Agriculture and Food

AIMS Agriculture and Food, 9(4): 1151–1172.
DOI: 10.3934/agrfood.2024060
Received: 17 July 2024
Revised: 23 October 2024
Accepted: 04 December 2024
Published:18 December 2024

https://www.aimspress.com/journal/agriculture

Research article

Boosting post-harvest quality of 'Coscia' pears: Antioxidant-enriched coating and MAP storage

Ilenia Tinebra[1], Roberta Passafiume[1,*], Alessandra Culmone[1], Eristanna Palazzolo[1], Giuliana Garofalo[1], Vincenzo Naselli[1], Antonio Alfonzo[1], Raimondo Gaglio[1] and Vittorio Farina[1,2]

[1] Department of Agricultural, Food and Forest Sciences (SAAF), Università degli Studi di Palermo, Viale delle Scienze, 90128 Palermo, Italy
[2] Centre for Sustainability and Ecological Transition, University of Palermo, Palermo, Italy

* **Correspondence:** Email: roberta.passafiume@unipa.it; Tel: +3909123896090.

Abstract: This study investigated the effects of combining an edible coating (EC) formulation with modified atmosphere packaging (MAP) on the postharvest quality of Coscia pears (*Pyrus communis* L.). The EC formulation consisted of *Aloe vera* gel, hydroxypropyl methylcellulose (HPMC), ascorbic acid, and citric acid. Pears were sliced and subjected to three treatments: untreated (CTR), EC with MAP1 (70% CO_2 + 30% N_2), and EC with MAP2 (30% CO_2 + 70% N_2). Physicochemical, microbiological, and sensory analyses, as well as assessments of proximate compounds and vitamin content, were conducted over a 9-day storage period at 4 ± 1 °C and 90% ± 5% relative humidity. The results showed that combining EC with MAP significantly reduced juice leakage, delayed browning, and preserved firmness compared to untreated samples. Additionally, MAP treatments, particularly MAP2, improved color stability by minimizing both aerobic and anaerobic respiration. Sensory evaluations indicated that treated samples had superior visual appearance and texture. Microbiological analyses confirmed that all samples maintained high hygienic standards throughout the storage period. Furthermore, mineral and vitamin content analyses demonstrated that EC and MAP treatments helped retain essential nutrients in the pear slices. In conclusion, the combination of EC and MAP effectively extended the shelf-life and preserved the nutritional quality of fresh-cut Coscia pears, offering substantial benefits for both consumers and the food industry.

Keywords: sicily; fresh cut; modified atmosphere packaging; edible coating; pear; postharvest; quality

1. Introduction

The pear (*Pyrus communis* L.) is one of the world's oldest cultivated plants. Of the approximately 2.000 varieties grown globally, India produces some of the most productive [1]. Italy ranks as the second-largest producer, yielding around 900,000 tons annually, second only to China's 11 million tons [2]. Pears are the second most significant temperate fruit after apples, known for their adaptability to a wide range of climates, soils, and altitudes [3]. The Coscia variety, a European pear, is renowned for its crisp, flavorful fruit but is less commercially successful compared to varieties like Butirra, Abate, Spadona, and William. Its smaller size and lower yield limits its marketability [4,5]. While primarily consumed fresh, a significant portion of Coscia pears is processed into juice, marmalade, dried, and canned products, which helps to reduce food waste [6].

Despite these challenges, Coscia pears are rich in antioxidants [7], leading to the development of various technologies aimed at extending their shelf-life. These include edible coatings (EC) [8], modified atmosphere packaging (MAP) [9], and refrigeration [10], all designed to mitigate microbial, chemical, and mechanical damage during postharvest handling and storage [11]. In this context, the food industry and researchers are exploring new techniques to boost consumer demand for ready-to-eat products. The combination of MAP with EC has shown promising effects on the sensory attributes of fruit and consumer preferences [12–14]. Amanatidou et al. (1999) demonstrated the effectiveness of O_2 in delaying enzymatic browning in fruit products. However, improper O_2 concentrations can encourage the growth of pathogenic organisms such as *L. monocytogenes, E. coli*, *Clostridium perfringens,* and *C. botulinum,* potentially leading to fermentation, off-flavors, and odors [16,17]. Oguz-Korkut et al. (2022) reported a reduction in the respiration rate of fresh-cut Deveci pears using MAP.

Optimal modified atmosphere (MA) conditions vary for different types of fresh produce and are generally defined as those that minimize aerobic rates. In addition to O_2 and CO_2, gases like nitrogen are carefully balanced within the packaging [19]. From a microbiological perspective, MAP, particularly with high CO_2 concentrations, can significantly inhibit microbial growth [20]. However, CO_2 can also suppress the natural fruit microflora due to its broad bacteriostatic effect [21]. The introduction of N_2 helps slow the growth of aerobic microorganisms and acts as a barrier to prevent bag collapse [16,22,23].

Edible coatings enhance the external appearance and shine of fruit surfaces while acting as a barrier to gas exchange, thus reducing water loss and vapor droplet formation inside the packaging [24]. Studies confirm that ECs containing plant extracts and plasticizers improve the effectiveness of the treatment [25–30].

To determine whether the respiration rate of fresh-cut pears can be minimized to extend their shelf-life, an experiment was conducted using a gas mixture insufflated into bags designated for fresh-cut pears treated with EC. The fruit slices were stored for nine days at 4 ± 1 °C and at 90% ± 5% relative humidity, simulating typical refrigerator conditions, while their physicochemical, microbiological, and sensory properties were monitored.

2. Materials and methods

2.1. Plant material

Twenty kilograms of Coscia pears (*Pyrus communis* L.) were harvested in Torrenova (ME, Italy) at coordinates 38°05'018.56" N, 14°40'18.08" E. The fruits were selected based on a firmness index

of 4–4.5 kg/cm^2 to ensure uniform maturity. Only pears of similar size and without biotic or abiotic peel alterations were chosen.

2.2. Edible coating (EC) and modified atmosphere packaging (MAP) formulation

The EC formulation was adapted from previous research on fresh-cut pears [31]: 300 mL of H_2O, 120 mL of *Aloe vera* gel (AVG), 4 g of hydroxypropyl-methylcellulose (HPMC), 0.5 g of ascorbic acid, and 0.5 g of citric acid.

All ingredients were diluted in water to maintain sensory acceptability, as higher concentrations resulted in bitterness [32,33]. Two gas mixtures were used to assess the impact of EC on fresh-cut pears: MAP1 (70% CO_2 + 30% N_2) and MAP2 (30% CO_2 + 70% N_2).

2.3. Experimental design

Before the experiment, all utensils and surfaces were cleaned and sterilized. Room temperature was maintained at 4 ± 1 °C to inhibit bacterial growth. Pears were washed under tap water and then immersed in chlorinated water (100 µL/L) for 5 min, following the method described by Arias E. et al. [34]. After air-drying for 20 min, pears were peeled and sliced into quarters using a sterilized stainless-steel knife. The core was removed using a pear corer.

The pears were divided into five lots corresponding to the treatments, with 100 g per bag:

- CTR: No coating; passive MAP = 21% O_2 + 0.04% CO_2 + 78% N_2.
- EC + MAP1: Immersion of the slices into 300 mL H_2O, 120 mL *Aloe vera* gel (AVG), 4 g hydroxypropyl-methylcellulose (HPMC), 0.5 g ascorbic acid, and 0.5 g citric acid and packed with 70% CO_2 + 30% N_2.
- EC + MAP2: immersion of the slices into 300 mL H_2O, 120 mL *Aloe vera* gel (AVG), 4 g hydroxypropyl-methylcellulose (HPMC), 0.5 g ascorbic acid, and 0.5 g citric acid and packed with 30% CO_2 + 70% N_2.

Untreated samples were packed, sealed, and stored according to the protocol. The remaining slices were immersed in the EC solution for 2 min and drained. Each slice was coated with approximately 0.3 mm of the solution and packed in biodegradable bags made of polyamide/polyethylene [PA/PE, 80% PA and 20% PE, 90 µm thickness, 500 cm^3 volume, oxygen permeability = 47.6 cm^2/(m^2·day·atm), and water vapor transmission rate = 3.9 g/(m^2·day·atm)]. Packaged slices underwent MAP treatments using a digitally controlled packaging machine (VM 16 Orved S.p.A, Musile di Piave, Venice, Italy). All bags were stored at 4 ± 1 °C and 90% ± 5% relative humidity.

Physicochemical, microbiological, and sensory analyses, proximate composition, and respiration rates were assessed on day 0 (fresh product), day 3 (d3), day 6 (d6), and day 9 (d9), with three replicates per treatment.

2.4. Physicochemical analyses

2.4.1. Percentage of juice leakage (% JL)

Juice leakage percentage (% JL) was determined by measuring the weight loss of each sample during storage. The bags with pear slices had an initial weight of 100 g, and the weight was recorded

after 3, 6, and 9 days using a digital balance. % JL was calculated using the formula (1):

$$\%JL = [(W1 - W2)/(W1 \times 100)] \quad (1)$$

were *W1* and *W2* represent the initial and final weights of the sample, respectively.

2.4.2. Browning index (BI) and total color difference (ΔE)

A Minolta colorimeter (Chroma Meter CR-400, Konica Minolta Sensing Inc., Tokyo, Japan) was used to determine BI and ΔE. The instrument was calibrated with a standard white plate. BI was calculated using the formula (2) by Ruangchakpet and Sajjaanantakul [35]:

$$(BI) = [100\ (x - 0.31)/0.17] \quad (2)$$

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

ΔE was determined using the formula (3):

$$\Delta E^* = [(L2^* - L1^*)2 + (a2^* - a1^*)2 + (b2^* - b1^*)2]1/2 \quad (3)$$

2.4.3. Total soluble solids content and titratable acidity

The juice extracted from pear slices using a centrifuge (Ariete, Florence, Italy) was analyzed for total soluble solids content (TSSC) and titratable acidity (TA). TSSC, measured in °Brix, was determined with an ATAGO digital refractometer (Atago Co., Ltd., Tokyo, Japan). TA, expressed in grams of malic acid per liter, was measured using a pH meter titrator (Crison Instruments, S.A., Barcelona, Spain).

2.4.4. Firmness (N)

Fruit firmness was measured using a texture analyzer TA.XTplus (Stable Microsystems, Ltd., Surrey, UK) with a 25 kg load cell, 1 mm/s test speed, 75 mm probe (P/75), and 5 g trigger force. Three replicates were conducted for each sample, and results were expressed in Newton (N).

2.5. Microbiological analysis

Samples from pear productions, including edible coating and control, as well as treated samples during refrigerated storage, were serially diluted at 1:10. Edible coating (1 mL) was directly diluted in Ringer's solution (Thermo Fisher Scientific, Inc., Waltham, MA, USA), while pear samples (25 g) were homogenized in 225 mL of Ringer's solution using a stomacher (Bag-Mixer 400, Interscience, Saint Nom, France) for 3 min at blending power 4. Serial dilutions were plated on agar media to monitor total mesophilic microorganisms, spoilage organisms (*Pseudomonas* spp., yeasts, and molds), and pathogens (Enterobacteriaceae, *Escherichia coli*, coagulase-positive staphylococci (CPS), *Listeria monocytogenes*, and *Salmonella* spp.) following the method of Passafiume et al. [31]. Plate counts were performed in triplicates for all samples at each sampling time.

2.6. Mineral and vitamin content

The contents of Ca, Mg, K, and Na were determined using atomic absorption spectroscopy

following wet mineralization [36,37]. P was measured using a colorimetric method [38]. Riboflavin (vitamin B2) was extracted in an autoclave with diluted H_2SO_4 and, after enzymatic treatment, determined via HPLC. For ascorbic acid (vitamin C) analysis, the dried methanolic extract (100 mg) was extracted with 10 mL of 1% metaphosphoric acid for 45 min at room temperature and filtered through Whatman No. 4 filter paper. The filtrate (1 mL) was mixed with 9 mL of 2.6–dichlorophenolindophenol, and absorbance was measured at 515 nm within 30 min against a blank. Ascorbic acid content was calculated using a calibration curve of L-ascorbic acid (0.02–0.12 mg/mL) [39].

2.7. Sensory analysis

Sensory analysis was conducted over nine days of storage according to ISO 13299 standards [40]. A panel of 11 semi-trained members (6 males, 5 females, aged 25−55) evaluated the pears for flesh color, brightness, herbaceous odor, roughness, texture, stickiness, and gumminess. Assessments were performed in a sensory testing room with individual booths and controlled lighting. The presentation order of samples was randomized, and water was provided for rinsing between samples. Scores ranged from 1 (no descriptor intensity) to 9 (highest descriptor intensity).

2.8. Statistical analysis

Data were presented as mean ± standard deviation. Statistical analysis was performed using XlStat® software version 9.0 (Addinsoft, Paris, France). Analyses included one-way analysis of variance (ANOVA) and Tukey's multiple range test, with significance set at $p < 0.05$. Significant differences between sampling dates for each treatment were denoted by different letters.

3. Results and discussion

3.1. Physicochemical analysis

3.1.1. Percentage of juice leakage

The combination of EC and MAP was shown to significantly reduce juice leakage during cold storage ($p \leq 0.05$), as demonstrated by the findings outlined in Table 1. This reduction can be largely attributed to the polymers in the coating, which, together with the gases present inside the packaging, form an effective barrier that minimizes gas exchange. This barrier is crucial in reducing water loss from fresh-cut samples, a phenomenon supported by previous studies [41]. Such a barrier also restricts the exchange of oxygen and carbon dioxide, leading to a decrease in the respiration rate and overall metabolic activity of the fruit, thereby extending its shelf-life [42]. The protective effect of the EC is further enhanced by the inclusion of *Aloe vera* gel, which, due to its hygroscopic nature, contributes to the stabilization of pectin, a key structural component in the fruit cell walls. *Aloe vera*'s moisture-attracting properties help preserve the fruit's texture and minimize water loss, thus maintaining quality during storage [43].

Table 1. Effect of the treatments on juice leakage (%) of fresh-cut Coscia pears stored at 4 ± 1 °C and 90% ± 5% RH for 9 days. Values are expressed as an average of three measurements. Different lowercase letters indicate significant differences ($p \leqslant 0.05$) between different sampling times for the same treatment; different capital letters indicate significant differences ($p \leqslant 0.05$) between different treatments for the same sampling time.

	%JL during cold storage		
Treatments	3 d	6 d	9 d
CTR	7.92% cA	18.43% bA	26.90% aA
EC + MAP1	7.89% bA	15.66% aB	18.00% aB
EC + MAP2	6.12% bA	15.14% aB	17.72% aB

The incorporation of ascorbic and citric acids in the EC formulation also plays a supportive role, particularly in helping the coating adhere more effectively to the fruit's surface. While these acids do not directly alter storage conditions, they contribute to the stability of the coating components, ensuring that the protective film remains intact throughout the storage period [44]. Furthermore, the modified atmosphere within the packaging material enhances the moisture retention rate of the fruit, limiting oxidative processes that would otherwise lead to rapid spoilage. In addition to reducing respiration, the MAP also plays a critical role in inhibiting microbial growth, thus prolonging the shelf-life of fresh-cut produce by creating an environment that is less favorable for microbial proliferation [45]. Overall, the synergistic effect of EC and MAP not only reduces water loss and juice leakage but also extends storage life by controlling respiration, limiting microbial spoilage, and maintaining the structural integrity of the fruit [46–49].

3.1.2. Browning index and total color difference

The change in color during cold storage is a critical factor influencing consumer preferences and product acceptance, as it is often the first quality attribute assessed [50]. In this study, over the 9-day cold storage period, the CTR samples demonstrated the most pronounced increase in browning value (21.26%), likely due to the absence of inhibitors for polyphenol oxidase (PPO) activity [51].

Results indicate that treatments with EC and a mix of N_2 and CO_2 in the bags tend to delay changes in the browning index (33.13% in EC + MAP1 and 24.65% EC + MAP2).

Browning in fruits is primarily driven by enzymatic oxidation, where PPO catalyzes the oxidation of phenolic compounds to quinones, which subsequently polymerize into brown pigments (Figure 1). This enzymatic browning is a major quality concern in fresh-cut fruit, as it directly impacts visual appeal and marketability [52]. The significant browning observed in the CTR samples compared to the treated samples ($p \geq 0.05$) underscores the efficacy of interventions such as EC and MAP in mitigating color degradation. It is likely that the EC used in conjunction with the MAP treatment interacts directly with the pear's PPO, reducing activity. Research by Yu K. et al. [53] indicates that the PPO of Conference pears has a strong affinity for ascorbic acid, with a Km of 0.55 mM at pH 7.0. Ascorbic acid, commonly used as an antioxidant in EC, can act as a competitive inhibitor of PPO activity, as oxygen is required for the enzymatic oxidation of phenolics [54].

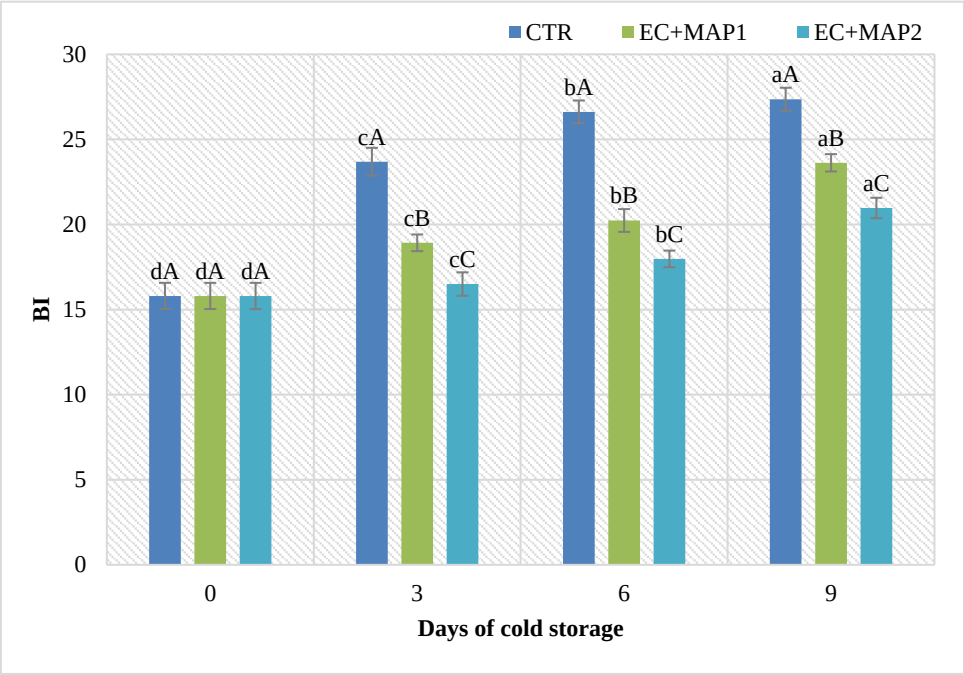

Figure 1. Effect of the treatments on browning index (BI) of fresh-cut Coscia pears stored at 4 ± 1 °C and 90% ± 5% RH for 9 days. Values are expressed as the average of three measurements. Different lowercase letters indicate significant differences ($p \leqslant 0.05$) between different sampling times for the same treatment; different capital letters indicate significant differences ($p \leqslant 0.05$) between different treatments for the same sampling time.

To more thoroughly assess the browning index of fresh-cut pear, the color difference (ΔE) is a valuable metric (Figure 2). The observed color change is influenced by the semi-permeability of cell membranes, where pigment migrations from intercellular space to intracellular fluid alters the refractive index and the visible color of the fruit [49]. Although no significant differences ($p \geq 0.05$) in ΔE were detected across different days of cold storage treatment, there were significant differences ($p \leq 0.05$) between the three treatments on the same day. These differences in color stability are likely attributable to the varying concentration of CO_2 within the MAP treatments. Lower CO_2 concentration in EC + MAP2 may promote oxidative processes at a more controlled rate, while the CTR samples, lacking such protective measures, undergo more rapid oxidative color changes [55].

Previous studies have shown that the combination of EC and MAP can effectively reduce oxygen availability, slow down respiration rates, and consequently delay browning and other oxidative changes in fresh-cut produce [56]. CO_2-enriched atmospheres are known to inhibit microbial growth and slow down enzymatic activity, further contributing to the maintenance of color during storage [57]. The findings of this study are consistent with other research demonstrating the role of MAP in controlling color changes and browning in minimally processed fruits, thus extending the shelf life and maintaining quality [58].

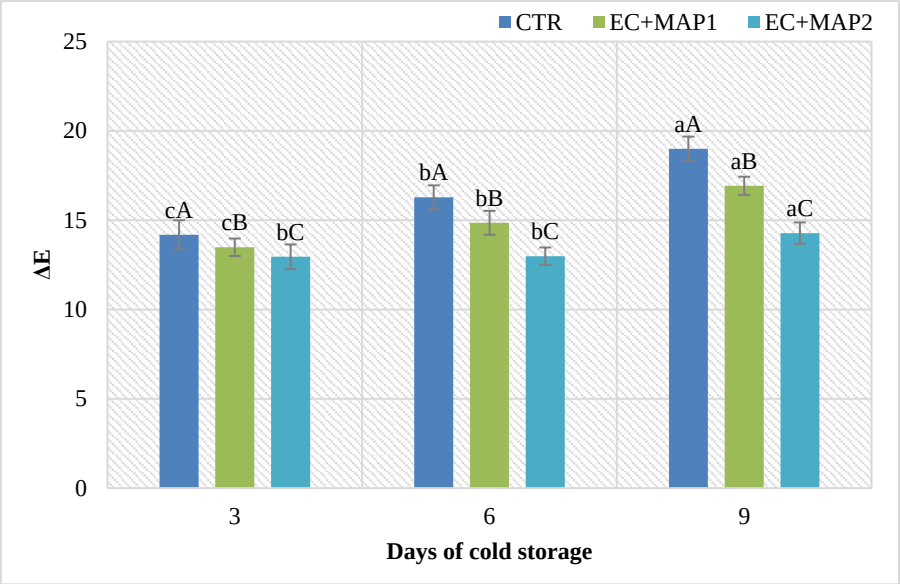

Figure 2. Effect of the treatments on color variation (Δ E) of fresh-cut Coscia pears stored at 4 ± 1 °C and 90% ± 5% RH for 9 days. Values are expressed as the average of three measurements. Different lowercase letters indicate significant differences ($p \leqslant 0.05$) between different sampling times for the same treatment; different capital letters indicate significant differences ($p \leqslant 0.05$) between different treatments for the same sampling time.

3.1.3. Total soluble solids content and titratable acidity

As shown in Figure 3, the total soluble solids content (TSSC) increases during cold storage. Statistical analysis indicates that the EC and MAP significantly affect the maintenance of TSSC levels. Notably, significant differences ($p \leq 0.05$) were observed in the EC+MAP1 treatment starting from day 6 compared to day 0. In fact, the two treatments significantly inhibited the loss of TSSC and TA contents, while for the untreated sample (CTR), significant differences were evident on the third day of analysis (day 3). As a climacteric fruit, pears naturally exhibit fluctuations in soluble solids content due to the hydrolytic conversion of polysaccharides to sugars [59]. This study found that softening was delayed during cold storage due to the presence of HPMC, according to a previous study [31]. In another study, Wong et al. (1994) [60] reported that EC was involved in the physiological processes, and thus, this seems to play an essential role in the structural maintenance of membranes and cell walls [61]. On the other hand, the high concentration of CO_2 in the package likely enhanced the conversion of sugars to organic acids [57]. Moreover, Siddiq et al. (2020) [62] and Gomes et al. (2012) [63] reported that the MAP treatment did not affect quality characteristics such as TSS and TA during storage.

Figure 4 illustrates the response of fruits to treatments during cold storage, showing a decrease in acidity for both untreated and treated samples: 75.76% in CTR, 42.42% in EC + MAP1, and 37.88% in EC + MAP2. Organic acids, the main respiratory substrates for pear slices, demonstrate a respiratory quotient of 1.38 [58]. The greater reduction in acidity in the CTR samples is likely due to the development of anoxic conditions [64]. This decrease may also be related to a physiological maturation process, where an increase in sugars corresponds to a decrease in titratable acidity (TA), consistent

with the findings of Mg AE-G. et al. (2019) [65]. Moreover, the rapid decline in TA in pears is associated with accelerated fruit senescence [66]. The smaller reduction in EC + MAP2 is probably due to the combined effect of MAP2 and EC, which helps maintain the integrity of cell membrane pectins [67].

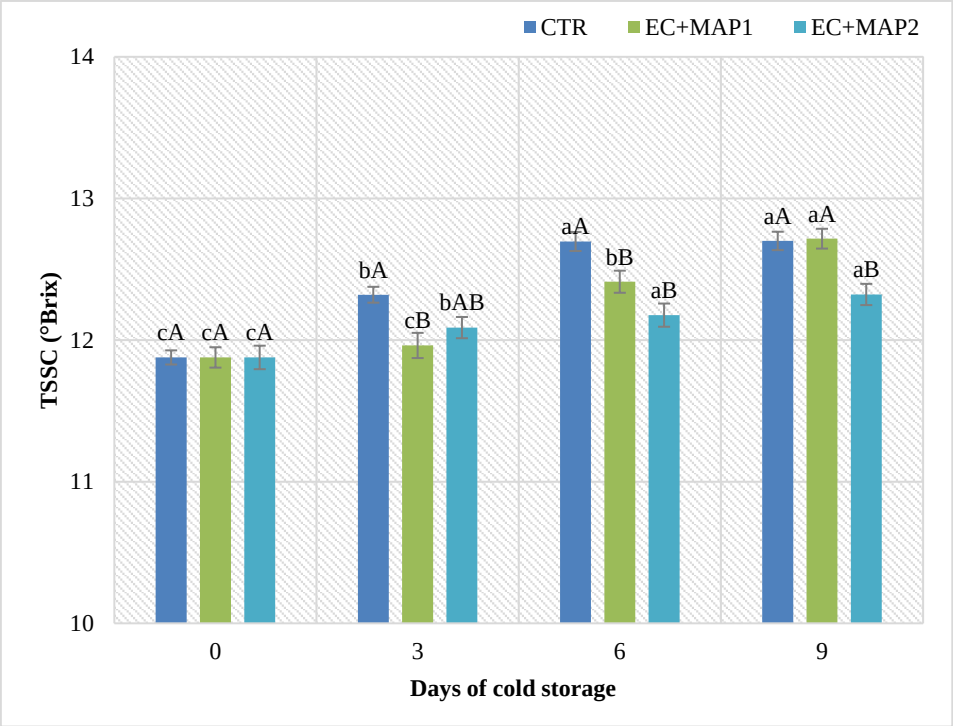

Figure 3. Effect of the treatments on total soluble solids content (TSSC) parameter of fresh-cut Coscia pears stored at 4 ± 1 °C and 90% ± 5% RH for 9 days. Values are expressed as the average of three measurements. Different lowercase letters indicate significant differences ($p \leqslant 0.05$) between different sampling times for the same treatment; different capital letters indicate significant differences ($p \leqslant 0.05$) between different treatments for the same sampling time.

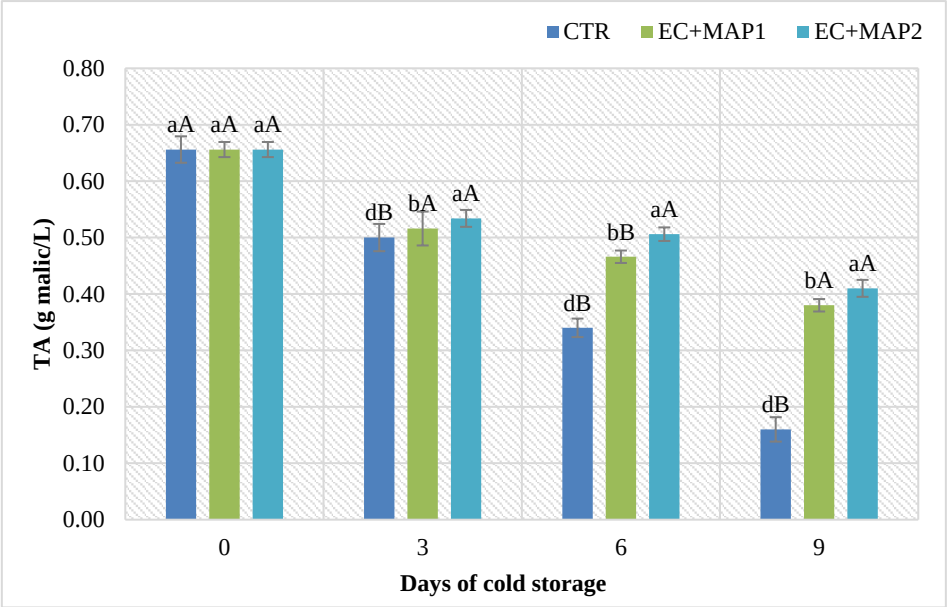

Figure 4. Effect of the treatments on titratable acidity (TA) parameter of fresh-cut Coscia pears stored at 4 ± 1 °C and 90% ± 5% RH for 9 days. Values are expressed as the average of three measurements. Different lowercase letters indicate significant differences ($p \leqslant 0.05$) between different sampling times for the same treatment; different capital letters indicate significant differences ($p \leqslant 0.05$) between different treatments for the same sampling time.

3.1.4. Firmness

The firmness of fresh-cut produce is a key indicator of quality, and in this study, untreated samples experienced a more rapid decline of this parameter (32.43%) compared to those treated with EC and stored in MAP, which showed reductions of 22.43% and 18.91%, respectively (Figure 5). This accelerated softening in untreated samples is likely due to the normal metabolic activities of the fruit, which lead to a loss of cell turgor, degradation of cell wall polysaccharides, and subsequent tissue softening [68]. During storage, the breakdown of pectin and hemicellulose is associated with the loosening of cell wall structure, which contributes to the observed reduction in firmness [69]. No significant differences were observed among the treated samples over the 9-day storage period ($p = 0.42257$), suggesting that both the EC and MAP treatments helped to maintain fruit texture. However, significant differences were found between the CTR and the EC + MAP2 treatments on day 6 ($p = 0.00441$) and day 9 ($p = 0.01077$), indicating that the combination of EC and MAP provided better firmness retention over time, while there was no significant difference between CTR and EC + MAP1 ($p = 0.10650$). This effect may be due to the PA/PE packaging used, which may have contributed to this effect by permitting adequate gas exchange with the environment, thus preventing excessive anaerobic conditions that can lead to tissue softening [45].

Packaging materials with controlled permeability are known to regulate the exchange of gases like oxygen (O_2) and carbon dioxide (CO_2), which can modulate respiration rates and help preserve firmness in fresh-cut fruits [70]. The ability of MAP to maintain firmness can also be linked to its impact on the fruit's internal atmosphere. Low O_2 levels, as shown by Zhang, Y. [71], can reduce

respiration rates and slow the enzymatic activity responsible for cell wall degradation, such as pectinases and cellulases. Reduced oxygen availability delays the breakdown of structural carbohydrates, thus helping to preserve cell turgor and firmness during storage [72]. Moreover, CO_2-enriched atmospheres can inhibit ethylene production and sensitivity, which are closely associated with the softening process in climacteric fruits like pears [73].

Previous research supports these findings, indicating that the combination of EC and MAP can effectively reduce moisture loss and limit metabolic activity, both of which contribute to maintaining fruit firmness [74]. In addition to controlling respiration, the use of EC forms a semi-permeable barrier that minimizes water loss and reduces enzymatic breakdown of cell wall components, further contributing to the retention of firmness [75]. These effects have been documented in other studies on fresh-cut fruits, where the application of EC and MAP treatments extended shelf life by maintaining textural integrity and reducing the rate of softening [76].

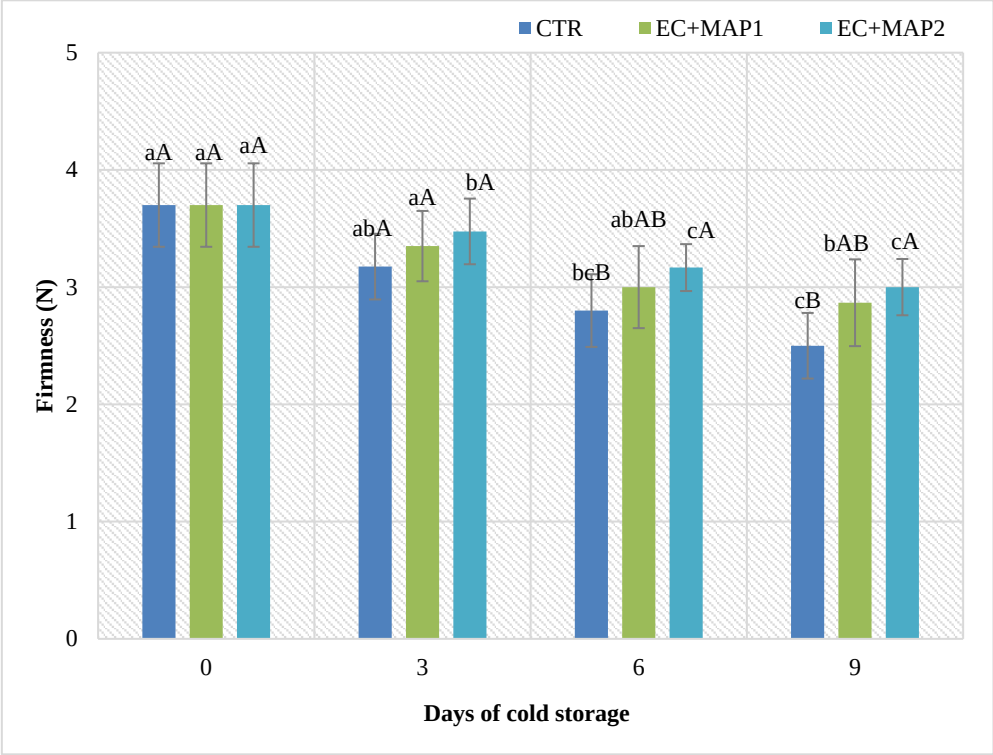

Figure 5. Effect of the treatments on firmness (N) parameter of fresh-cut Coscia pears stored at 4 ± 1 °C and 90% ± 5% RH for 9 days. Values are expressed as the average of three measurements. Different lowercase letters indicate significant differences ($p \leqslant 0.05$) between different sampling times for the same treatment; different capital letters indicate significant differences ($p \leqslant 0.05$) between different treatments for the same sampling time.

3.2. Microbiological analysis

Assessing the microbiological aspects during refrigerated storage of fresh-cut fruits is crucial for predicting their quality and safety [77]. In this study, ready-to-eat pear samples treated with edible coating (EC), untreated (CTR), and EC combined with MAP (EC + MAP1 and EC + MAP2) were

analyzed to detect key undesirable microbial populations commonly associated with horticultural products [78].

The presence of pseudomonads, yeasts, or molds, responsible for microbial spoilage of fruit commodities [79], and pathogenic bacteria such as *E. coli*, CPS, *L. monocytogenes,* and *Salmonella* spp., responsible for foodborne diseases associated with the consumption of fresh fruit and vegetables [80], were below the detection limit in all analyzed samples throughout the entire period of analysis (results not shown).

These findings align with those reported by Passafiume et al. [31] in both uncoated and coated fresh-cut Italian pears (*Pyrus communis* L.) using two different *Aloe vera* gel-based edible coatings. The absence of spoilage and pathogenic microorganisms in all analyzed samples is likely due to the presence of organic acids such as citric acid, malic acid, oxalic acid, quinic acid, and shikimic acid, naturally found in pears [81]. Additionally, adherence to high hygienic standards during postharvest operations likely contributed to inhibiting the growth and survival of undesirable microorganisms in both CTR and treated fresh-cut pear fruits.

3.3. Mineral and vitamin content

The concentration of chemical components in fruits is crucial due to their impact on the fruit's organoleptic properties [7]. Potassium (K) is the most abundant mineral, followed by phosphorus (P), magnesium (Mg), and calcium (C) [82]. Studies have shown that MAP can help retain potassium in fruits during storage [83]. Potassium is vital for cardiovascular health, making its preservation essential for maintaining the fruit's nutritional quality. Calcium, important for bone health, was relatively high in the Coscia variety studied here compared to USDA Data. Table 2 indicates no significant differences in mineral content between treatments or during storage.

Table 2. Effect of the treatments on the mineral content of fresh-cut Coscia pears stored at 4 ± 1 °C and 90% ± 5% RH for 9 days. Values are expressed as the average of three measurements. ns = not significant ($p \leq 0.05$).

Treatments	Day of cold storage	Ca	Mg	K	Na	P
		mg%d.m.	mg%d.m.	mg%d.m.	mg%d.m.	mg%d.m.
CTR	0	11.00 ± 0.05^{ns}	7.00 ± 0.02^{ns}	127.00 ± 5.00^{ns}	2.02 ± 0.01^{ns}	15.00 ± 0.04^{ns}
	3	11.05 ± 0.05^{ns}	7.01 ± 0.03^{ns}	127.11 ± 5.00^{ns}	2.00 ± 0.02^{ns}	15.01 ± 0.05^{ns}
	6	10.86 ± 0.03^{ns}	6.43 ± 0.03^{ns}	130.00 ± 6.00^{ns}	1.90 ± 0.02^{ns}	15.12 ± 0.03^{ns}
	9	10.70 ± 0.06^{ns}	6.45 ± 0.04^{ns}	130.04 ± 7.00^{ns}	1.89 ± 0.04^{ns}	15.14 ± 0.04^{ns}
EC + MAP1	0	11.00 ± 0.05^{ns}	7.00 ± 0.02^{ns}	127.00 ± 5.00^{ns}	2.00 ± 0.01^{ns}	15.00 ± 0.04^{ns}
	3	10.90 ± 0.03^{ns}	7.05 ± 0.03^{ns}	127.02 ± 4.02^{ns}	2.20 ± 0.02^{ns}	15.03 ± 0.04^{ns}
	6	11.02 ± 0.02^{ns}	6.89 ± 0.04^{ns}	126.77 ± .01^{ns}	2.05 ± 0.02^{ns}	15.10 ± 0.02^{ns}
	9	11.01 ± 0.03^{ns}	7.02 ± 0.03^{ns}	126.80 ± 3.00^{ns}	2.04 ± 0.04^{ns}	15.13 ± 0.03^{ns}
EC + MAP2	0	11.00 ± 0.05^{ns}	7.00 ± 0.02^{ns}	127.00 ± 5.01^{ns}	2.00 ± 0.01^{ns}	15.00 ± 0.04^{ns}
	3	11.10 ± 0.02^{ns}	7.01 ± 0.03^{ns}	127.00 ± 4.0.1^{ns}	2.02 ± 0.01^{ns}	15.07 ± 0.02^{ns}
	6	11.06 ± 0.02^{ns}	7.07 ± 0.03^{ns}	127.04 ± 3.00^{ns}	2.02 ± 0.03^{ns}	15.05 ± 0.03^{ns}
	9	11.03 ± 0.02^{ns}	7.04 ± 0.04^{ns}	127.08 ± 4.03^{ns}	2.05 ± 0.02^{ns}	15.05 ± 0.01^{ns}

Vitamin C is a key antioxidant in fresh-cut pears, prone to degradation during postharvest handling [84]. Factors such as oxygen exposure, light, and processing can reduce vitamin C levels, impacting the fruit's overall antioxidant capacity [85]. The Coscia pears exhibited higher vitamin C content in this study compared to previous studies on different cultivars [86]. The data show greater vitamin C losses in the untreated control (CTR) samples.

Vitamin C content is closely linked to enzymatic browning in fruits like pears and apples [87–89]. Browning begins once vitamin C levels fall below a certain cultivar-dependent threshold. By comparing Table 3 with Figure 1 (browning index), it is clear that CTR fruits experienced more browning than treated fruits. Additionally, the vitamin C concentration remained higher in MAP2-treated fruits throughout the storage period, likely due to the lower CO_2 concentration, which influences browning, as reported in the literature [90].

Table 3. Effect of the treatments on the titratable acidity (TA) parameter of fresh-cut Coscia pears stored at 4 ± 1 °C and 90% ± 5% RH for 9 days. Values are expressed as the average of three measurements. Different lowercase letters indicate significant differences ($p \leq 0.05$) between different sampling times for the same treatment; different capital letters indicate significant differences ($p \leq 0.05$) between different treatments for the same sampling time. n.d. = not detectable. ns = not significant ($p \leq 0.05$).

Treatments	Day of cold storage	Ascorbic acid vitamin C	Riboflavin vitamin B2
		mg%	mg%
	0	4.85 ± 0.5^{aA}	0.03 ± 0.01^{ns}
	3	4.31 ± 0.4^{aA}	0.02 ± 0.01^{ns}
CTR	6	3.21 ± 0.5^{bB}	n.d
	9	2.56 ± 0.5^{bB}	n.d
EC + MAP1	0	4.85 ± 0.5^{aA}	0.03 ± 0.01^{ns}
	3	5.12 ± 0.7^{aA}	0.01 ± 0.02^{ns}
	6	5.00 ± 0.7^{aA}	0.02 ± 0.01^{ns}
	9	4.75 ± 0.5^{aA}	0.03 ± 0.03^{ns}
EC + MAP2	0	4.85 ± 0.5^{aA}	0.03 ± 0.01^{ns}
	3	5.22 ± 0.5^{aA}	0.04 ± 0.01^{ns}
	6	5.11 ± 0.5^{aA}	0.01 ± 0.02^{ns}
	9	5.10 ± 0.5^{aA}	0.02 ± 0.04^{ns}

3.4. Sensory analysis

As shown in Figure 6, fresh pears at day 0 received the highest scores for flesh color and texture (8).

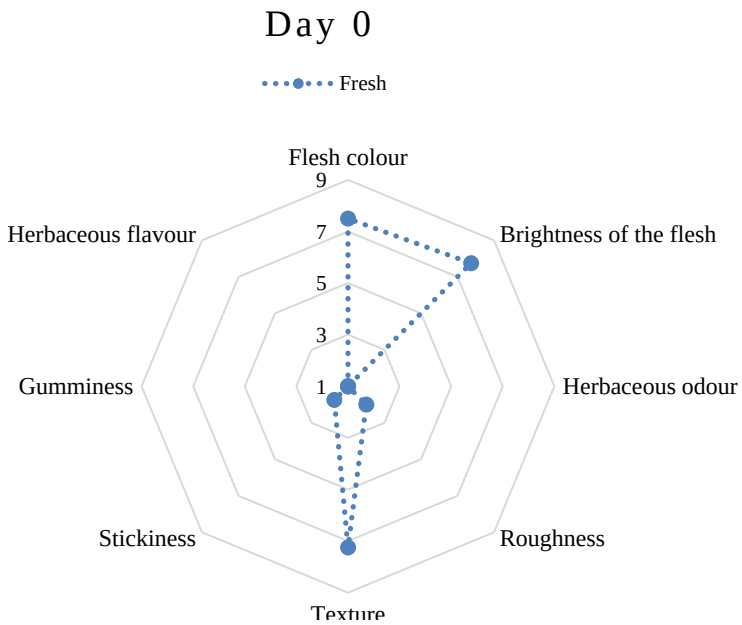

Figure 6. Sensory analysis of treated and untreated fresh-cut pears at day 0 of storage at 4 ± 1 °C and 90% ± 5% RH. Values are expressed as average.

After 3 days of storage (Figure 7), differences between the CTR and treated samples became noticeable. Both treatments (EC + MAP1 and EC + MAP2) maintained high scores for texture (7) and for flesh color and gloss (8). Conversely, CTR samples began to show signs of senescence, such as reduced brightness and flesh color, as confirmed by instrumental analysis.

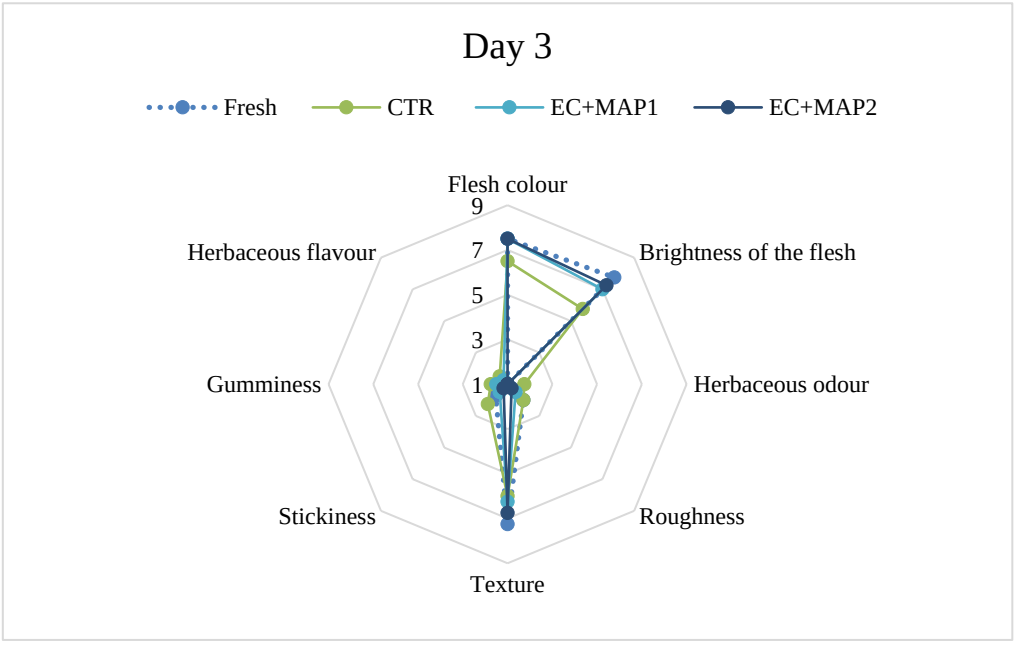

Figure 7. Sensory analysis of treated and untreated fresh-cut pears at day 3 of storage at 4 ± 1 °C and 90% ± 5% RH. Values are expressed as average.

By the sixth day of storage (Figure 8), significant differences between the treatments emerged. CTR samples scored lower for descriptors like flesh color and brightness (4) and exhibited roughness, which was absent in the treated fruits. Treated samples continued to maintain high scores for flesh color and brightness, with EC + MAP2 showing the most favorable outcomes.

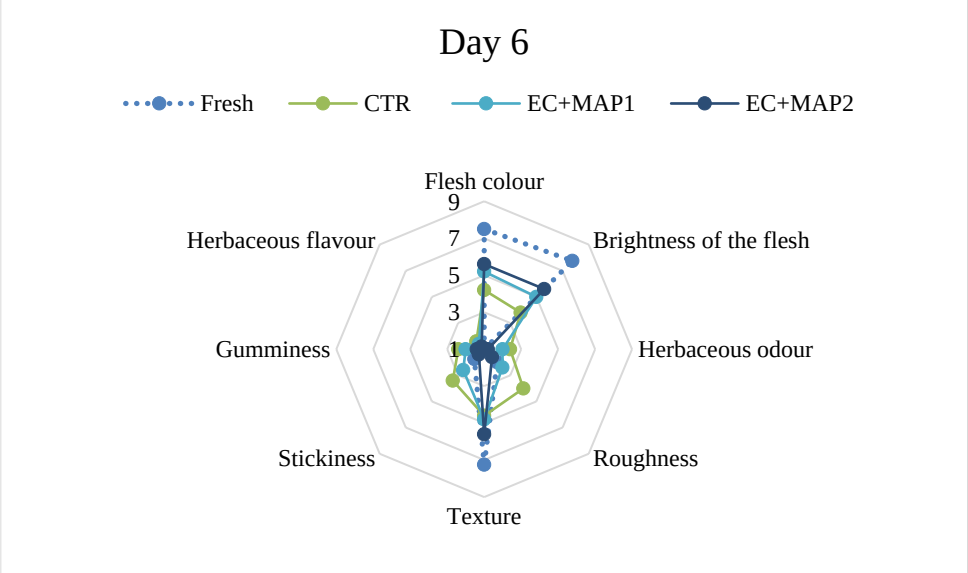

Figure 8. Sensory analysis of treated and untreated fresh-cut pears at day 6 of storage at 4 ± 1 °C and 90% ± 5% RH. Values are expressed as average.

By the final day of storage (Figure 9), EC + MAP2 fruits were evaluated most positively, retaining high values for descriptors such as flesh color and firmness. In contrast, CTR fruits exhibited an herbaceous odor and received a negative evaluation for flesh color and firmness.

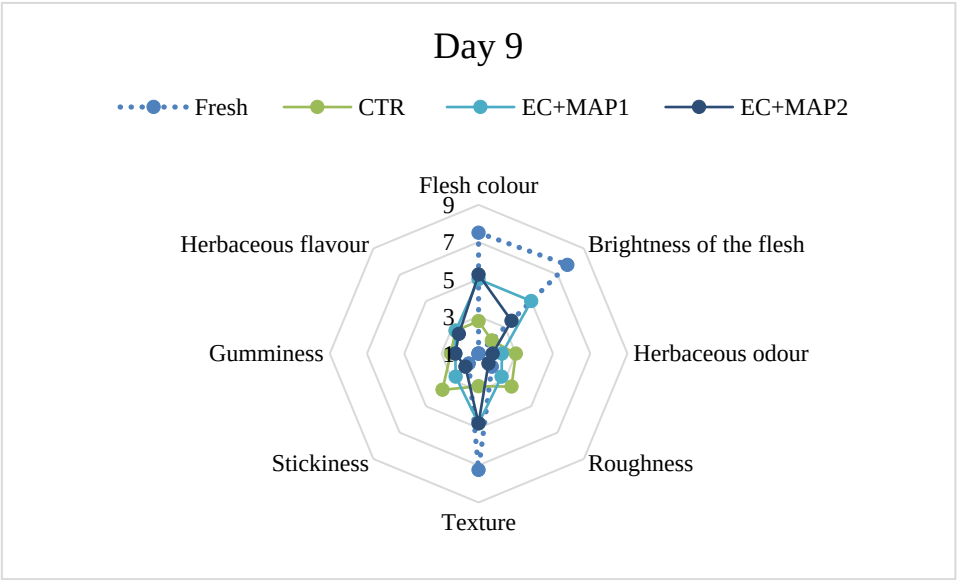

Figure 9. Sensory analyses of treated and untreated fresh-cut pears at day 9 of storage at 4 ± 1 °C and 90% ± 5% RH. Values are expressed as average.

4. Conclusions

The combination of an edible coating (EC) formulation with modified atmosphere packaging (MAP) significantly improves the postharvest quality of Coscia pears.

The study identified several key findings. The application of EC in conjunction with MAP effectively reduced juice leakage, delayed browning, and preserved firmness compared to untreated samples. The EC formulation, which includes *Aloe vera* gel, hydroxypropyl-methylcellulose, ascorbic acid, and citric acid, was instrumental in maintaining the fruit's visual and textural quality throughout storage.

MAP treatments, particularly MAP2 (30% CO_2 + 70% N_2), had a positive effect on the color stability of the pears, minimizing changes over the storage period. This stability was attributed to the balanced gas composition inside the packaging, which reduced both aerobic and anaerobic respiration, thereby slowing metabolic processes and curbing microbial growth.

Sensory analysis confirmed the beneficial impact of EC and MAP on the overall quality of the pears. Panelists reported improvements in visual appearance and texture compared to the untreated samples. Microbiological tests indicated that all samples maintained high hygienic standards throughout storage, further demonstrating the effectiveness of EC combined with MAP in preserving fruit quality. Additionally, analyses of mineral and vitamin content revealed that the EC and MAP treatments helped retain essential nutrients in the pears, thereby enhancing their nutritional value over time.

Overall, these findings suggest that the combination of EC and MAP is a promising strategy for extending the shelf life of fresh-cut Coscia pears while maintaining their nutritional value. This approach offers significant potential benefits for both consumers and the food industry.

Use of AI tools declaration

The authors declare they have not used Artificial Intelligence (AI) tools in the creation of this article.

Acknowledgments

The support for this research was provided through different funding that were used to support and develop different and separate parts of total research. There was no overlap in the use of funds for the same activity. The fundings were: Project PRIMA MEDIET4ALL - "Transnational Movement to Support the Sustainable Transition towards a Healthy and Eco-friendly Agri-Food System through the Promotion of MEDIET and its Lifestyle in Modern Society."– Transnational call PRIMA Partnership for Research and Innovative in the Mediterranean Area - Call 2022, Tematic Area 3-Food value chain: Topic 2.3.1-2022 (RIA) Enabling the transition to healthy and sustainable dietary behaviour. Grant number: B73C23000060001.

Conflict of interest

Vittorio Farina is an editorial board member for AIMS Agriculture and Food and was not involved in the editorial review or the decision to publish this article. All authors declare that there are no competing interests.

Author contributions

Conceptualization, T.I., P.R., G.R.; methodology, T.I., P.R., P.E., G.G., A.A.; chemical analysis, C.A., P.E., N.V.; statistical analysis R.P., C.A.; field sampling and agronomical management, N.V., A.A.; writing—original draft preparation, T.I., P.R., A.A.; writing—review and editing, G.R., F.V.; project administration, A.A.; funding acquisition, A.A., G.R.. All authors have read and agreed to the published version of the manuscript.

References

1. Cyril K, Rahman MM, Singh G, et al. (2023) The impact of pear on nutrition and health: A review. *Energy KJ* 264: 227.
2. FAOSTAT. Available from: https://www.fao.org/faostat/en/#data/QCL.
3. Ozturk A, Faizi ZA (2023) Growth, yield and quality performance of pear (Pyrus communis L.) cv.'Santa Maria'under high density planting. *Braz Arch Biol Technol* 66: e23220414. https://doi.org/10.1590/1678-4324-2023220414
4. Dondini L, Sansavini S (2012) European pear. *Fruit Breed* 369–413. https://doi.org/10.1007/978-1-4419-0763-9_11
5. Guccione E, Allegra A, Farina V, et al. (2023) Use of xanthan gum and calcium ascorbate to prolong cv. Butirra pear slices shelf life during storage. *Adv Hortic Sci* 37: 59–66. https://doi.org/10.36253/ahsc-13872
6. Kolniak-Ostek J (2016) Chemical composition and antioxidant capacity of different anatomical parts of pear (Pyrus communis L.). *Food Chem* 203: 491–497. https://doi.org/10.1016/j.foodchem.2016.02.103
7. Chen J, Wang Z, Wu J, et al. (2007) Chemical compositional characterization of eight pear cultivars grown in China. *Food Chem* 104: 268–275. https://doi.org/10.1016/j.foodchem.2006.11.038
8. Olunusi SO, Ramli NH, Fatmawati A, et al. (2024) Revolutionizing tropical fruits preservation: Emerging edible coating technologies. *Int J Biol Macromol* 264: 130682. https://doi.org/10.1016/j.ijbiomac.2024.130682
9. Tinebra I, Passafiume R, Scuderi D, et al. (2022) Effects of tray-drying on the physicochemical, microbiological, proximate, and sensory properties of white- and red-fleshed loquat (Eriobotrya Japonica Lindl.) fruit. *Agronomy* 12: 540. https://doi.org/10.3390/agronomy12020540
10. Farina V, Sortino G, Saletta F, et al. (2017) Effects of rapid refrigeration and modified atmosphere packaging on litchi (Litchi chinensis Sonn.) fruit quality traits. *Chem Eng* 58: 415–420.
11. Lamani NA, Ramaswamy HS (2023) Composite alginate–ginger oil edible coating for fresh-cut pears. *J Compos Sci* 7: 245. https://doi.org/10.3390/jcs7060245
12. Allegra A, Inglese P, Farina V, et al. (2023) Effects of xanthan gum and calcium ascorbate treatments on color and nutritional quality of fresh cut pear fruit. *ACTA Hortic* 1364: 351–358. https://doi.org/10.17660/ActaHortic.2023.1364.45
13. Just DR, Goddard JM (2023) Behavioral framing and consumer acceptance of new food technologies: Factors influencing consumer demand for active packaging. *Agribusiness* 39: 3–27. https://doi.org/10.1002/agr.21778
14. Zhang H, Gallardo RK, McCluskey JJ, et al. (2010) Consumers' willingness to pay for treatment-induced quality attributes in Anjou pears. *J Agric Resour Econ* 35: 105–117.

15. Amanatidou A, Smid E, Gorris L (1999) Effect of elevated oxygen and carbon dioxide on the surface growth of vegetable-associated micro-organisms. *J Appl Microbiol* 86: 429–438. https://doi.org/10.1046/j.1365-2672.1999.00682.x
16. Farber J, Harris L, Parish M, et al. (2003) Microbiological safety of controlled and modified atmosphere packaging of fresh and fresh-cut produce. *Compr Rev Food Sci Food Saf* 2: 142–160. https://doi.org/10.1111/j.1541-4337.2003.tb00032.x
17. Ares G, Lareo C, Lema P (2007) Modified atmosphere packaging for postharvest storage of mushrooms. A review. *Fresh Prod* 1: 32–40.
18. Oguz-Korkut G, Kucukmehmetoglu S, Gunes G (2022) Effects of modified atmosphere packaging on physicochemical properties of fresh-cut 'Deveci'pears. *J Food Process Preserv* 46: e16002. https://doi.org/10.1111/jfpp.16002
19. Roppolo P, Tinebra I, Passafiume R, et al. (2023) Tray-drying is a new way to valorise white-fleshed peach fruit. *AIMS Agric Food* 8: 944–961. https://doi.org/10.3934/agrfood.2023050
20. Phillips CA (1996) Modified atmosphere packaging and its effects on the microbiological quality and safety of produce. *Int J Food Sci Technol* 31: 463–479. https://doi.org/10.1046/j.1365-2621.1996.00369.x
21. Sandhya (2010) Modified atmosphere packaging of fresh produce: Current status and future needs. *LWT-Food Sci Technol* 43: 381–392. https://doi.org/10.1016/j.lwt.2009.05.018
22. Ahmed M, Yousef AR, Sarrwy S (2011) Modified atmosphere packaging for maintaining quality and shelf life extension of persimmon fruits. *Asian J Agric Sci* 3: 308–316.
23. Ikiz D, Gallardo RK, Dhingra A, et al. (2018) Assessing consumers' preferences and willingness to pay for novel sliced packed fresh pears: A latent class approach. *Agribusiness* 34: 321–337. https://doi.org/10.1002/agr.21532
24. Qu P, Zhang M, Fan K, et al. (2022) Microporous modified atmosphere packaging to extend shelf life of fresh foods: A review. *Crit Rev Food Sci Nutr* 62: 51–65. https://doi.org/10.1080/10408398.2020.1811635
25. Passafiume R, Tinebra I, Gaglio R, et al. (2022) Fresh-cut mangoes: How to increase shelf life by using neem oil edible coating. *Coatings* 12: 664. https://doi.org/10.3390/coatings12050664
26. Piechowiak T, Skóra B (2023) Edible coating enriched with cinnamon oil reduces the oxidative stress and improves the quality of strawberry fruit stored at room temperature. *J Sci Food Agric* 103: 2389–2400. https://doi.org/10.1002/jsfa.12463
27. Kumar P, Kumar L, Tanwar R, et al. (2023) Active edible coating based on guar gum with mint extract and antibrowning agents for ber (Ziziphus mauritiana) fruits preservation. *J Food Meas Charact* 17: 129–142. https://doi.org/10.1007/s11694-022-01609-6
28. Pashova S (2023) Application of plant waxes in edible coatings. *Coatings* 13: 911. https://doi.org/10.3390/coatings13050911
29. Priya K, Thirunavookarasu N, Chidanand DV (2023) Recent advances in edible coating of food products and its legislations: A review. *J Agric Food Res* 12: 100623. https://doi.org/10.1016/j.jafr.2023.100623
30. Pham TT, Nguyen LLP, Dam MS, et al. (2023) Application of edible coating in extension of fruit shelf life: Review. *AgriEngineering* 5: 520–536. https://doi.org/10.3390/agriengineering5010034
31. Passafiume R, Gugliuzza G, Gaglio R, et al. (2021) Aloe-based edible coating to maintain quality of fresh-cut Italian pears (Pyrus communis L.) during cold storage. *Horticulturae* 7: 581. https://doi.org/10.3390/horticulturae7120581

32. Scramin JA, de Britto D, Forato LA, et al. (2011) Characterisation of zein–oleic acid films and applications in fruit coating. *Int J Food Sci Technol* 46: 2145–2152. https://doi.org/10.1111/j.1365-2621.2011.02729.x
33. Benítez S, Achaerandio I, Pujolà M, et al. (2015) Aloe vera as an alternative to traditional edible coatings used in fresh-cut fruits: A case of study with kiwifruit slices. *LWT-Food Sci Technol* 61: 184–193. https://doi.org/10.1016/j.lwt.2014.11.036
34. Arias E, López-Buesa P, Oria R (2009) Extension of fresh-cut "Blanquilla" pear (Pyrus communis L.) shelf-life by 1-MCP treatment after harvest. *Postharvest Biol Technol* 54: 53–58. https://doi.org/10.1016/j.postharvbio.2009.04.009
35. Ruangchakpet A, Sajjaanantakul T (2007) Effect of browning on total phenolic, flavonoid content and antioxidant activity in Indian gooseberry (Phyllanthus emblica Linn.). *Agric Nat Resour* 41: 331–337.
36. Palazzolo E, Letizia Gargano M, Venturella G (2012) The nutritional composition of selected wild edible mushrooms from Sicily (southern Italy). *Int J Food Sci Nutr* 63: 79–83. https://doi.org/10.3109/09637486.2011.598850
37. Morand P, Gullo J (1970) Mineralisation des tissus vegetaux en vue du dosage de P, Ca, Mg, Na, K. *Ann Agron* 21: 229–236.
38. Fogg DN, Wilkinson NT (1958) The colorimetric determination of phosphorus. *Analyst* 83: 406–414. https://doi.org/10.1039/an9588300406
39. Asfaw TB, Tadesse MG, Tessema FB, et al. (2024) Ultrasonic-assisted extraction and UHPLC determination of ascorbic acid, polyphenols, and half-maximum effective concentration in Citrus medica and Ziziphus spina-christi fruits using multivariate experimental design. *Food Chem: X* 22: 101310. https://doi.org/10.1016/j.fochx.2024.101310
40. ISO (International Organisation for Standardisation) (2007) ISO 8589: 2007. Sensory analysis-general guidance for the design of test rooms.
41. Vishwasrao C, Ananthanarayan L (2016) Postharvest shelf-life extension of pink guavas (Psidium guajava L.) using HPMC-based edible surface coatings. *J Food Sci Technol* 53: 1966–1974. https://doi.org/10.1007/s13197-015-2164-x
42. Avcı V, Islam A, Ozturk B, et al. (2023) Effects of Aloe vera gel and modified atmosphere packaging treatments on quality properties and bioactive compounds of plum (Prunus salicina L.) fruit throughout cold storage and shelf life. *Erwerbs-Obstbau* 65: 71–82. https://doi.org/10.1007/s10341-022-00694-7
43. Gorsi FI, Hussain A, Kausar T, et al. (2024) Structural and thermal interaction studies of aloe vera (aloe barbadensis miller) gel powder and developed food bars. *J Therm Anal Calorim* 149: 4543–4559. https://doi.org/10.1007/s10973-024-13007-9
44. Suriati L, Utama IMS, Harsojuwono BA, et al. (2022) Effect of additives on surface tension, viscosity, transparency and morphology structure of aloe vera gel-based coating. *Front Sustain Food Syst* 6: 831671. https://doi.org/10.3389/fsufs.2022.831671
45. Siracusa V (2012) Food packaging permeability behaviour: A report. *Int J Polym Sci* 2012: 302029. https://doi.org/10.1155/2012/302029
46. Liao X, Xing Y, Fan X, et al. (2023) Effect of composite edible coatings combined with modified atmosphere packaging on the storage quality and microbiological properties of fresh-cut pineapple. *Foods* 12: 1344. https://doi.org/10.3390/foods12061344

47. Esmaeili Y, Zamindar N, Paidari S, et al. (2021) The synergistic effects of aloe vera gel and modified atmosphere packaging on the quality of strawberry fruit. *J Food Proc Preserv* 45: e16003. https://doi.org/10.1111/jfpp.16003
48. Ghidelli C, Pérez-GagoMB (2018) Recent advances in modified atmosphere packaging and edible coatings to maintain quality of fresh-cut fruits and vegetables. *Crit Rev Food Sci Nutr* 58: 662–679. https://doi.org/10.1080/10408398.2016.1211087
49. Coskun MG, Omeroglu PY, Copur OU (2017) Increasing shelf life of fruits and vegetables with combined system of modified atmosphere packaging and edible films coating. *Eur J Food Sci Technol* 1: 47–53.
50. Pathare PB, Opara UL, Al-Said FA-J (2013) Colour measurement and analysis in fresh and processed foods: A review. *Food Bioprocess Technol* 6: 36–60. https://doi.org/10.1007/s11947-012-0867-9
51. Awad AHR, Parmar A, Ali MR, et al. (2021) Extending the shelf-life of fresh-cut green bean pods by ethanol, ascorbic acid, and essential oils. *Foods* 10: 1103. https://doi.org/10.3390/foods10051103
52. Huglin MB, Zakaria MB (1983) Comments on expressing the permeability of polymers to gases. *Angew Makromol Chem* 117: 1–13. https://doi.org/10.1002/apmc.1983.051170101
53. Yu K, He W, Ma X, et al. (2024) Purification and biochemical characterization of polyphenol oxidase extracted from wheat bran (Wan grano). *Molecules* 29: 1334. https://doi.org/10.3390/molecules29061334
54. Parry R (2012) Principles and applications of modified atmosphere packaging of foods. Springer Science & Business Media.
55. Wilson MD, Stanley RA, Eyles A, et al. (2019) Innovative processes and technologies for modified atmosphere packaging of fresh and fresh-cut fruits and vegetables. *Crit Rev Food Sci Nutr* 59: 411–422. https://doi.org/10.1080/10408398.2017.1375892
56. Passafiume R, Roppolo P, Tinebra I, et al. (2023) Reduction of pericarp browning and microbial spoilage on litchi fruits in modified atmosphere packaging. *Horticulturae* 9: 651. https://doi.org/10.3390/horticulturae9060651
57. Saeed Khan M, Zeb A, Rahatullah K, et al. (2013) Storage life extension of plum fruit with different colored packaging and storage temperatures. *IOSR J Environ Sci Toxicol Food Technol* 7: 86–93. https://doi.org/10.9790/2402-0738693
58. Goncalves E, Antunes P, Brackmann A (2000) Controlled atmosphere storage of Asian pears cv. Nijisseiki.
59. Kou X, Jiang B, Zhang Y, et al. (2016) The regulation of sugar metabolism in Huangguan pears (Pyrus pyrifolia Nakai) with edible coatings of calcium or Pullulan during cold storage. *Hortic Sci Technol* 34: 898–911. https://doi.org/10.12972/kjhst.20160094
60. Wong DW, Camirand WM, Pavlath AE (1994) Development of edible coatings for minimally processed fruits and vegetables. *Edible Coatings and Films to Improve Food Quality,* US, 65–88.
61. Zheng G, Pan D, Niu X, et al. (2014) Changes in cell Ca^{2+} distribution in loquat leaves and its effects on cold tolerance. *Korean J Hortic Sci Technol* 32: 607–613. https://doi.org/10.7235/hort.2014.13009
62. Siddiq R, Auras R, Siddiq M, et al. (2020) Effect of modified atmosphere packaging (MAP) and NatureSeal® treatment on the physico-chemical, microbiological, and sensory quality of fresh-cut d'Anjou pears. *Food Packag Shelf Life* 23: 100–454. https://doi.org/10.1016/j.fpsl.2019.100454

63. Gomes MH, Fundo JF, Poças MF, et al. (2012) Quality changes in fresh-cut 'Rocha'pear as affected by oxygen levels in modified atmosphere packaging and the pH of antibrowning additive. *Postharvest Biol Technol* 74: 62–70. https://doi.org/10.1016/j.postharvbio.2012.06.014
64. Soliva-Fortuny RC, Grigelmo-Miguel N, Hernando I, et al. (2002) Effect of minimal processing on the textural and structural properties of fresh-cut pears. *J Sci Food Agric* 82: 1682–1688. https://doi.org/10.1002/jsfa.1248
65. Mg AE-G, Zaki ZA, Ekbal ZA (2019) Effect of some postharvest treatments on quality of alphonse mango fruits during cold storage. *Middle East J Agric Res* 8: 1067–1079.
66. Abbasi NA, Iqbal Z, Maqbool M, et al. (2009) Postharvest quality of mango (Mangifera indica L.) fruit as affected by chitosan coating. *Pak J Bot* 41: 343–357.
67. Zhang Y, Kong Q, Niu B, et al. (2024) The dual function of calcium ion in fruit edible coating: Regulating polymer internal crosslinking state and improving fruit postharvest quality. *Food Chem* 447: 138952. https://doi.org/10.1016/j.foodchem.2024.138952
68. Mannozzi C, Tylewicz U, Chinnici F, et al. (2018) Effects of chitosan based coatings enriched with procyanidin by-product on quality of fresh blueberries during storage. *Food Chem* 251: 18–24. https://doi.org/10.1016/j.foodchem.2018.01.015
69. Negi PS, Handa AK (2008) Structural deterioration of the produce: the breakdown of cell wall components. In: *Postharvest Biology and Technology of Fruits, Vegetables, and Flowers* 978: 0–8138.
70. Gontard N, Guillaume C (2010) 16—Packaging and the shelf life of fruits and vegetables. In: *Food Packaging and Shelf Life,* 297. https://doi.org/10.1201/9781420078459-c16
71. Zhang Y (2024) Post-harvest cold shock treatment enhanced antioxidant capacity to reduce chilling injury and improves the shelf life of guava (Psidium guajava L.). *Front Sustain Food Syst* 8: 1297056. https://doi.org/10.3389/fsufs.2024.1297056
72. Watkins, C. B. (2017). Postharvest physiology of edible plant tissues. In: *Fennema's Food Chemistry,* CRC press, 1017–1085.
73. Knee M (1990) Ethylene effects in controlled atmosphere storage of horticultural crops. In: *Food Preservation by Modified Atmospheres,* 225–235.
74. Liao X, Xing Y, Fan X, et al. (2023) Effect of composite edible coatings combined with modified atmosphere packaging on the storage quality and microbiological properties of fresh-cut pineapple. *Foods* 12: 1344. https://doi.org/10.3390/foods12061344
75. Dhall RK (2016) Application of edible coatings on fruits and vegetables. *Imp J Interdiscip Res* 3: 591–603. https://doi.org/10.1002/9781119185055.ch4
76. Sousa-Gallagher MJ, Tank A, Sousa R (2016) Emerging technologies to extend the shelf life and stability of fruits and vegetables. In: *The Stability and Shelf Life of Food,* Woodhead Publishing, 399–430. https://doi.org/10.1016/B978-0-08-100435-7.00014-9
77. Sortino G, Inglese P, Farina V, et al. (2022) The use of opuntia ficus-indica mucilage and aloe arborescens as edible coatings to improve the physical, chemical, and microbiological properties of 'Hayward' kiwifruit slices. *Horticulturae* 8: 219. https://doi.org/10.3390/horticulturae8030219
78. Alegbeleye O, Odeyemi OA, Strateva M, et al. (2022) Microbial spoilage of vegetables, fruits and cereals. *Appl Food Res* 2: 100122. https://doi.org/10.1016/j.afres.2022.100122
79. Karanth S, Feng S, Patra D, et al. (2023) Linking microbial contamination to food spoilage and food waste: The role of smart packaging, spoilage risk assessments, and date labeling. *Front Microbiol* 14: 1198124. https://doi.org/10.3389/fmicb.2023.1198124

80. Leff JW, Fierer N (2013) Bacterial communities associated with the surfaces of fresh fruits and vegetables. *PloS One* 8: e59310. https://doi.org/10.1371/journal.pone.0059310
81. Wu J, Fan J, Li Q, et al. (2022) Variation of organic acids in mature fruits of 193 pear (Pyrus spp.) cultivars. *J Food Compos Anal* 109: 104483. https://doi.org/10.1016/j.jfca.2022.104483
82. Yim S-H, Nam S-H (2016) Physiochemical, nutritional and functional characterization of 10 different pear cultivars (Pyrus spp.). *J Appl Bot Food Qual* 89: 73–81.
83. Artés F, Gómez PA, Artés-Hernández F (2006) Modified atmosphere packaging of fruits and vegetables. *Crit Rev Food Sci Nutr* 28: 1–30.
84. Carr AC, Maggini S (2017) Vitamin C and immune function. *Nutrients* 9: 1211. https://doi.org/10.3390/nu9111211
85. Di Vaio C, Graziani G, Marra L, et al. (2008) Antioxidant capacities, carotenoids and polyphenols evaluation of fresh and refrigerated peach and nectarine cultivars from Italy. *Eur Food Res Technol* 227: 1225–1231. https://doi.org/10.1007/s00217-008-0840-z
86. Ozturk I, Ercisli S, Kalkan F, et al. (2009) Some chemical and physico-mechanical properties of pear cultivars. *Afr J Biotechnol* 8: 687–693.
87. Arora B, Sethi S, Joshi A, et al. (2018) Antioxidant degradation kinetics in apples. *J Food Sci Technol* 55: 1306–1313. https://doi.org/10.1007/s13197-018-3041-1
88. Rojas-Graü M, Soliva-Fortuny R, Martín-Belloso O (2008) Effect of natural antibrowning agents on color and related enzymes in fresh-cut Fuji apples as an alternative to the use of ascorbic acid. *J Food Sci* 73: S267–S272. https://doi.org/10.1111/j.1750-3841.2008.00794.x
89. Lin L, Li Q, Wang B, et al. (2007) Inhibition of core browning in 'Yali' pear fruit by post-harvest treatment with ascorbic acid. *J Hortic Sci Biotechnol* 82: 397–402. https://doi.org/10.1080/14620316.2007.11512250
90. Veltman R, Kho R, Van Schaik A, et al. (2000) Ascorbic acid and tissue browning in pears (Pyrus communis L. cvs Rocha and Conference) under controlled atmosphere conditions. *Postharvest Biol Technol* 19: 129–137. https://doi.org/10.1016/S0925-5214(00)00095-8

AIMS Press