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Calcium Ascorbate Coating Improves Postharvest Quality and Storability of Fresh-Cut Slices of Coscia and Abate Fétel Pears (*Pyrus communis* L.)

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Abstract: Flesh firmness is closely related to fruit ripeness and is typically a reliable indicator of shelf-life potential so it could be considered a crucial quality index for the determination of pear quality. Flesh softening after cutting could considerably affect consumer acceptance of fresh-cut pears (*Pyrus communis* L.). Indeed, mechanical stress (cutting, peeling, etc.) could lead to ethylene production that results in the hydrolysis of pectic substances in the cell walls. The effectiveness of an edible coating treatment on the physical-chemical, nutraceutical, and sensorial analysis was evaluated on two pear cultivars: the summer-ripening 'Coscia' and the late-ripening 'Abate Fétel', both harvested at their commercial ripening stage. Pear fruit slices were treated with calcium ascorbate, xanthan gum or HPMC coating and stored at 4 °C for 12 days. Weight loss, flesh firmness, soluble solid content, titratable acidity, ΔE color, browning surface, total polyphenol content, and antioxidant capacity were measured. Sensory analysis was carried out. Results showed that calcium ascorbate treatment applied to fruit slices significantly extended their shelf-life because it considerably inhibited browning and color changes in fresh-cut slices of both pear cultivars over seven days of storage. Furthermore, pear slices treated with calcium ascorbate revealed a higher antioxidant capacity and a lower content of total phenols during cold storage.

Keywords: quality; cold storage; sensory analysis; calcium ascorbate; antioxidant activity

1. Introduction

The poor shelf-life of fresh-cut fruit, particularly fresh-cut pear (*Pyrus communis* L.), is a key barrier to commercialization. This is due to severe weakening of the tissues and browning of the cut surface [1]. Indeed the action of polyphenol oxidase (PPO) on the phenolic compounds, generated during the cutting process, causes browning at the cut surface of sliced pears, making them unsuitable for commercialization [2]. Flesh firmness at commercial harvest maturity of pear fruit ranges between 4.5 kg cm^{-2} and 5.8 kg cm^{-2} [3] and, together with genotype and storage conditions prior to processing is among the key factors that affect the shelf-life of fresh-cut pear slices [4,5]. Various chemical and physical storage strategies could be used to reduce enzymatic browning [6,7] and softening of fruit tissues after cutting.

Ascorbic acid or calcium ascorbate has been reported to be an effective browning inhibitor for fresh-cut apples and pear [4,8]. A combination of controlled atmosphere and treatments with/without ascorbic acid and/or calcium salt has been used to reduce browning of fresh-cut pears during storage [3,9]. Indeed, ascorbic acid is a widely used antioxidant whose reducing action against quinones and diphenols prevents browning [10]. Ascorbic acid can be used with calcium to strengthen the membranes and protect the cells from the damage caused by hydrolytic enzymes [11]. Indeed, calcium chloride has been

used to maintain the compactness of minimally processed pears [12] to maintain the structure of the cell walls by binding to pectins and forming calcium pectate. Edible coatings are also useful to extend shelf-life of minimally processed pears [13]. Edible coatings act as a selective barrier to gas exchanges between the food itself and the external environment in order to limit the loss of quality as much as possible [14]. Coatings are composed of hydrocolloids such as polysaccharides and proteins, as well as lipids and waxes, which form an invisible, odorless, and tasteless barrier over the product [15,16]. Recently, some edible coatings made of xanthan gum and hydroxypropyl methylcellulose (HPMC) have been used to improve the quality of fresh-cut pear fruit. Xanthan gum is an exopolysaccharide obtained by a fermentation process in pure culture of a carbohydrate by strains of *Xanthomonas campestris*, subsequently purified by extraction with ethanol or 2-propanol, dried and ground, and is also a Generally Recognized as Safe (GRAS) compound [17]. Recently, edible coatings made of xanthan gum combined with antioxidant agents reduced weight loss and low oxidative browning, increased flesh firmness, reduced the growth of psychotropic microorganisms, molds and yeasts in minimally processed apples and pears [18]. As reported by Sharma et al. [19], xanthan gum coatings enriched with cinnamic acid had an inhibition on the activity of browning related PPO and peroxidase (POX) in fresh-cut pears. The HPMC based coatings combined with soy protein isolate, olive oil and potassium sorbate showed a maintenance of moisture and firmness of 'Babughosha' pears [20]. Gol et al. [21] showed a significant effect in terms of firmness, and color changes in treated strawberry fruits during cold storage. The use of HPMC coating incorporated with oregano and bergamot essential oils extended the storage quality of minimally processed Formosa plums [22]. 'Coscia' and 'Abate Fétel' pear cultivars are cultivated in Italy and are appreciated by consumers for their flesh texture and sensory characteristics. The 'Abate' cultivar represents about 36% of the total European pear crop and is acknowledged as a Protected Geographical Indication (IGP) product [23].

Despite this, there is limited research on the impact of edible coatings on the qualitative features of fresh-cut pears during refrigerated storage. In this study we investigated the effects of xanthan gum, HPMC and calcium ascorbate on minimally processed fruit of the summer-ripening 'Coscia' and the late-ripening 'Abate Fétel' pear cultivars.

2. Materials and Methods

2.1. Plant Material

The experiment was carried out in 2020 in two pear (*Pyrus communis* L.) commercial orchards located in Southwestern Sicily (Italy).

The pear cultivars investigated were 'Coscia' and 'Abate Fétel'. Fruit of 'Coscia' were harvested during the second week of August in an orchard located near Castronovo di Sicilia (PA), Italy (600 m above sea level). The soil is a sandy clay loam with a pH of 7.7 and active carbonates below 6% (50% sand, 18% silt, and 32% clay). The orchard was planted in 2010 with a density of 1000 trees per hectare at a spacing of 4 m between rows and 2.5 m on North-South rows. Trees were trained to free palmette and grafted on quince (*Cydonia oblonga*) BA29 rootstock.

Fruit of 'Abate Fétel' were harvested during the first week of September in an orchard located near Zafferana Etnea (CT), Italy (730 m above sea level). The soil is a sandy clay loam (63% sand, 19% silt, 18% clay), with pH 6.9 and active carbonates lower than 5%. The orchard was planted in 2008 and the density was 1333 trees ha^{-1}, with a spacing of 3 m between rows and 2.5 m on North-South oriented rows. Trees were trained to free palmette and grafted on quince (*Cydonia oblonga*) BA29 rootstock.

All trees received the same conventional cultural cares from planting until the end of the current experiment.

2.2. Experimental Design

Three hundred fruit of each cultivar were individually hand-picked from 30 trees at commercial harvest maturity stage with a firmness value of 4.6 ± 0.2 kg/cm^2. Immediately after harvest, the fruit were brought to the laboratory and dipped in chlorinated water (100 ppm of free chlorine) for 360 s. Next, 75–80 defective fruit (bruised, other physical damage, incorrect maturity, and odd color) were discarded, and the remaining fruit were then selected by firmness (4.3 ± 0.35 kg/cm^2) and average weight (110 ± 20.8 g).

All utensils and surfaces were previously washed and sterilized. The temperature inside the room was set at 4 °C to reduce bacterial proliferation and the fruit were first washed under tap water and then immersed in chlorinated water ($100 \ \mu L \cdot L^{-1}$) for 5 min, according to the methodology reported by Arias [24]. The 'Abate' and 'Coscia' fruit were then air-dried for 2 min. The fruit were then peeled and cut into 8 slices with a medium length of 4 cm with a sterilized stainless-steel knife and the core was removed by means of a pear corer tool.

After being peeled, fruit were cut and placed in bi-oriented polystyrene (PS) bags (Carton Pack s.r.l., Rutigliano, Italy) before receiving any treatment. The fruit slices were dipped in different coating solutions, for 60 s; the excessive coating was drained, and the coated slices were dried in a forced-air dryer (20 °C) for 30 s. The coating treatments consisted of:

1) distilled water (500 mL) with 1% hydroxypropyl methylcellulose (HPMC**)** and 50 mL of glycerol used as plasticizer;
2) distilled water (500 mL) with 2% calcium ascorbate (ASC) and 50 mL of glycerol used as plasticizer;
3) distilled water (500 mL) with 3% Xanthan gum (XAN) and 50 mL of glycerol used as plasticizer.

One hundred (100) fruit slices per pear cultivar were dipped in distilled water +50 mL of glycerol and used as control (CTR). After being coated or dipped, the fruit slices were stored in macro perforated bags at 4 ± 0.4 °C and 85% RH for 24 h. The physicochemical, antioxidant activity, sensorial analysis and quality parameters were analyzed at the beginning of the experiment (after coating/dipping = day 0) and at 3, 5, 7 and 12 days after storage, on nine slices used as single replicates for treatment ($9_{slices} \times 3_{bags}$).

2.3. Fresh-Cut Slice Analysis

2.3.1. Firmness

Fruit hardness was tested with a flat tip of fruit texture analyzer (Instron 5564, Norwood, MA, USA). Each slice (six replicates for each treatment and sample date) was compressed to a depth of 4 mm using a 2.5-cm flat tip at a speed of $5 \ mm \cdot s^{-1}$, and the maximal force was expressed in kg cm^{-2}.

2.3.2. Weight Loss

The difference in weight of each box was measured throughout the storage period using a digital scale of decimal precision (Gibertini, Novate Milanese, Italy) and the values were expressed as a percentage of weight loss:

$$\text{Weight loss (\%)} = [(W_i - W_d)/W_i] \times 100$$

where W_i is the initial weight and W_d is the weight measured during cold storage.

Weight of individual fruit was recorded immediately after the treatment (day 0) and at the different sampling dates (3, 5, 7, and 12 days of storage).

2.3.3. Soluble Solids and Titratable Acidity

The total soluble solids content (TSS) was determined with a hand-held refractometer (ATAGO PR-32) and pH was determined with a pH meter. Titratable acidity (TA) (expressed as% malic acid) was determined by titrating (CRIMSON Titromatic 1S, Auckland, New Zealand) with 0.1 M sodium hydroxide (NaOH) to an endpoint of pH 8.10.

2.3.4. Color

Flesh color was measured at the time of storage (time 0) and after 3, 5, 7 and 12 days of storage at 4 °C on six single fruit slice replicates for each treatment and sampling date. A portable colorimeter (Minolta CR 400 HEAD, Minolta, Osaka, Japan) was used, equipped with an 8 mm measuring head and a C illuminant (6774 K). The instrument was calibrated using the manufacturer's standard white plate. Color changes were quantified in L*, a* and b* color space.

Total color difference (ΔE) expressed the magnitude of difference between the initial non-aged color pulp (zero time) and storage-aged samples. Total color difference (ΔE) was calculated according to the following [14]:

$$\Delta E^* = [(\Delta L^*)^2 + (\Delta a^*)^2 + (\Delta b^*)^2]^{1/2} \tag{1}$$

All trials were carried out in triplicate, and data were reported as mean ± standard error (SE, $n = 6$).

Browning index (BI) was determined, following the equation of [25]:

$$(BI) = [100 \, (x - 0.31)]/0.17 \tag{2}$$

where $x = (a^* + 1.75 \, L^*)/(5.645 \, L^* + a^* - 0.3012 b^*)$.

2.3.5. Antioxidant Activity

The antioxidant activity was determined by the following methods [26,27]. Frozen pear samples (6.0 g) were homogenized with 15 mL of 50% methanol and centrifuged at $10,000 \times g$ for 20 min at 4 °C. The supernatant was collected for 2,2-Diphenyl-1-picrylhydrazyl (DPPH), 2,20-Azino-bis (3-ethylben zothiazoline-6-sulfonic acid) (ABTS), and ferric ion reducing antioxidant power (FRAP) analysis. The DPPH and ABTS free radical scavenging capacities were expressed in µmol ascorbic acid equivalent antioxidant capacity (AEAC) kg^{-1} fresh weight. The FRAP was expressed as mmol FeSO$_4$ kg^{-1} fresh weight

2.3.6. Total Phenols Content

The phenol content was determined following Sortino et al. [28]. This method includes the use of thirty grams of pear fresh tissue for each replication was homogenized with methanol (1:10, *w/v*). After filtration through a Whatman grade N. 1 filter paper, methanolic extracts were concentrated under reduced pressure and the residue was suspended in 50% (*v/v*) aqueous methanol and used for phenolic content assay. The phenols content was determined spectrophotometrically at 700 nm and was expressed as gallic acid equivalent (mg kg^{-1} fresh weight).

2.3.7. Sensory Analysis

Sensory analysis was performed by a panel of 12 panelists. All panelists were specifically trained [29] on the visual aspect and aroma, flavor and texture attributes of the fruit, using product and ingredient references. All the samples were subjected to a panel consisting of 14 descriptors as follows: external color uniformity (ECU), compactness (COM), pulp color intensity (PCI), odor (O), herbaceous odor (HO), floral odor (FO), sweetness (SW), sourness (S), bitterness (B), juiciness (J), pear flavor (PF), herbaceous (HF) and floral flavor (FF) and overall rating (OR). All samples were scored from 1 (no descriptor intensity) to 9 (highest descriptor intensity) and descriptors were evaluated from day 0 (fresh) to day 12.

2.4. Statistical Analysis

The experimental design on fresh-cut pear slices consisted of three treatments and one untreated control, observed at 0, 3, 5, 7 and 12 days after treatment. For treated and untreated fruit slices, nine were used as single replicates and analyzed at each sampling date. Analysis of variance was applied to collected data (Systat 13.0 for Windows was used as statistical software). Significant differences ($p \leq 0.05$) were evaluated with the Tukey's test.

3. Results and Discussion

3.1. Solid Soluble, Titratable Acid, Weight Loss, and Firmness

The TSS content in fresh-cut 'Coscia' and 'Abate' pear cultivars (Table 1) increased in all treatments (CTR, ASC, HPMC and XAN) by 10–11% from 0 to 7 days after harvest, except for untreated 'Coscia' slices, in which the increase in TSS was twice as much (Table 1). The same reduced TSS accumulation due to ASC coating was reported by Ali et al. [30] on papaya fruit. In general, it seems that the TSS content tends to increase over storage period as a consequence of the ripening process in climateric and aclimateric fruits [31,32]. Different results were found by Sharma (2015) on fresh-cut Nashpati and Babughosha pear cultivars. The authors reported a decrease of TSS mean values during storage time caused by the amount of carbohydrates and pectis, partial hydrolysis of protein, and decomposition of glycosides into sub-units during respiration.

Differences among treatments occurred only after seven days storage in both cultivars, when untreated fresh-cut 'Coscia' slices showed the highest TSS content. On the other hand, ASC treated fresh-cut slices showed the lowest TSS content from 7 to 12 days after storage (Table 1).

Table 1. Total solid soluble content of untreated (CTR) fruit slices (Coscia and Abate Fètel) of *Pyrus communis* L. and fruit slices treated with xanthan gum (XAN), hydroxypropyl methylcellulose (HPMC), calcium ascorbate (ASC), when first coated (0) and after storage for 3, 5, 7, 12 days at 4 °C. At each sampling date, different letters indicate substantial changes between treatments. At each sampling date, ns indicate no changes between treatments. $p \leq 0.05$ was used in the Tukey's test. The data are provided as the mean ± S.E. (*n* = 3).

Cultivar			
Time of Storage (Days)		**Coscia**	**Abate**
0		11.9 ± 0.37	13.4 ± 0.4
3	**CTR**	12.7 ± 0.1 ns	13.7 ± 0.2 ns
	XAN	12.0 ± 0.2	13.1 ± 0.1
	HPMC	12.2 ± 0.2	13.5 ± 0.2
	ASC	12.1 ± 0.3	13.2 ± 0.2
5	**CTR**	12.9 ± 0.2 ns	14.0 ± 0.3 ns
	XAN	12.3 ± 0.4	13.5 ± 0.3
	HPMC	12.5 ± 0.1	13.8 ± 0.2
	ASC	12.3 ± 0.1	13.6 ± 0.2
7	**CTR**	13.5 ± 0.5 a	15.2 ± 0.5 a
	XAN	12.5 ± 0.2 b	14.5 ± 0.1 a
	HPMC	12.8 ± 0.1 b	14.5 ± 0.1 a
	ASC	12.4 ± 0.2 b	13.9 ± 0.1 b
12	**CTR**	14.5 ± 0.2 a	15.2 ± 0.4 a
	XAN	12.8 ± 0.05 b	14.5 ± 0.1 a
	HPMC	13.1 ± 0.2 b	14.8 ± 0.2 a
	ASC	12.6 ± 0.2 b	14.2 ± 0.3 b

The TA content decreased with storage time, with no significant changes related to treatment, in fresh-cut 'Coscia' slices. The 'Abate' fruit coated with HPMC showed the lowest TA content at all dates (Table 2). The same results were found for Tommy Atkins mango fruit slices coated with chitosan, registering a decreased mean value of 33% [33]; on fresh-cut banana coated fruit with 1% calcium chloride, 0.75% cysteine and 0.75% ascorbic acid, the TA content decreased of 5% during five days at 5 °C [34]. Allegra et al. [35] reported that the use of mucilage coating on breba figs caused an increase of organic acids in comparison to untreated controls after seven days.

Table 2. The titratable acidity content of untreated (CTR) fruit slices (Coscia and Abate Fètel) of *Pyrus communis* L. and fruit slices treated with xanthan gum (XAN), hydroxypropyl methylcellulose (HPMC), calcium ascorbate (ASC), when first coated (0) and after storage for 3, 5, 7, 12 days at 4 °C. At each sampling date, different letters indicate substantial changes between treatments. At each sampling date, ns indicate no changes between treatments. $p \leq 0.05$ was used in the Tukey's test. The data are provided as the mean ± S.E. (n = 3).

Cultivar			
Time of Storage (Days)	Treatment	Coscia	Abate
0		1.9 ± 0.01	2.1 ± 0.02
3	**CTR**	1.8 ± 0.1 ns	2.0 ± 0.2 a
	XAN	1.7 ± 0.1	1.9 ± 0.1 a
	HPMC	1.7 ± 0.1	1.6 ± 0.3 b
	ASC	1.7 ± 0.1	2.0 ± 0.3 a
5	**CTR**	1.8 ± 0.4 ns	1.9 ± 0.1 a
	XAN	1.7 ± 0.2	1.8 ± 0.4 a
	HPMC	1.7 ± 0.3	1.6 ± 0.4 b
	ASC	1.7 ± 0.3	2.0 ± 0.1 a
7	**CTR**	1.6 ± 0.3 ns	1.9 ± 0.1 a
	XAN	1.6 ± 0.4	1.8 ± 0.1 a
	HPMC	1.6 ± 0.5	1.6 ± 0.6 b
	ASC	1.6 ± 0.6	1.9 ± 0.1 a
12	**CTR**	1.5 ± 0.1 ns	1.8 ± 0.4 a
	XAN	1.6 ± 0.7	1.7 ± 0.5 a
	HPMC	1.6 ± 0.4	1.4 ± 0.1 b
	ASC	1.6 ± 0.4	1.6 ± 0.3 a

All treatments significatively reduced weight loss of fresh-cut 'Coscia' slices during storage. Indeed, after seven and 12 days of storage, the weight loss of untreated fruit was twice as much as coated ones (Table 3). Despite an overall reduced weight loss, a similar effect of all coating treatments in reducing weight loss was significant after seven and 12 days storage, while HPMC was apparently not effective in reducing weight loss during the first five days of storage (Table 3). Xanthan gum coating did not reduce weight loss on fresh-cut pear slices [19].

Fresh-cut 'Coscia' slices treated with ASC retained the highest firmness throughout the sampling periods. Differences among coating treatments became significant after five days of storage. Untreated fruit and those coated with HPMC showed the lowest firmness from five to 12 days after storage (Figure 1).

Table 3. Weight loss (%) of untreated (CTR) fruit slices (Coscia and Abate Fètel) of *Pyrus communis* L. and fruit slices treated with xanthan gum (XAN), hydroxypropyl methylcellulose (HPMC), calcium ascorbate (ASC), when first coated (0) and after storage for 3, 5, 7, 12 days at 4 °C. At each sampling date, different letters indicate substantial changes between treatments. At each sampling date, ns indicate no changes between treatments. *p* ≤ 0.05 was used in the Tukey's test. The data are provided as the mean ± S.E. (*n* = 3).

Cultivar			
Time of Storage (Days)	**Treatment**	**'Coscia'**	**Abate**
0		-	-
3	**CTR**	0.97 ± 0.15 a	0.6 ± 0.19 a
	XAN	0.73 ± 0.12 b	0.10 ± 0.04 b
	HPMC	0.33 ± 0.15 c	0.8 ± 0.34 a
	ASC	0.35 ± 0.28 c	0.2 ± 0.29 b
5	**CTR**	1.33. ± 0.15 a	0.8 ± 0.14 a
	XAN	0.75 ± 0.2 b	0.29 ± 0.08 b
	HPMC	0.90 ± 0.11 b	1.01 ± 0.24 a
	ASC	0.69 ± 0.12 b	0.4 ± 0.19 b
7	**CTR**	1.85 ± 0.15 a	1.3 ± 0.17 a
	XAN	1.0 ± 0.2 b	0.58 ± 0.03 ab
	HPMC	0.90 ± 0.15 b	1.12 ± 0.19 ab
	ASC	0.81 ± 0.15 b	0.6 ± 0.39 b
12	**CTR**	3.80 ± 0.19 a	2.3 ± 0.51 a
	XAN	2.0 ± 0.12 b	1.28 ± 0.02 b
	HPMC	1.9 ± 0.12 b	1.42 ± 0.15 b
	ASC	1.81 ± 0.19 b	1.6 ± 0.21 b
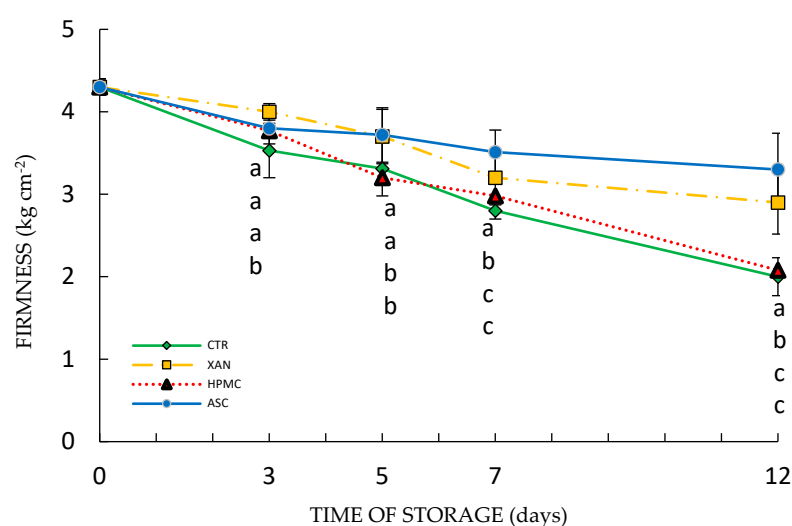
Figure 1. Firmness (kg cm^{-2}) of treated (XAN, HPMC, ASC) and untreated fresh-cut pear slices of *Pyrus communis* L. (Coscia) just after cut (0) and at 3, 5, 7, 12 days of storage at 4 °C. At each sampling date, different letters indicate substantial changes between treatments. At each sampling date, ns indicate no changes between treatments. *p* ≤ 0.05 was used in the Tukey's test. The data are provided as a mean ± S.E. (*n* = 3).

Significant differences in firmness of fresh-cut slices of 'Abate' (Figure 2) began to occur after five days. At this stage and until seven days of storage, the ASC treated fresh-cut slices kept the highest firmness values. However, 12 days after storage, the firmness of both the ASC treatment and the untreated fruit dropped to the lowest values (Figure

2). The delayed softening observed here could be attributable to the higher calcium level in fruit tissue, in addition to the advantage of calcium ascorbate in preventing browning. Calcium (Ca^{2+}) is an important mineral for fruit as it helps to maintain cell wall integrity and fruit quality [36]. While suppressing polygalacturonase (PG) activity, the production of calcium pectates and membrane system stability improved the stiffness of the middle lamella and cell walls [11]. Calcium has been shown to protect and maintain fruit quality by enhancing antioxidant capacity, avoiding softening, and preventing postharvest deterioration [37].
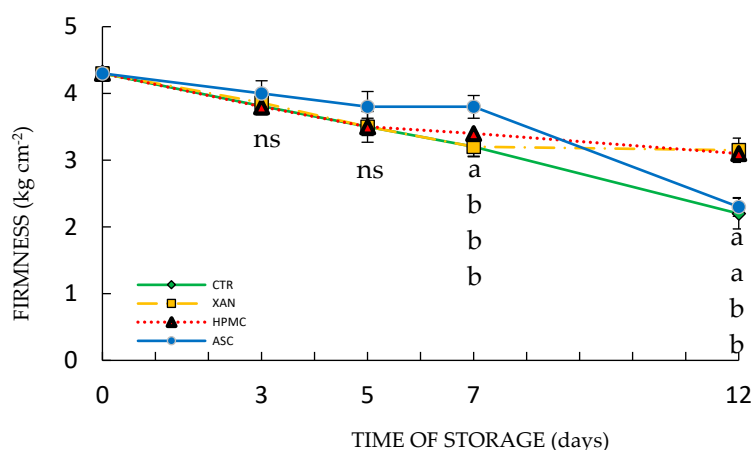
Figure 2. Development of firmness (kg cm^{-2}) of treated (XAN, HPMC, ASC) and untreated fresh-cut slices of *Pyrus communis* L. pear (Abate Fétel) just after cut (0) and at 3, 5, 7, 12 days of storage at 4 °C. At each sampling date, different letters indicate substantial changes between treatments. At each sampling date, ns indicate no changes between treatments. $p \leq 0.05$ was used in the Tukey's test. The data are provided as the mean ± S.E. (*n* = 3).

3.2. Color Loss and Browning Index

Browning of the cut surface is the major issue in the processing and marketing of fresh-cut products like pear. The genotype had a great difference on browning appearance and 'Abate' untreated fresh-cut slices showed significant lower values than 'Coscia' ones, at each sampling date (Figures 3 and 4).
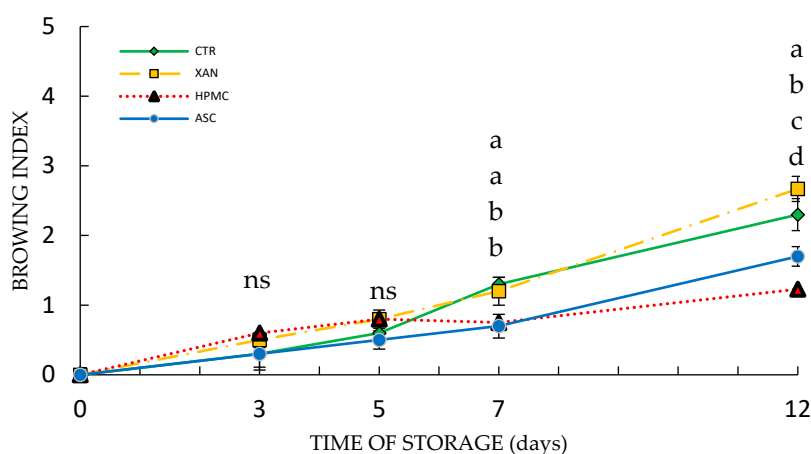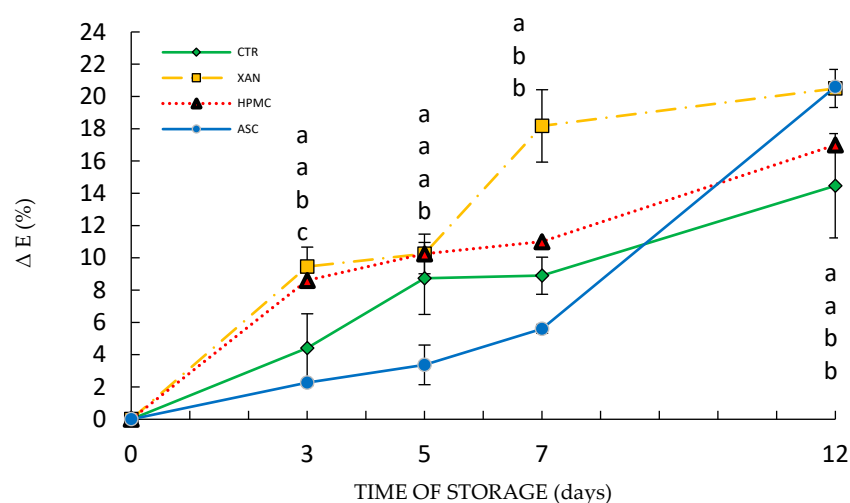

Figure 3. Browning index of treated (XAN, HPMC, ASC) and untreated fresh-cut slices of *Pyrus communis* L. pear (Abate Fétel) just after cut (0) and at 3, 5, 7, 12 days of storage at 4 °C. At each sampling date, different letters indicate substantial changes between treatments. At each sampling date, ns indicate no changes between treatments. $p \leq 0.05$ was used in the Tukey's test. The data are provided as a mean ± S.E. (*n* = 3) average.
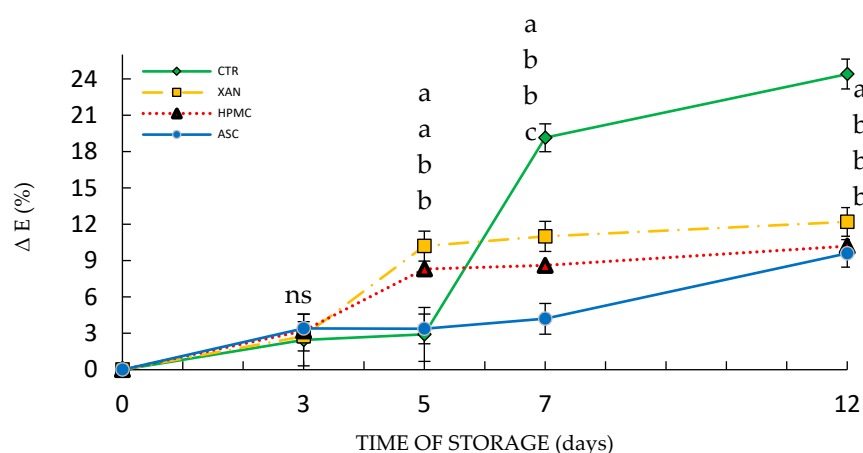
(**a**)

(**b**)
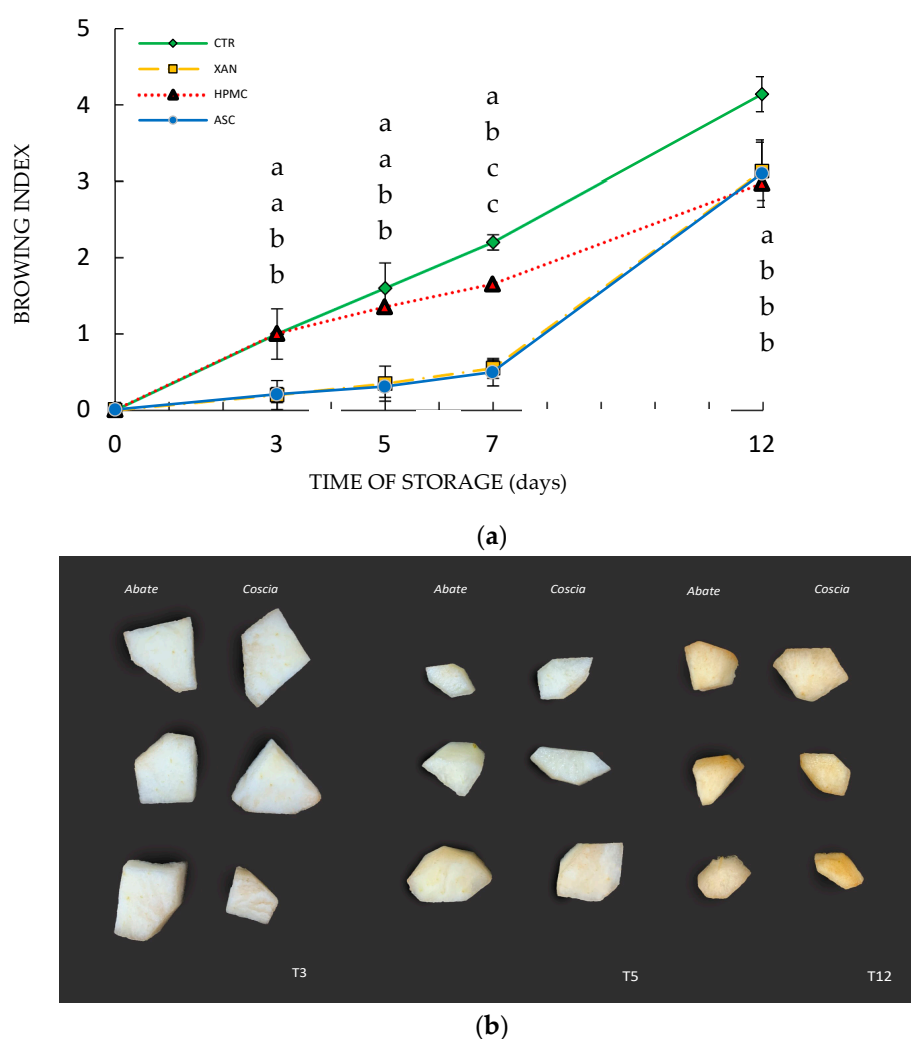
Figure 4. (**a**) The browning index of treated (XAN, HPMC, ASC) and untreated fresh-cut slices of *Pyrus communis* L. pear (Coscia) just after cut (0) and at 3, 5, 7, 12 days of storage at 4 °C. At each sampling date, different letters indicate substantial changes between treatments. At each sampling date, ns indicate no changes between treatments. $p \leq 0.05$ was used in the Tukey's test. The data are provided as a mean ± S.E. ($n = 3$). (**b**) Effect of browning on flesh of the 'Abate Fétel' and 'Coscia' pear *Pyrus communis* L. fresh-cut slices treated with calcium ascorbate (ASC) after 3, 5 and 12 days of storage at 4 °C.

Moreover, significant differences among treatments, in 'Abate' fresh-cut slices, began to occur only seven days after storage. At this stage, the XAN treatment and the untreated ones showed a higher browning index than the ASC and HPMC ones. At 12 days after treatment, the HPMC fruit slices had the lowest browning index, while the XAN ones had the highest (Figure 3). Untreated 'Coscia' fruit slices had the highest browning values at each sampling date, while the ASC and XAN treated slices had the lowest, but at 12 days after storage all coatings showed the same browning index (Figure 4). A similar trend was also confirmed by Sharma et al. [19] on fresh-cut packaged pear treated with xanthan gum for eight days where no significant differences were detected between them and untreated slices until the fifth day of storage at 4 °C. The effect of the coating treatments was significant throughout the sampling dates, even though it appeared controversial and genotype dependent. The 'Coscia' ASC treated slices had the lowest ΔE values until seven days of storage, when they began to change color very sharply (Figure 5).

Figure 5. Color variation (ΔE%) of treated (XAN, HPMC, ASC) and untreated fresh-cut slices of *Pyrus communis* L. pear (Coscia) just after cut (0) and at 3, 5, 7, 12 days of storage at 4 °C. At each sampling date, different letters indicate substantial changes between treatments. At each sampling date, ns indicate no changes between treatments. $p \leq 0.05$ was used in the Tukey's test. The data are provided as a mean ± S.E. (*n* = 3).

A similar result was confirmed by the smooth and uniform texture provided by HPMC with essential oils [22]. Untreated slices showed the lowest ΔE values 12 days after storage. On the other hand, a similar sharp increase in ΔE values occurred in untreated 'Abate' pear seven days after storage, while all coating treatments showed steady values from five to 12 days after storage. Eventually, the ASC treated ones had the lowest values at seven and 12 days after storage (Figure 6). Those results showed the effect of ascorbic acid on reducing leakage rate and the change of color. Indeed, fresh-cut processing causes the disruption of surface cells and injury stress to the underlying tissues. Enzymatic activity rises as a result of increased membrane permeability caused by tissue disturbance, which allows enzymes and substrates that would normally be confined within vacuoles to mix [38].
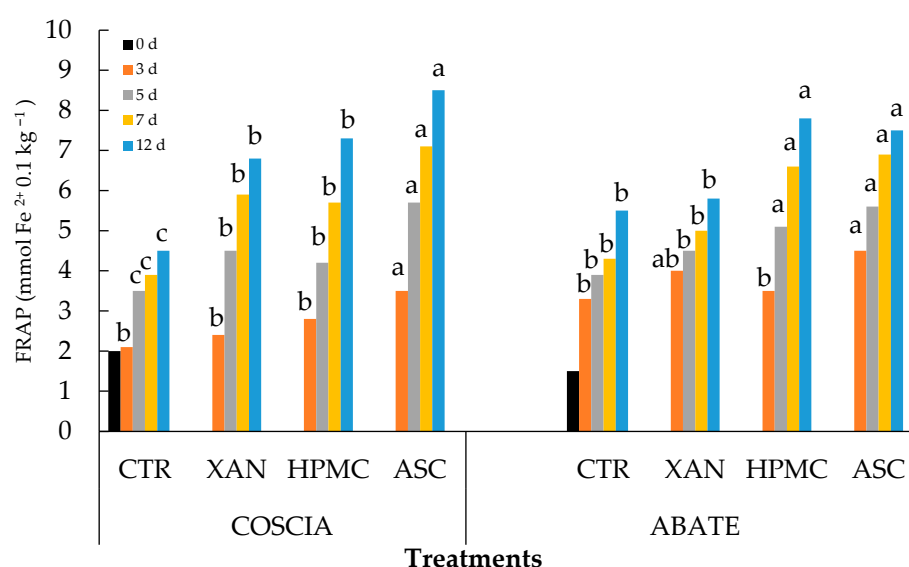

Figure 6. Color variation (ΔE%) of treated (XAN, HPMC, ASC) and untreated fresh-cut slices of *Pyrus communis* L. pear (Abate Fétel) just after cut (0) and at 3, 5, 7, 12 days of storage at 4 °C. At each sampling date, different letters indicate substantial changes between treatments. At each sampling date, ns indicate no changes between treatments. $p \leq 0.05$ was used in the Tukey's test. The data are provided as a mean ± S.E. (*n* = 3).

3.3. ABTS, DPPH, FRAP and Phenols Content

The ABTS, DPPH, FRAP and phenols content increased significatively ($p \leq 0.05$) over time in all treatments, although at different rates (Figures 7–10). The 'Coscia' and 'Abate' fresh-cut slices coated with ASC showed the highest ABTS, FRAP and DPPH values throughout the sampling dates (Figures 7 and 8). In our experiment, the antioxidant activity increased immediately after fresh-cut, and higher wounding, confirming a signal for the stress-induced synthesis of phenolics in plant tissues [39]. Similar results were reported by Li et al. [40] in fresh-cut pitaya fruit; the authors demonstrated that cutting styles did not have much adverse effect on the organoleptic quality, but significantly induced the biosynthesis of phenolic compounds and improved the antioxidant activity of fresh-cut pitaya fruit. Differences between other treatments and the untreated controls did not allow to determine any specific trends or the effect of the treatment itself.
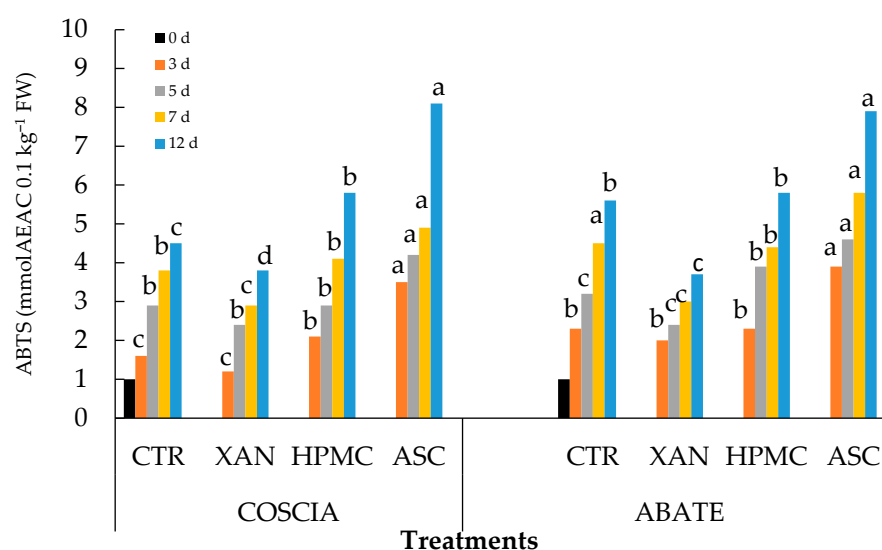
Figure 7. The ABTS (mmol AEAC 0.1 kg^{-1} FW) of treated (XAN, HPMC, ASC) and untreated pear slices of *Pyrus communis* L. (Coscia and Abate Fétel) just after cut (0) and at 3, 5, 7, 12 days of storage at 4° C. At each sampling date, different letters indicate substantial changes between treatments. At each sampling date, ns indicate no changes between treatment. $p \leq 0.05$ was used in the Tukey's test. The data are provided as a mean ± S.E. ($n = 3$).

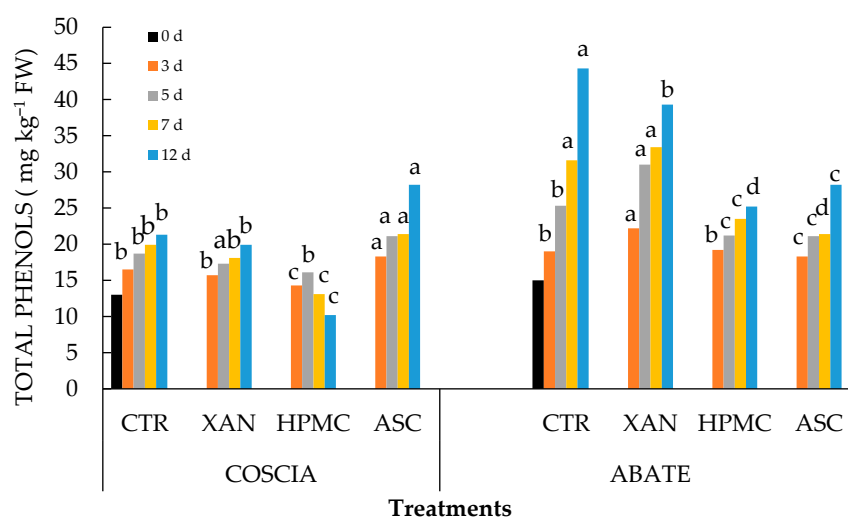**Figure 8.** Ferric ion reducing antioxidant power (FRAP) (mmol Fe²⁺ 0.1 kg⁻¹) of treated (XAN, HPMC, ASC) and untreated slices of *Pyrus communis* L. pear (Coscia and Abate Fétel) just after cut (0) and at 3, 5, 7, 12 days of storage at 4 °C. At each sampling date, different letters indicate substantial changes between treatments. At each sampling date, ns indicate no changes between treatments. $p \leq 0.05$ was used in the Tukey's test. The data are provided as a mean ± S.E. ($n = 3$).
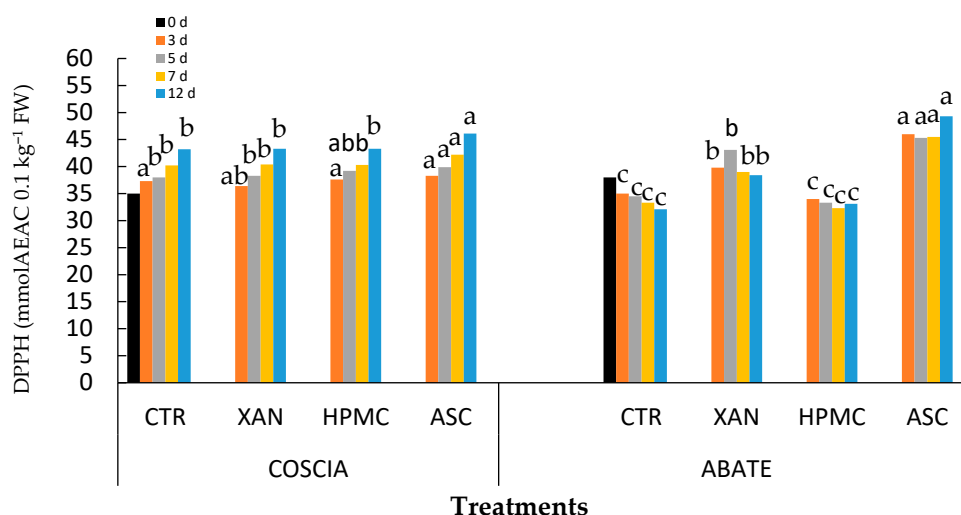
Figure 9. The radical-scavenging activity DPPH (mmolAEAC 0.1 kg⁻¹ FW) of treated (XAN, HPMC, ASC) and untreated slices of *Pyrus communis* L. pear (Coscia and Abate Fétel) just after cut (0) and at 3, 5, 7, 12 days of storage at 4 °C. At each sampling date, different letters indicate substantial changes between treatments. At each sampling date, ns indicate no changes between treatments. $p \leq 0.05$ was used in the Tukey's test. The data are provided as a mean ± S.E. ($n = 3$).

As far as DPPH is concerned, no significant differences occurred between CTR, XAN and HPMC treatments of fresh-cut slices of 'Coscia', but for 'Abate', XAN had higher values than CTR and HPMC on all sampling dates (Figure 9). A similar trend was obtained for five pear fruit cultivars with the DPPH method, where 'Rocha' pear presented the highest radical scavenging activity, followed by 'Comice', 'Abate', 'General Leclerc', and 'Passe Crassane' cultivars. Abiotic stresses that increase the formation of phenylalanine ammonia-lyase (PAL) activity, which is the first stage in phenylpropanoid metabolism, typically cause phenolic content alterations in fresh-cut products [41]. In our work, total phenols in untreated and XAN treated 'Abate' pear slices, had significatively higher values than other treatments at from day five to 12 of storage (Figure 10).

Figure 10. Total phenols content (mg kg^{-1} FW) of treated (XAN, HPMC, ASC) and untreated slices of *Pyrus communis* L. pear (Coscia and Abate Fétel) after just cut (0) and at 3, 5, 7, 12 days of storage at 4 °C. At each sampling date, different letters indicate substantial changes between treatments. At each sampling date, ns indicate no changes between treatments. *p* ≤0.05 was used in the Tukey's test. The data are provided as a mean ± S.E. (*n* = 3).

The total phenols content in fresh-cut slices of 'Coscia' decreased in mean values from five to 12 days storage for the HPMC treated slices. The phenols content increased in untreated and XAN and ASC treated samples during storage time. The increase in the antioxidant capacity may be related to an increase in total phenolic content or stress conditions after cutting [42]. In other work on pear fruit, a significant correlation between phenolic concentration and free radical scavenging activity has been found [43].

3.4. Sensory Analysis

Intrinsic and extrinsic attributes are not the key drivers of liking, on the contrary the sensory attributes are [44]. In our work, at harvest time the sensory analysis showed high values (>8) for all descriptors in both genotypes except for bitterness, sourness, herbaceous and floral odor and flavor (Figures 11 and 12). The SW descriptor decreased over storage time in both genotypes and for all treatments. The fresh-cut pear slices treated with different solutions showed a slower decrease than untreated ones (Figures 11 and 12). In other work, it was shown that the Williams cultivar released a higher sugar content and a typical pear aroma and they were as well perceived by panelists, so they could have influenced the consumer's liking. In other works, different solutions of coating influenced the sweetness in fresh-cut mango fruit.

The rating of most descriptors of untreated (CTR) and coated fruit slices decreased with time (from just cut to 12 days); all coatings had significant higher values than CTR, with no significant differences among treatments. The external color uniformity (ECU) of 'Coscia' and 'Abate' fresh-cut pear slices decreased rapidly during storage with significant differences between treatments. In another work, the percentage of brown area of fresh-cut pear was highly correlated with human visual evaluations [33].

At day 7 and 12 the rating of sourness and bitterness was higher in untreated than in coated fruit (Figure 12).
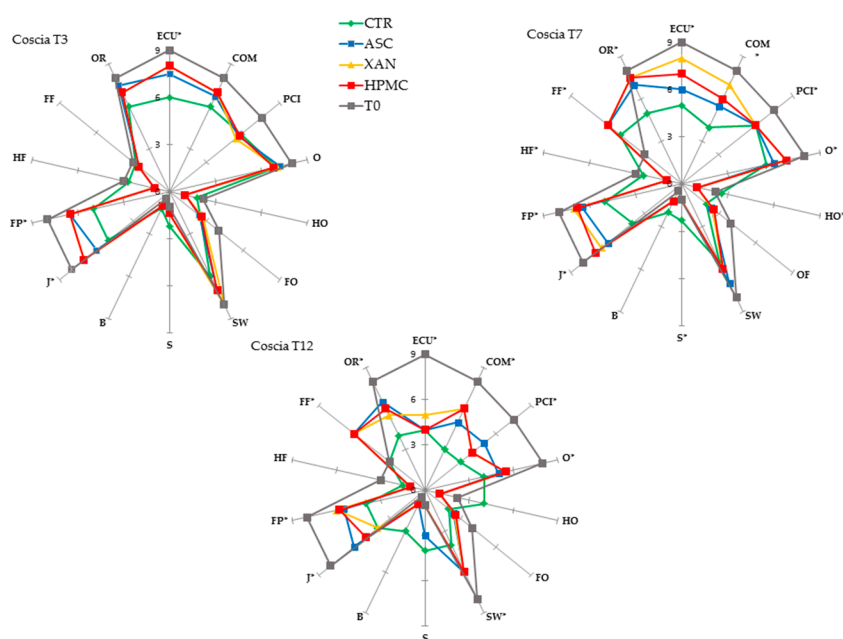
Figure 11. Sensory analysis of treated (XAN, HPMC, ASC) and untreated fresh cut slices of *Pyrus communis* L. pear (Coscia) just after cut (0) and at 3, 7 and 12 days of storage at 4 °C. At each sampling

date, * indicates substantial changes between treatments. At each sampling date, ns indicate no changes between treatments. $p \leq 0.05$ was used in the Tukey's test. Legend: external color uniformity (ECU), compactness (COM), pulp color intensity (PCI), odor (O), herbaceous odor (HO), floral odor (FO), sweetness (SW), sour (S), bitter (B), juiciness (J), pear flavor (PF), herbaceous flavor (HF), floral flavor (FF) and overall rating (O).
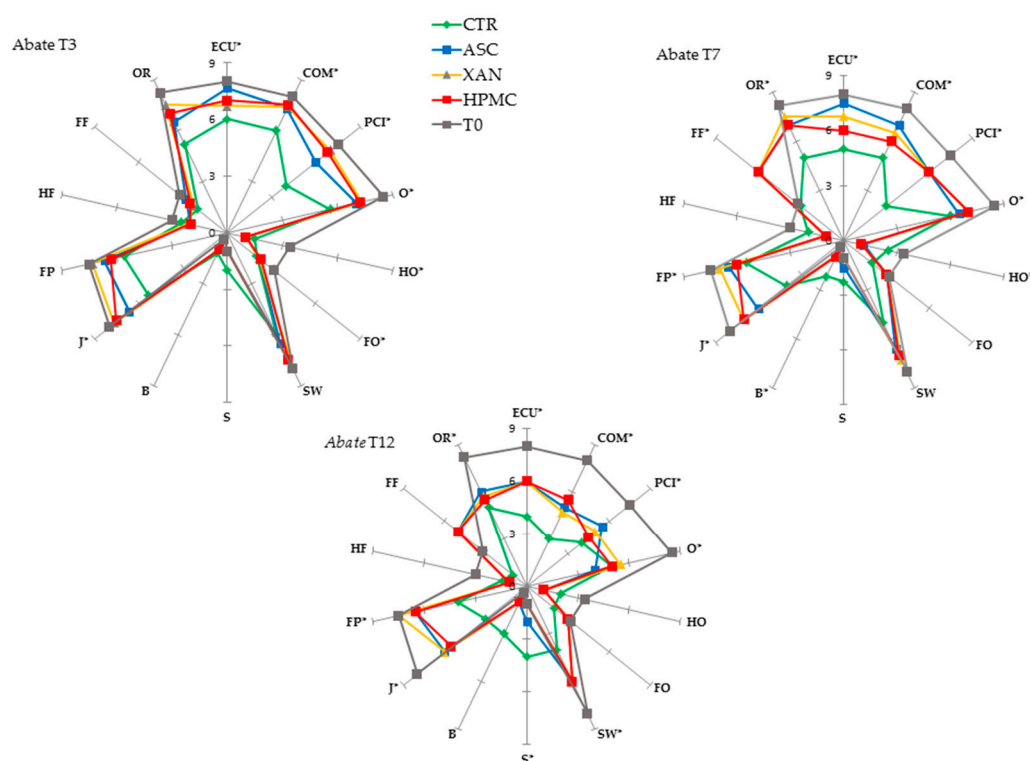
Figure 12. Sensory analysis of treated (XAN, HPMC, ASC) and untreated slices of *Pyrus communis* L. pear (Abate Fétel) just after cut (0) and at 3, 7 and 12 days of storage at 4 °C. At each sampling date, * indicates substantial changes between treatments. At each sampling date, ns indicate no changes between treatments. $p \leq 0.05$ was used in the Tukey's test. Legend: external color uniformity (ECU), compactness (COM), pulp color intensity (PCI), odor (O), herbaceous odor (HO), floral odor (FO), sweetness (SW), sour (S), bitter (B), juiciness (J), pear flavor (PF), herbaceous flavor (HF), floral flavor (FF) and overall rating (O).

In details, the largest differences between CTR and coated fruit at 3, 7 and 12 days occurred for the OR, ECU, COM, FP, J and SW descriptors, in both genotypes. For all of them, the largest differences among treatments occurred in both genotypes at day 7.

Eventually, coating preserved the decay of most descriptors with a limited differences between treatments.

4. Conclusions

Calcium ascorbate is an effective anti-browning agent in fresh-cut 'Abate Fétel' and 'Coscia' pear fruit slices, which would otherwise have a short shelf-life. Other authors have used ascorbic or calcium ascorbate to reduce browning in apples, cherry, persimmons and peach with good results [8,34,45,46]. Calcium ascorbate treatment applied on 'Abate Fétel' and 'Coscia' pear fruit, stored in macro-perforated bags, preserved the flesh color and firmness of pear slices until seven days of storage. Moreover, the addition of calcium ascorbate increased the oxidant activity more than the untreated slices one.

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