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Original article

Alginate-based coatings charged with hydroxyapatite and quercetin for fresh-cut papaya shelf life

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Summary In this study, the effect of alginate-based coatings charged with quercetin glycoside compounds and hydroxyapatite/quercetin glycoside compounds (HA/QUE) on the microbiological quality, and on bioactive compounds of fresh-cut papaya, was evaluated for 14 days at 6 °C. Alginate coatings with hydroxyapatite/quercetin showed a high capability to slow down the growth of all microbiological parameters investigated. At the end of cold storage, the total bacteria count in papaya samples covered with HA/QUE alginate coating was 4.8 log CFU g^{-1} which is significantly lower ($P < 0.05$) than 8.3 log CFU g^{-1} for uncoated samples. Total carotenoids’ percentage decrease, at the end of storage, was about 20% in papaya with active coatings, with respect to the losses of 39 and 35%, registered in uncoated and alginate-coated samples respectively. Vitamin C content and the antioxidant activity measured in papaya coated with HA/QUE alginate showed significantly higher values ($P < 0.05$) for each storage day than those detected for control- and alginate-coated samples. Based on the sensory evaluation, active-coated fresh-cut papaya reached, at the end of the storage period, suitable values for commercial purposes.

Keywords Active edible coating, antioxidant activity, cold storage, microbial growth, papaya, total carotenoids.

Introduction

Papaya (*Carica papaya* L.) is a fruit native to Central America and widespread in all tropical and subtropical regions (Brazil, Florida, India, Indonesia and Sri Lanka). The demand for ready to eat papaya is increasing, due to the interest of consumers for convenient fruits with high nutritional and healthy properties. However, in minimally processed fruit, the quality decay occurs more rapidly than the whole ones due to the influence of different processing steps during the preparation. The quality losses can be reduced by the application of several preservation techniques such as modified atmospheres packaging and edible coating. Edible coatings (EC) could be an effective method to extend the shelf-life of fresh sliced fruit: They form a thin layer on the surface of the food that can be consumed with it or after their removal; they provide partial moisture, oxygen and carbon dioxide barrier, reduce water loss and slow down fruit ripening (Pinzon *et al*., 2019). Proteins, lipids, polysaccharides and composite materials are the principal substances employed for the production of edible coatings. Sometimes, other compounds showing antimicrobial and antioxidant activity are added in the formulations (Mohamed *et al*., 2020). Different studies investigated the capability of active edible coatings to preserve the quality of fresh-cut fruits during the storage (Hasan *et al*., 2020; Marringgal *et al*., 2020). Among active compounds, quercetin is a phenolic compound showing a strong antioxidant activity due to its capability to reduce the formation of free radicals and pro-inflammatory substances (Xu *et al*., 2019). In addition, it showed antimicrobial activity against spoilage bacteria such as *Pseudomonas fluorescens* (Malvano *et al*., 2021). Since quercetin is a compound sensitive to pH, temperature, light and oxygen, the use of carriers for its controlled release could be useful to overcome the problem of its limited use in foods as ingredient (Silva-Weiss *et al*., 2018). Hydroxyapatite (HA) is a calcium phosphate with numerous characteristics such as biocompatibility, biomimetic dimensions

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and biodegradability (Fulgione *et al.*, 2019). Several techniques were studied to protect the bioactive compounds, such as polymeric nanoparticles, nanoemulsions and nanosystems (Zambrano-Zaragoza *et al.*, 2018). Since HA is able to interact with organic compounds (Malvano *et al.*, 2021), it could be a novel and promising carrier for the release of active substances in the development of edible coatings to apply for the shelf-life extension of minimally processed fruits. Thus, activated edible coatings could be innovative strategies to preserve papayas by controlling fungal rot and post-harvest quality parameters. To the best of our knowledge, for the first time, we were here evaluated the effects of an alginate-based edible coating loaded with quercetin/hydroxyapatite complexes on the shelf-life of fresh-cut fruit (papaya). Physicochemical and microbiological parameters, as well as sensory attributes, have been evaluated during a 14-day storage period at 6 °C.

Material and methods

Materials

Biomimetic hydroxyapatite (HA), in form of colloidal dispersion, was provided by Research and development department (Chemical Center S.r.l., Bologna, Italy). Quercetin glucoside compounds (QUE, 98.6% food grade) were obtained from Oxford® Vitality Company (Biecester, Oxford, UK). Papaya fruits (*C. papaya* L, cv. *Formosa*) were bought from a farm in Palermo (Italy).

Alginate-based coatings

Edible coatings were produced whit the *layer-by-layer* technique, using sodium alginate (1.5% w/v; Sigma Aldrich, Milano, Italy) and $CaCl_2$ (1% w/v; Sigma Aldrich) as negatively and positively charged coating solutions respectively. Coating solutions were prepared in a water solution of sodium alginate and glycerol (2% w/v; Sigma Aldrich) by mixing for 2 h at 70 °C. According to Malvano *et al.* (2022), three different sodium alginate solutions were prepared: control sodium alginate solution (SA), sodium alginate with 500 ppm of quercetin glycosides (QUE) and sodium alginate with hydroxyapatite/quercetin glucosides complexes (HA/QUE) with 500 ppm of quercetin glycosides. HA-QUE complexes were produced by adsorption method, as reported by Montone *et al.* (2021).

Coated fresh-cut papaya

Papayas were selected for ripeness level based on external colour, then washed and hand peeled. The peeled fruits were cut into cubes of approximate 3 cm, then washed in NaClO solution (5% v/v) for 1 min and finally dried with paper. The coating process was carried out according to the *layer-by-layer* technique by dipping papaya cubes into sodium alginate solutions and calcium chloride solution. The dipping time for both solutions was 2 min. After that, the coated samples were air-dried for 5 min and finally packed into food polyethylene terephthalate boxes (13.5 × 12.5 × 5 cm) provided with a lid.

The shelf-life tests were performed by comparing four different fresh-cut papaya samples prepared as below:

- fresh-cut papaya without coating (Control);
- fresh-cut papaya covered by alginate coating (SA);
- fresh-cut papaya covered in alginate coating enriched with QUE (QUE);
- fresh-cut papaya covered in alginate coating enriched with HA/QUE (HA/QUE).

A total of 12 boxes, for each treatment, were prepared and kept at 6 °C for 14 days (Albanese *et al.*, 2007). Measurements of the microbiological and quality parameters were performed on three replicates at regular interval times (0, 3, 7, 10 and 14 days).

Thickness and water vapour permeability

The thickness of different coatings was measured with P6 stylus profilometer (KLA-Tencor, Milpitas, CA, USA). Coatings' water vapour permeability (WVP) was determined gravimetrically according to Vieira *et al.* (2020). The weight of each capsule was monitored regularly for 7 days. WVP was calculated as follows:

$$\mathrm{WVP} = \frac{\Delta g}{\Delta t} * \left(\frac{x}{A * \Delta P}\right) \tag{1}$$

where $\frac{\Delta g}{\Delta t}$ is the rate of weight change (g h^{-1}), x is the thickness (mm), A is the area (0.00025434 m^2), and ΔP is the partial pressure difference (3.169 kPa at 25 °C).

Headspace gas composition and pH

O_2 and CO_2 in the headspace of the packages were determined by an O_2/CO_2 gas analyser (PBI Dansensor, Checkmate3, Ringsted-Denmark) according to Liguori *et al.* (2021). The pH was measured using a digital pH-meter (Model 2001; Crison, Barcellona, Spain) with a penetration pH-electrode.

Analysis of microbiological parameters

Ten gram of papaya sample was homogenised in 90 mL of peptone-saline solution (PSS) by a homogenising mixer for 3 min at room temperature, and after, decimal serial dilutions were prepared. Total viable count (TVC) was plated in plate count agar (Oxoid; Thermo Fisher Scientific™, Milano, Italy) and incubated at 30 °C for 3 days. LAB was analysed by spread plate method onto de Man, Rogosa and Sharpe (MRS) agar and kept in aerobiosis, at 30 °C for 72 h. The count of moulds and yeasts was carried out using the spread plate method in Rose Bengal Agar and then kept at 25 °C for 5–7 days. The plates with 10 to 150 colonies were selected, and all the different colony morphologies (fungal, yeast-like, *etc.*) were selectively counted.

ABTS and DPPH radical-scavenging assays

Methanolic extracts of papaya samples were prepared by homogenisation of 4 g samples in 20 mL of methanol:water solution (1:1 v/v). The mixture was stirred at dark for 20 min and then centrifuged at 2516 ***g*** at 4 °C for 8 min. The antioxidant activity (AA) of extracts was evaluated through both DPPH and ABTS, performed according to Liguori *et al.* (2019) and Gayosso-García Sancho *et al.*, 2010 respectively.

For both radical-scavenging assays, a Trolox standard calibration curve was carried out and the antioxidant activity results were expressed as Trolox equivalent (TE) mg/g_{dw}.

Total carotenoids content

Total carotenoid (TC) extraction was carried out according to Gayosso-García Sancho *et al.* (2011). TC content was measured by a Perkin Elmer Lambda 25 spectrophotometer at the wavelength of 450 nm. β-carotene standard was employed for the construction of a calibration curve to calculate TC.

Vitamin C content

Extracts of uncoated and coated papaya for vitamin C content detection were prepared after homogenisation of 5 g of pulp with 50 mL of bidistilled water using an Ultraturrax Homogenizer (T25; IKA, Staufen, Germany). The homogenised extracts were then centrifuged (4000 rpm, 8 min, 4 °C) and filtered with 0.45-μm filter. Ionic exchange chromatography was used for the analysis of Vit C content according to the method previously reported (Liguori *et al.*, 2017).

Texture profile analysis

Texture profile analysis (TPA) of fresh-cut papaya samples was performed at room temperature by a texturometer (LRX Plus; Lloyd Instruments, Chicago). The samples underwent a double compression up to 50% of the original height by a cylindrical probe (diameter 1 cm) at 1 mm s^{-1}. The parameters evaluated were hardness, cohesiveness, springiness and chewiness. The data are reported as the average of five measurements per sample.

Assessment of sensory attributes

Sensory attributes of fresh-cut papaya samples were evaluated by five members from the University of Salerno who were selected based on their experience in the sensory analysis. All panellists were specifically trained using different samples of fresh papaya, allowing them to recognise the quality characteristics to be assessed and to familiarise themselves with the scales and procedures adopted. Fresh-cut papaya samples of about 10 g were presented to each taster in random order and evaluated, at each storage day, by odour, colour, taste, firmness, off flavours and overall acceptability using a 5-points hedonic scale (5 = very good-1 = very poor). Scores equal to or lower than 3 were considered unacceptable for the marketing.

Statistical analysis

Thickness and WVP of the three edible coatings as well as the microbiological parameters, antioxidant activity, vitamin C, total carotenoids and TPA of the fresh-cut papaya samples were reported as mean and standard deviation and subjected to analysis of variance (ANOVA).

The significance of difference ($P < 0.05$) among different samples (C, SA, HA and HA/QUE) and for each sample during the storage time (0, 3, 7, 10 and 14 days) were determined by LSD test by the Analysis Lab software.

Results and discussions

Physical properties of edible coatings

The main physical properties (thickness and WVP) of alginate-based coatings developed for fresh-cut papaya are reported in Table 1.

The thickness of alginate-based coatings varied from 6.12 μm (QUE) to 7.17 μm (HA/QUE). A significant increase ($P < 0.05$) in thickness was observed when HA crystals were added to the coatings. No significant differences were found between SA and QUE coatings (Table 1). This result suggests that the presence of HA crystals influenced the density of film probably due to the increase in solid content (Vieira *et al.*, 2020). Similar data were reported by Vieira *et al.* (2020) and Arfat *et al.* (2017) during the characterisation of edible films containing gold and silver nano/microparticles. One of the main actions of edible coatings is control water transfer between the food and headspace of the

Table 1 Thickness and water vapour permeability (WVP) of developed alginate-based coatings

	Thickness (μm)	WVP (g·mm/h·m^2·kPa)
SA	6.21 ± 0.44^a	0.11 ± 0.0020^a
QUE	6.12 ± 0.080^a	0.091 ± 0.0010^b
HA/QUE	7.17 ± 0.48^b	0.11 ± 0.0010^c

Mean values in the same column with different letters (a, b, c) are significantly different ($P < 0.05$) among the coatings.

packages. The WVP of coatings changed significantly from 0.09 to 0.11 g·mm/h·m^2·kPa in the different edible coatings (Table 1). The hydrophilic nature of sodium alginate leads to a water-permeable coating, as well as the addition of plasticiser glycerol increases the WVP values due to the reduction in intermolecular bonds between polymer chains (Parreidt *et al*., 2018). SA coating showed the highest value of WVP compared with QUE and HA/QUE coatings probably due to the presence of HA crystals and quercetin glycoside compounds which reduce the diffusion of water molecules.

Headspace gas evaluation

Fruits keep breathing even after harvesting and cutting (Tabassum & Khan, 2020). The effect of alginate-based coatings on the O_2 and CO_2 levels in the headspace of the packed fresh-cut papaya is shown in Fig. 1.CO_2 production and O_2 consumption were recorded in all samples, without significant differences ($P < 0.05$) among samples, until day 7. A higher O_2 decrease for uncoated fruits was observed at the 10th storage day, whereas no significant differences ($P < 0.05$) were found between coated samples during the storage, that reached after 14 days a O_2 value close to 10%. As regards the CO_2 increase, uncoated and QUE samples showed the highest CO_2 production during the last days of storage. No differences ($P < 0.05$) in CO_2 production were observed between SA and HA/QUE samples, that reached CO_2 final values close to 10%. These results pointed out the capability of alginate-based coatings to slow down the respiration rate of fresh-cut fruits, according to Azarakhsh *et al*. (2012) who studied the effect of alginate coatings for fresh-cut pineapples. The high level of respiration rate recorded for the QUE samples may be due to a degradation of the alginate polymer caused by the oxidation of quercetin glycoside compounds. Although quercetin is a strong antioxidant compound, it is also chemically unstable and can be subjected to chemical and enzymatic oxidation by peroxidase and polyphenol oxidase enzymes, which are contained in fresh papaya naturally (Cano *et al*., 1995). The oxidation products, mainly phenolic acids (Zenkevich *et al*., 2007), may have induced the degradation of alginate-based coatings, which are easily unstable in acidic conditions (Tonnesen & Karlsen, 2002).

Microbiological analysis of papaya and pH evaluation

The cut surface of fresh-cut fruit is exposed to environment, inducing the degradation and causing an increase in microbial count as consequence (Fig. 2). The absence of a protective physical barrier in control samples makes the fruit more prone to spoilage by microorganisms. As shown in Fig. 2a, the initial microbial charge (day 0) was characterised by the presence of a total bacterial count (TBC) ranging from 2.7 log CFU g^{-1} in HA/QUE to 4.0 log CFU g^{-1} in control samples, acceptable charge if we consider the common values related to the microbial population of fruits and vegetables ranging between 5 and 7 log CFU g^{-1} (Di Cagno *et al*., 2013). The lowest values (4.5 log CFU g^{-1}) observed for activated coated

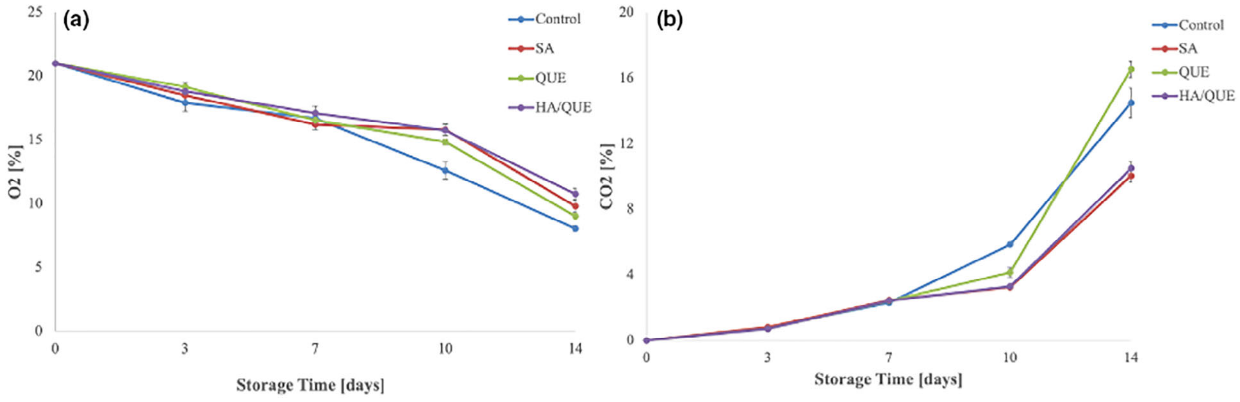

Figure 1 Changes in O_2 (%) (a) and CO_2 (%) (b) in fresh-cut papaya packages during the storage time at 6 °C.

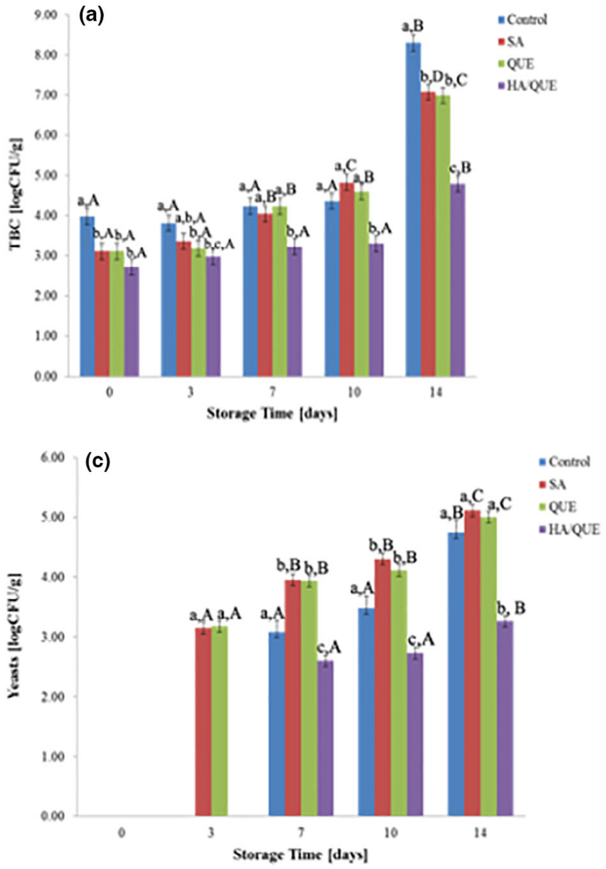

Figure 2 Changes in total bacterial count (TBC) (a), lactic acid bacteria (b), yeasts (c) and moulds (d) in fresh-cut papaya during the storage time at 6 °C. Different letters (a, b, c, d) reveal significant differences ($P < 0.05$) among the samples for each storage time, and different letters (A, B, C.) reveal significant differences ($P < 0.05$) among treatments during the storage time.

samples showed the antimicrobial effect of quercetin glycosides as reported in our previous study (Malvano *et al.*, 2021). These results are in accordance with Tabassum & Khan (2020) who evaluated the effect of alginate-based coating enriched with 2% of thyme or oregano essential oil on the TBC growth in fresh-cut papaya stored for 12 at 4 °C.

Microbial growth in fruits and vegetables is a complex phenomenon that involves microbial ecology, microbial competition, substrate composition and pH values. Many microorganisms, in particular LAB and fungi (yeasts and moulds), are capable of using fruit as substrate and cause spoilage (Tournas *et al.*, 2006). Microbial competition and the initial acidic pH of papaya samples (Fig. 3) could justify the no detectability of LAB, yeasts and moulds at time 0 measured in all investigated samples (Jin & Kirk, 2018). As expected and according to previous study on the subject (Tabassum & Khan, 2020; Cortez-Vega *et al.*, 2014; Brasil *et al.*, 2012), the growth of all microbiological parameters was observed as the storage time increased. As regards TBC, significantly lower values were observed for HA/QUE in comparison with control, SA and QUE samples, during all storage periods. Given the value ranging from 6 to 7 log CFU g^{-1}, which are recognised as accepted limits of TBC value for minimally processed fruit (Corbo *et al.*, 2006; Lavelli *et al.*, 2006), HA/QUE showed TBC values lower than acceptable limits for all storage periods, unlike control, SA and QUE, which reached these limit values after 14 days. LAB was registered in all papaya samples with the highest value of 2.50 log CFU g^{-1} in control sample and the lowest in HA/QUE (1.50 log CFU g^{-1}) only after the 7th day, probably due to microbial competition and to the lowering of pH that reached in all samples values close to 5.4 or lower. As observed for total bacteria counts significant ($P < 0.05$), lower LAB charges were measured for HA/QUE during the following storage days (Fig. 2b). These results highlighted that, according to literature (Raybaudi-Massilia *et al.*, 2008; Tabassum & Khan, 2020), the coating with only alginate did not show effective antimicrobial activity. Moreover, the

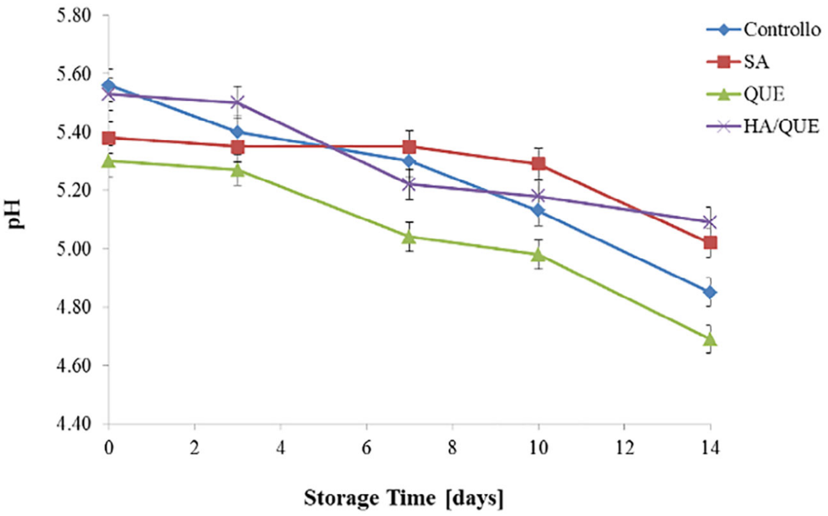

Figure 3 pH of fresh-cut papaya samples during the storage time at 6 °C.

comparison between QUE and HA/QUE samples pointed out that coating with QUE alone did not effectively inhibit the microbiological growth, showing a similar charge as in the SA sample. The effectiveness of quercetin glycoside compounds in slowing down microbial growth is shown only when it is adsorbed into HA crystals. Thanks to their biomimetic property, different authors have underlined the capability of HA crystals to be used as a delivery carrier of antimicrobial and antioxidant agents (Nocerino *et al.*, 2014; Fulgione *et al.*, 2016; Calasans-Maia *et al.*, 2019; Fulgione *et al.*, 2019). Our previous studies have shown a very fast release of quercetin glycoside compounds from alginate-based coatings when the bioactive compounds were complexed with HA crystals, pointing out how an edible coating enriched with hydroxyapatite/quercetin complexes could be an interesting alternative for the shelf-life extension of fresh chicken fillets (Malvano *et al.*, 2022). A similar trend to the TBC was observed for yeast and mould count where the control samples had values much above the consumable limit, while among the coated samples, HA/QUE sample exhibited the lowest mould count with 3.30 log CFU g^{-1}. The detected data showed an antimicrobial effect of quercetin glycoside compound *versus* moulds that appears in QUE and QUE/HA samples after 10 and 14 days, respectively. Conversely, the yeasts seemed to benefit from the presence of quercetin compounds in the alginate coatings, probably due to the significant decrease in pH values.

Total carotenoids content and antioxidant activity evaluation

Fresh-cut papaya shows a high nutritional interest as it is an excellent source of carotenoids, nutritional compounds that act as natural antioxidants, protecting cellular components from oxidative damage. The alginate-based coating showed a positive effect in maintaining the total carotenoids content of the fresh-cut papaya, as shown in Fig. 4. Carotenoid compounds, susceptible to enzymatic and non-enzymatic oxidation continue to be synthesised during ripening. In fact, until storage day 3, the amount of total carotenoids increased in both coated and uncoated fruits, reaching the maximum values ranging from 0.16 to 0.19 mg g_{dw}^{-1}, respectively, close to the total carotenoids content related to the maximum level of ripeness of the papaya fruit (Rajyalakshmi *et al.*, 2003; Gayosso-García Sancho *et al.*, 2011). The reduction in total carotenoid content started from day 7 for all papaya samples. QUE and HA/QUE samples showed the highest carotenoids content for all days of the storage period: No significant changes ($P < 0.05$) from day 7 to day 10 for both samples were recorded. At the end of storage, the carotenoids percentage decrease compared with time 0 in QUE and HA/QUE was about 20%, while in control and SA, carotenoids showed losses of 39 and 35%, respectively. Brasil *et al.* (2012) observed a total carotenoids reduction of 50% in uncoated fresh-cut papaya after 15 days at 4 °C in contrast a more limited losses were registered when papaya samples were covered by beta-cyclodextrin based coatings. The losses of carotenoids could be due to the oxygen exposure to the product since b-carotene is oxidised when exposed to light and oxygen (Rivera-Lopez *et al.*, 2005). The lowest losses in total carotenoids observed for QUE and HA/QUE, recorded in all storage days, could be explained by the presence of quercetin glycoside compounds which, acting as a reducing agent, protect carotenoids from oxidative degradation and thus preserve their content

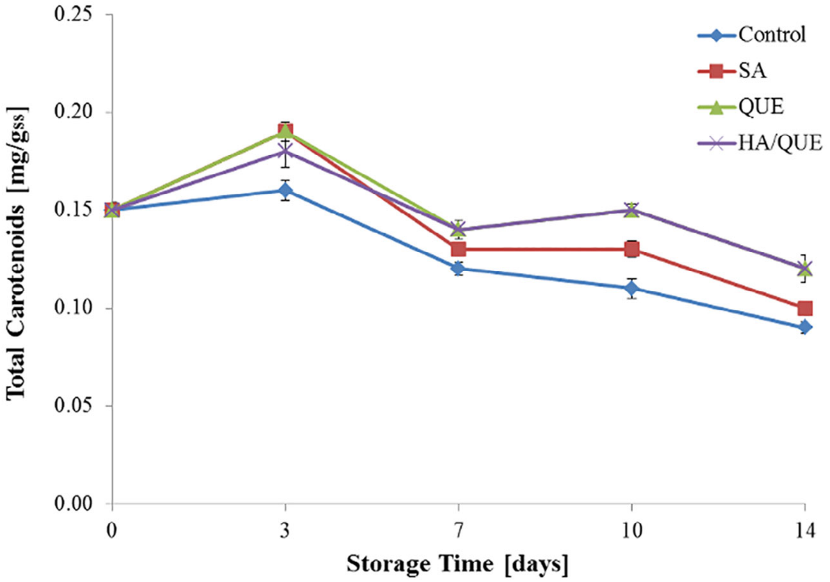

Figure 4 Changes in total carotenoid content in coated and uncoated fresh-cut papaya during the storage time at 6 °C.

in the fruits (Wang *et al.*, 2016). According to the total carotenoids results, during the first 3 days of the storage, while the ripening went on, the antioxidant activity of coated and uncoated fresh-cut papaya increased, reaching their maximum values. Fig. 5 shows the percentage change in antioxidant activity of all samples, evaluated through both DPPH and ABTS radical-scavenging assays were reported.

From the 3rd day until the end of the storage time, the oxidation reactions became prominent and, along with the degradation of carotenoid compounds, the antioxidant activity, measured by DPPH, was subjected to a reduction in all samples (Fig. 5a). However, smaller reductions in the antioxidant activities were found in QUE and HA/QUE samples during storage period. The reduction in antioxidant activity in control and SA samples derived from the degradation of antioxidant compounds (carotenoids and ascorbic acid) during the storage period, while in the activated coatings, the presence of quercetin glycoside allowed preserving the antioxidant activity. ABTS results (Fig. 5b) showed the same trend of DPPH ones: A lower degradation of antioxidant compounds in coated fruits with quercetin was reached in all days of the storage period, with an antioxidant activity significantly ($P < 0.05$) higher for HA/QUE samples than the other ones after 14 days of storage. These results confirmed the effectiveness

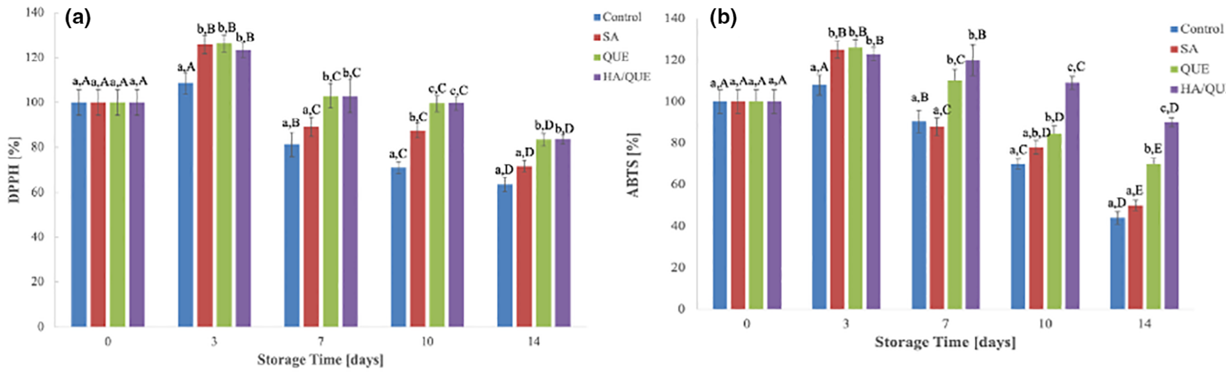

Figure 5 Percentage change in antioxidant activity of coated and uncoated samples, evaluated through DPPH (a) and ABTS (b) radical-scavenging assays. Different letters (a, b, c, d) reveal significant differences ($P < 0.05$) among the samples for each storage time, and different letters (A, B, C...) reveal significant differences ($P < 0.05$) among treatments during the storage time.

of the alginate-based edible coating enriched with HA/QUE complexes to preserve antioxidant compounds of fresh-cut papaya during the entire storage period.

Vitamin C evaluation

The measurements of vitamin C content were carried out at the beginning, at the middle time and the end of the storage period. At time 0, fresh-cut papaya showed about 48 mg/100 g_{fw} of vitamin C according to data previously reported for *Formosa* fresh papaya (Oliveira *et al.*, 2010).As shown in Fig. 6, the slight but significant ($P < 0.05$) increase in vitamin C content occurred in all samples from the beginning until the 7th storage day due to the ripening of papaya, while a remarkable reduction was recorded at the end of storage period. In particular, the drastic reduction in vitamin C content in control samples, which is in accordance with previous study on active edible coating on minimally processed papaya (Brasil *et al.*, 2012), is due to the direct exposure of fresh-cut fruit to air, which caused the oxidation of the compound. A lower reduction in vitamin C content was observed for fresh-cut papaya covered with active coatings compared with SA samples: This behaviour is explained by the presence of quercetin glycoside compounds that acted as reducing agents, by partially protecting vitamin C from oxidative degradation. The higher reduction in vitamin C in the QUE compared with HA/QUE could be due to the quercetin glycoside compounds oxidation, with the production of acidic compounds, which may have induced a partial degradation of the coating and thus a higher air exposition of the fruits, which caused the losses of vitamin C.

Texture profile analysis

Texture parameters of coated and uncoated fresh-cut papaya during the storage time are shown in Table 2. It can be seen that the hardness values of all papaya samples decreased during the storage period. The hardness decrease in papaya is due to enzymatic degradation of the cell wall and decomposition of intracellular materials (dos Passos Braga *et al.*, 2020). The comparison among the samples pointed out the positive effect of HA/QUE coating to slow down in the hardness decrease during the cold storage. The reduced loss of firmness in HA/QUE-coated papaya could be due to a reduction in enzymatic activity in the fruit as a consequence of decreased endogenous ethylene production and respiratory rate (Monzón-Ortega *et al.*, 2018).

At the end of storage time, HA/QUE sample registered a 44.24% loss of hardness in contrast to 82.59%, 75.89% and 72.54% shown in Control, SA and QUE samples respectively. Cortez-Vega *et al.* (2014) observed a 17.64% loss of firmness after 12 days of storage at 4 °C in minimally processed papaya coated with edible coatings from protein isolate with organoclay montmorillonite. The difference with the data obtained in this study could be due to the different cold temperature used for the storage as well as to the ripening state of fresh papaya employed. A decrease in cohesiveness values was shown for all samples during the storage time. The lowest cohesiveness in control samples at the end of the storage period indicated a prominent decay of cell tissues. The HA/QUE samples appeared to have the highest cohesiveness, which implied the samples still retained their texture also after 14 days of storage. On the contrary, no significant differences ($P < 0.05$) during the storage time were

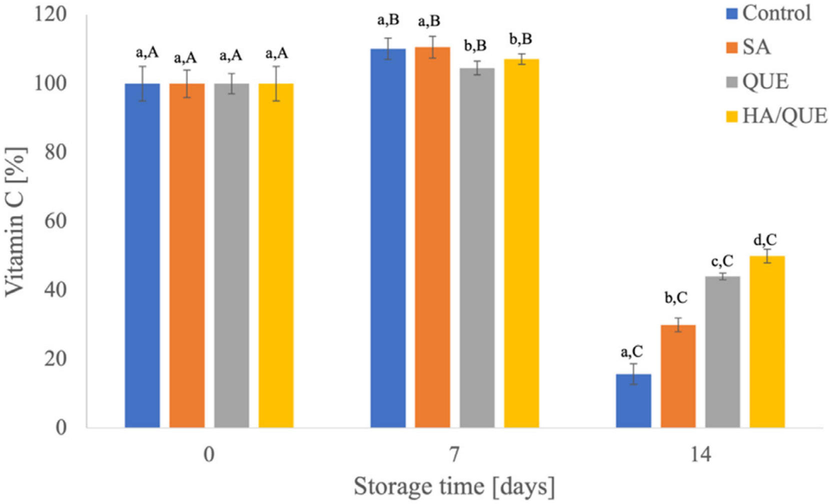

Figure 6 Percentage change in vitamin C content of coated and uncoated samples. Different letters (a, b, c, d) reveal significant differences ($P < 0.05$) among the samples for each storage time, and different letters (A, B, C…) reveal significant differences ($P < 0.05$) among treatments during the storage time.

Table 2 Texture profile analysis parameters of fresh-cut papaya during the storage time at 6 °C

		Storage time (days)				
	Sample	**0**	**3**	**7**	**10**	**14**
Hardness (N)	Control	$12.06 \pm 0.40^{a,A}$	$7.10 \pm 0.72^{a,B}$	$5.47 \pm 0.18^{a,B}$	$3.15 \pm 0.06^{a,C}$	$2.10 \pm 0.07^{a,D}$
	SA	$13.77 \pm 1.97^{a,A}$	$7.62 \pm 0.38^{a,B}$	$4.99 \pm 0.06^{a,C}$	$4.46 \pm 0.07^{b,D}$	$3.32 \pm 0.19^{b,E}$
	QUE	$12.93 \pm 0.80^{a,A}$	$7.74 \pm 0.60^{a,B}$	$5.02 \pm 0.09^{a,C}$	$4.53 \pm 0.10^{b,D}$	$3.55 \pm 0.10^{b,E}$
	HA/QUE	$12.93 \pm 0.67^{a,A}$	$11.37 \pm 0.39^{b,B}$	$9.46 \pm 0.12^{b,D}$	$8.19 \pm 0.20^{c,E}$	$7.21 \pm 0.20^{c,F}$
Cohesiveness	Control	$0.40 \pm 0.01^{a,A}$	$0.35 \pm 0.01^{a,B}$	$0.33 \pm 0.02^{a,B}$	$0.20 \pm 0.01^{a,C}$	$0.11 \pm 0.01^{a,D}$
	SA	$0.37 \pm 0.01^{b,A}$	$0.35 \pm 0.01^{a,A}$	$0.27 \pm 0.01^{b,B}$	$0.23 \pm 0.01^{b,C}$	$0.19 \pm 0.01^{b,D}$
	QUE	$0.41 \pm 0.02^{c,A}$	$0.36 \pm 0.01^{a,B}$	$0.32 \pm 0.01^{a,C}$	$0.26 \pm 0.02^{c,D}$	$0.20 \pm 0.02^{b,E}$
	HA/QUE	$0.40 \pm 0.01^{c,A}$	$0.40 \pm 0.02^{b,A}$	$0.30 \pm 0.01^{a,B}$	$0.30 \pm 0.01^{d,B}$	$0.30 \pm 0.01^{c,B}$
Springiness (mm)	Control	$0.41 \pm 0.03^{a,A}$	$0.41 \pm 0.02^{a,A}$	$0.40 \pm 0.01^{a,A}$	$0.38 \pm 0.01^{a,AB}$	$0.37 \pm 0.01^{a,B}$
	SA	$0.59 \pm 0.07^{b,A}$	$0.54 \pm 0.01^{b,A}$	$0.53 \pm 0.02^{b,A}$	$0.51 \pm 0.01^{b,AB}$	$0.51 \pm 0.01^{b,B}$
	QUE	$0.56 \pm 0.03^{b,A}$	$0.55 \pm 0.03^{b,A}$	$0.53 \pm 0.01^{b,A}$	$0.51 \pm 0.01^{b,B}$	$0.51 \pm 0.01^{b,B}$
	HA/QUE	$0.64 \pm 0.02^{c,A}$	$0.62 \pm 0.03^{c,A}$	$0.62 \pm 0.02^{c,A}$	$0.61 \pm 0.01^{c,A}$	$0.60 \pm 0.01^{c.A}$
Chewiness (N*mm)	Control	$0.35 \pm 0.05^{a,A}$	$0.31 \pm 0.01^{a,A}$	$0.29 \pm 0.01^{a,A}$	$0.21 \pm 0.01^{a,B}$	$0.20 \pm 0.01^{a,B}$
	SA	$0.40 \pm 0.01^{ab,A}$	$0.40 \pm 0.02^{b,A}$	$0.39 \pm 0.01^{b,A}$	$0.37 \pm 0.01^{b,A}$	$0.34 \pm 0.02,^{b,B}$
	QUE	$0.41 \pm 0.01^{ab,A}$	$0.41 \pm 0.01^{b,A}$	$0.39 \pm 0.02^{b,A}$	$0.37 \pm 0.01^{b,AB}$	$0.35 \pm 0.02^{b,B}$
	HA/QUE	$0.42 \pm 0.01^{ab,A}$	$0.42 \pm 0.02^{b,A}$	$0.40 \pm 0.01^{b,A}$	$0.38 \pm 0.02^{b,AB}$	$0.36 \pm 0.01^{b,B}$

Different letters (a, b, c, d) reveal significant differences ($P < 0.05$) among the samples for each storage time, and different letters (A, B, C, ...) reveal significant differences ($P < 0.05$) among treatments during the storage time.

registered in the springiness values in all coated and uncoated papaya. The higher springiness values recorded in all coated samples with respect to uncoated ones could be due to the elasticity of the alginate-based coatings. Finally, the chewiness, defined as the energy required to chew a solid food until its swallowing, was significant ($P < 0.05$) lower in control samples with respect to coated ones, on each day of the storage period. As reported by Dhall (2013), edible coating works to modify the internal gas composition of individual fresh-cut fruit, with a high influence on the lowering respiration rate. By limiting the respiration of papaya, the coatings have delayed the maturation phenomena, thus preventing the softening of fresh-cut papaya. The effectiveness of polysaccharides-based coating in slowing down the tissue breakdown of fresh-cut fruits was also reported elsewhere (Brasil *et al.*, 2012).

Texture profile analysis results highlighted the high potential of coatings loaded with HA/QUE in retaining the texture of fresh-cut papaya.

Assessment of sensory attributes

The evaluation of coated and uncoated sample at time 0 highlighted that the alginate-based coatings did not affect the sensory attributes of fresh-cut papaya, but a slight decrease in odour for the coated samples was evaluated (Fig. 7). During the first 7 storage days, a slight decrease in sensory attributes was recorded in all coated papaya samples in comparison with time 0. A strong loss in the scores was observed on the 10th day in all samples except for HA/QUE samples that preserved the attributes of colour, taste and firmness. This difference could be explained by the higher microbial load, responsible for spoilage with consequent production of unpleasant compounds. On the 14th day, the sensory evaluation was carried out only for the HA/QUE samples, due to the presence of visible mould colonies on the surface of other samples. Finally, the evolution of sensory attributes during the storage highlighted the positive effects of alginate-based coatings charged with HA/QUE complexes which were still assessed acceptable after 14 storage days.

Conclusion

The capability of alginate-based coatings, incorporated with bioactive quercetin glycoside compounds to preserve the quality parameters of fresh-cut papaya stored for 14 days at 6 °C, was evaluated. The physical characterisation of alginate-based coatings with and without active compounds showed how the presence of HA crystals allowed an increase in the film thickness as well as a decrease in water vapour transmission. The microbial analysis carried out during the storage period pointed out the positive effect of HA charged with QUE to inhibit the growth of spoilage bacteria, as well as to slow down the respiration rate of fresh-cut papaya. Moreover, the activated coatings have shown high efficacy in preserving the antioxidant compounds naturally present in papaya,

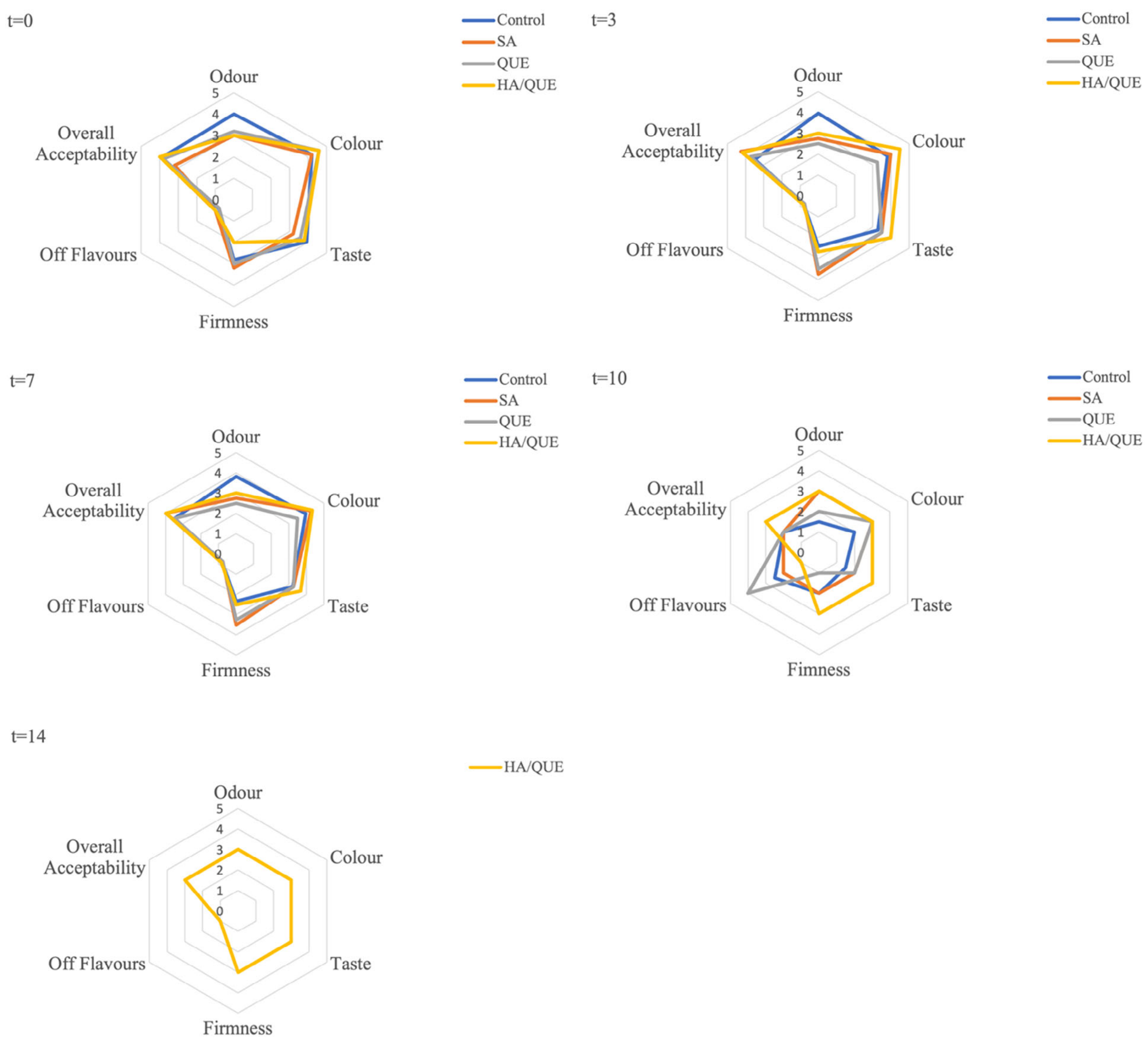

Figure 7 Spider plots of sensory attributes (odour, colour, taste, firmness, off flavours and overall acceptability) of fresh-cut papaya during the storage time at 6 °C.

including carotenoid compounds. Therefore, the use of hydroxyapatite/quercetin complexes loaded into an alginate-based coating could be an effective method of preserving the quality of fresh-cut papaya, by extending its shelf-life.

Conflict of interest

The authors declare that they have no conflict of interest.

Ethical approval

Ethics approval was not required for this research.

Author contributions

Angela Michela Immacolata Montone: Data curation (equal); formal analysis (equal); investigation (equal). **Francesca Malvano:** Conceptualization (equal); data curation (equal); formal analysis (equal); investigation (equal); writing – original draft (equal). **Phuong Ly Pham:** Data curation (equal); formal analysis (equal). **LUCIANO CINQUANTA:** Writing – review and editing (equal). **Rosanna Capparelli:** Conceptualization (equal); writing – review and editing (equal). **Federico Capuano:** Conceptualization (equal); writing – review and editing (equal). **Donatella Albanese:** Conceptualization (equal);

supervision (equal); validation (equal); writing – review and editing (equal).

Peer review

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Data availability statement

The data that supported the findings of this study are available from the corresponding author upon reasonable request.

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