypothesis could be related to the entrapment of volatile compounds in the internal atmosphere of cut fruit, which could eventually trigger deleterious phenomena jeopardizing the sensory characteristics of fresh-cut apple. On the other hand, the fiber addition did not introduce any significant change on sensory attributes of apple cubes.

4. Conclusions

The use of pectin-based edible coatings enriched with apple fiber as well as the application of pulsed light treatments have been proven to be feasible for extending the shelf-life of fresh-cut apples. Dipping the apple samples in an ascorbic acid/chloride calcium solution was effective to minimize browning and softening of the cut apple surface regardless the applied combination of treatments. A preservation approach based on the combination of both technologies led to a significant reduction in the counts of spoilage microorganisms, although an additive effect of both treatments could not be observed. Sensory attributes scores for any of the assayed alternatives were above the rejection limit over the first week and subsequently declined. The presence of off-odors was the main factor limiting the acceptability of pectin-coated samples after prolonged storage. Future research should focus on analyzing these findings and elucidating the causes for the development of objectionable flavours.

Acknowledgments

This work was supported by Agencia Nacional de Promoción Científica y Tecnológica (ANPCyT, Argentina) and by Spanish Ministry of Economy and Competitiveness, through the project AGL2010-21572. The ICREA Academia Award to Professor Olga Martín-Belloso is also acknowledged.

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Table 1. Effect of pulsed-light and coating treatments on the lightness (L*) and Hue angle values of fresh-cut apples stored for 14 days at 4±1 °C.

		Storage time (days)											
Parameter	*Treatment*	*0*		*2*		*4*		*7*		*10*		*14*	
L*	Fr	81.50 ± 1.32	a,A	81.13 ± 2.33	a,A	81.80 ± 2.15	a,A	81.08 ± 1.57	a,A	80.94 ± 1.00	a,A	80.48 ± 2.72	a,A
	LP	77.33 ± 2.77	b,A	77.96 ± 3.19	ab,A	76.03 ± 2.47	bc,A	79.24 ± 2.21	a,A	79.48 ± 2.80	a,A	78.07 ± 3.10	a,A
	Pe	81.61 ± 1.56	a,A	80.75 ± 1.67	a,AB	80.20 ± 2.60	ab,AB	80.64 ± 1.82	a,AB	78.42 ± 2.43	a,B	80.17 ± 2.02	a,AB
	Pe LP	77.33 ± 2.74	b,ABC	75.34 ± 2.38	b,BC	74.13 ± 2.48	c,C	78.34 ± 2.11	a,AB	79.83 ± 2.56	a,A	78.60 ± 1.58	a,AB
	Pe Fi	78.55 ± 1.72	ab,A	79.45 ± 1.91	a,A	79.91 ± 2.46	ab,A	78.00 ± 1.82	a,A	78.43 ± 1.83	a,A	78.81 ± 2.05	a,A
	Pe Fi LP	76.58 ± 2.87	b,AB	74.94 ± 2.20	b,B	76.61 ± 2.93	bc,AB	78.15 ± 3.04	a,AB	79.61 ± 1.81	a,A	80.17 ± 1.43	a,A
Hue°	Fr	103.37 ± 2.78	a,ABC	104.35 ± 2.04	a,A	101.61 ± 2.30	ab,BC	103.83 ± 0.90	a,AB	102.33 ± 1.48	a,ABC	100.92 ± 1.59	ab,C
	LP	102.93 ± 2.57	c,AB	105.42 ± 1.80	a,A	104.28 ± 2.41	a,A	105.33 ± 1.77	a,A	100.57 ± 1.71	ab,BC	98.76 ± 2.18	cd,C
	Pe	106.30 ± 3.18	ab,A	103.50 ± 3.70	a,AB	102.87 ± 2.90	ab,B	100.50 ± 1.97	bc,BC	98.02 ± 1.19	c,CD	97.04 ± 1.44	d,D
	Pe LP	102.85 ± 1.13	c,AB	103.94 ± 2.99	a,A	101.90 ± 1.97	ab,ABC	102.97 ± 2.98	ab,AB	100.42 ± 0.73	ab,BC	99.50 ± 1.43	abc,C
	Pe Fi	106.47 ± 1.57	a,A	102.42 ± 2.84	a,BC	102.29 ± 2.35	ab,B	99.45 ± 1.27	c,C	101.88 ± 1.91	a,BC	101.27 ± 1.13	a,BC
	Pe Fi LP	102.32 ± 1.15	c,A	102.41 ± 2.11	a,AB	101.36 ± 1.45	b,B	104.16 ± 1.98	a,A	98.79 ± 1.64	bc,C	99.05 ± 1.22	bcd,C

Fr: untreated fresh-cut apples; PL: pulsed light-treated apples; Pe: pectin-coated apples; Pe Fi: pectin+fiber-coated apples. Data represent the mean values ± standard deviation. Different lowercase letters (a,b) within columns indicate significant differences (*P* < 0.05) among the treatments, and different uppercase letters (A,B,C) within rows indicate significant differences (*P* < 0.05) among the storage times.

Table 2. Effect of pulsed-light and coating treatments on the firmness (N) of fresh-cut apples stored for 14 days at 4±1 °C.

	Storage time (days)					
Treatment	*0*	*2*	*4*	*7*	*10*	*14*
Fr	10.49 ± 1.42 a,B	12.17 ± 2.24 a,A	10.80 ± 0.97 ab,AB	11.86 ± 1.17 a,AB	11.29 ± 1.15 a,AB	11.05 ± 0.98 a,AB
LP	8.62 ± 1.36 b,B	9.73 ± 1.07 b,AB	9.89 ± 0.82 b,A	10.95 ± 1.38 a,A	9.81 ± 0.66 bc,AB	9.98 ± 0.80 a,A
Pe	10.37 ± 1.43 a,A	10.58 ± 2.38 ab,A	10.85 ± 1.82 ab,A	11.36 ± 1.41 a,A	10.87 ± 1.24 ab,A	10.38 ± 1.41 a,A
Pe LP	8.31 ± 1.42 b,B	9.32 ± 1.66 b,AB	9.24 ± 0.94 b,AB	10.71 ± 1.33 a,A	9.52 ± 0.94 c,AB	10.73 ± 1.16 a,A
Pe Fi	9.69 ± 1.31 ab,B	9.98 ± 1.88 ab,B	12.26 ± 2.53 a,A	11.04 ± 1.64 a,AB	11.63 ± 1.50 a,AB	10.98 ± 1.07 a,AB
Pe Fi LP	8.35 ± 1.48 b,C	8.74 ± 1.58 b,BC	9.45 ± 1.08 b,ABC	10.29 ± 1.36 a,AB	9.49 ± 0.95 c,ABC	10.80 ± 1.80 a,A

Fr: untreated fresh-cut apples; PL: pulsed light-treated apples; Pe: pectin-coated apples; Pe Fi: pectin+fiber-coated apples. Data represent the mean values ± standard deviation (n=20). Different lowercase letters (a,b,c) within columns indicate significant differences ($P < 0.05$) among the treatments, and different uppercase letters (A,B,C) within rows indicate significant differences ($P < 0.05$) among the storage times.

Figure 1

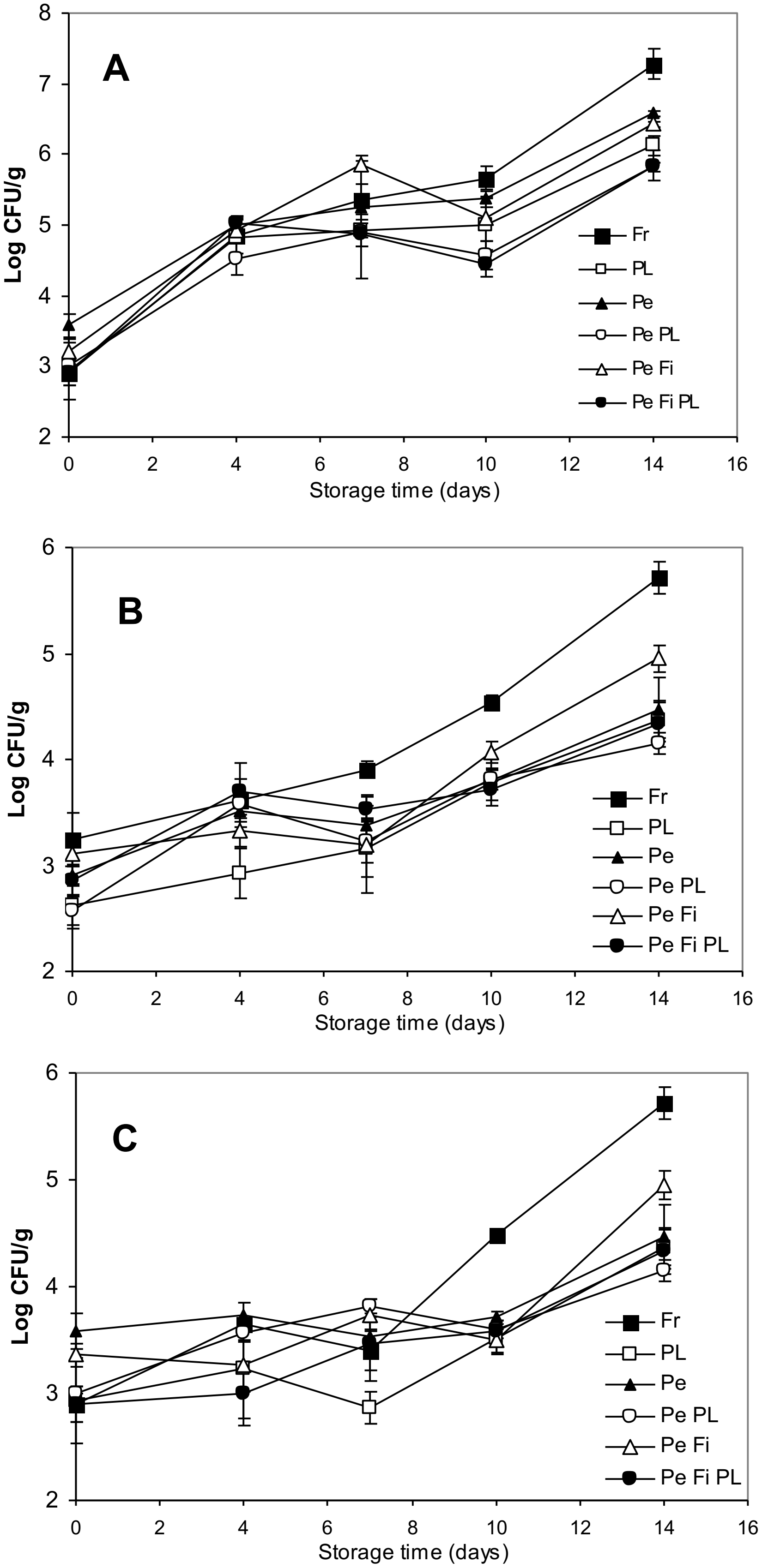
A
B
C
Log CFU/g
Storage time (days)
8
7
6
5
4
3
2
0
2
4
6
8
10
12
14
16
Fr
PL
Pe
Pe PL
Pe Fi
Pe Fi PL

Figure 2

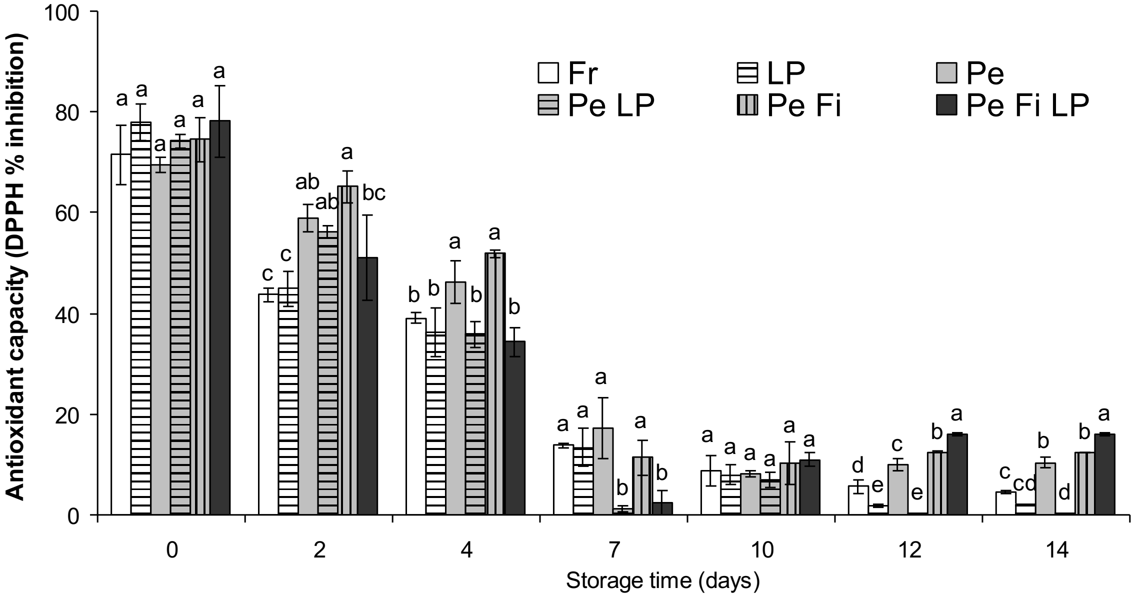
Antioxidant capacity (DPPH % inhibition)
100
80
60
40
20
0
Fr
LP
Pe
Pe LP
Pe Fi
Pe Fi LP
a a a a a a
c c ab ab a bc
b b a b a b
a a a b a b
a a a a a a
d e c e b a
c cd b d b a
0
2
4
7
10
12
14
Storage time (days)

Figure 3

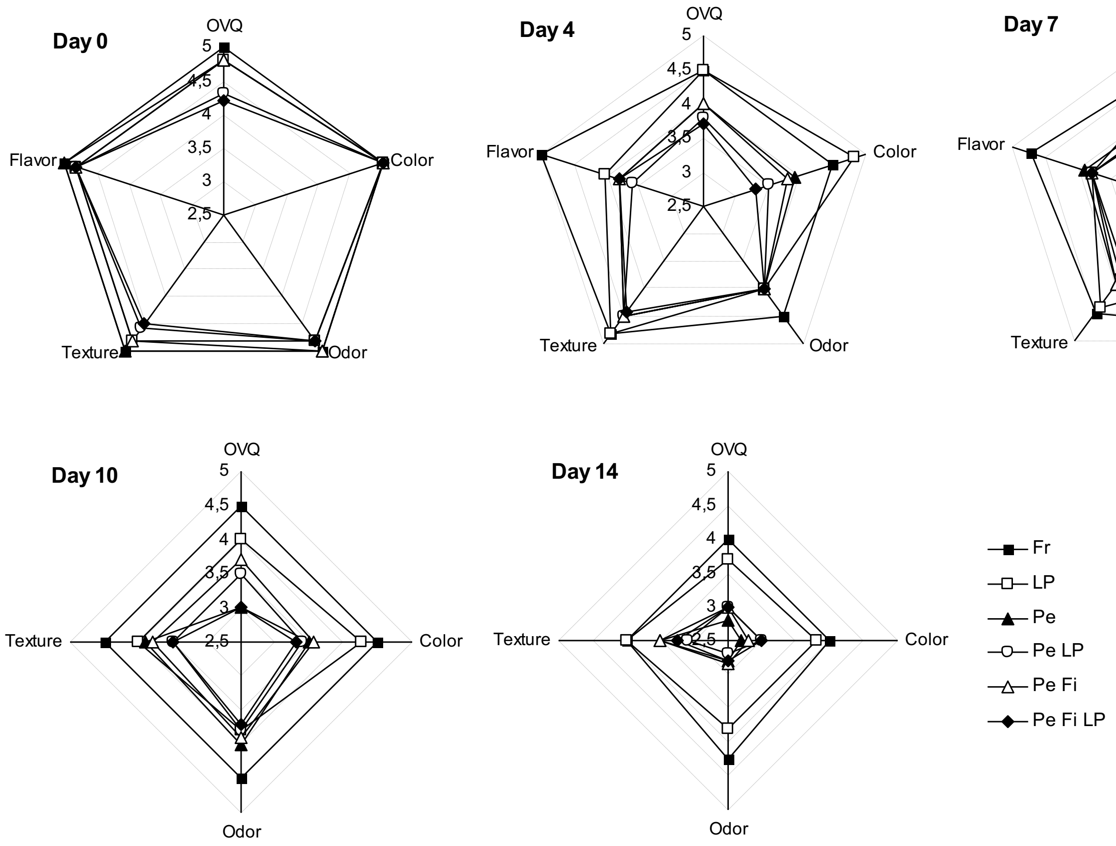
Day 0
Day 4
Day 7
Day 10
Day 14
OVQ
Color
Odor
Texture
Flavor
5
4,5
4
3,5
3
2,5
Fr
LP
Pe
Pe LP
Pe Fi
Pe Fi LP

Figure Captions

Figure 1. Changes in the native-occurring microbiota of fresh-cut apples as affected by PL treatments, the application of pectin-based edible coatings enriched with apple fiber and stored at 4 °C: (A) total mesophilic bacteria; (B) psychrophilic bacteria; (C) yeast and molds counts. Bars indicate standard deviations. Two replicate counts were performed for each tray. Fr: untreated, PL: pulsed light, Pe: pectin, Fi: fiber.

Figure 2. Changes in the DPPH radical-scavenging activity of fresh-cut apples as affected by PL treatments, the application of gellan gum-based edible coatings enriched with apple fiber and storage. Bars indicate standard deviations. Different letters stand for significantly different mean values at 5% level. Each assay was performed in triplicate on 2 separate experimental runs. Fr: untreated, PL: pulsed light, Pe: pectin, Fi: fiber.

Figure 3. Changes in the sensory scores of fresh-cut apples as affected by PL treatments, the application of pectin-based edible coatings enriched with apple fiber and storage. Bars indicate standard deviations. Each assay was performed in triplicate on 2 separate experimental runs. Fr: untreated, PL: pulsed light, Pe: pectin, Fi: fiber.