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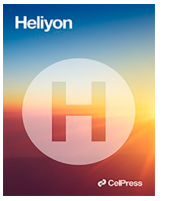

Prolonging the shelf life of fresh-cut guava (*Psidium guajaya* L.) by coating with chitosan and cinnamon essential oil

Z.A. Nur Hanani [a,b,*], K.L. Soo [a], W.I. Wan Zunairah [c], S. Radhiah [a]

[a] Department of Food Technology, Faculty of Food Science and Technology, Universiti Putra Malaysia, 43400, UPM, Serdang, Selangor, Malaysia
[b] Halal Products Research Institute, Universiti Putra Malaysia, 43400, UPM, Serdang, Selangor, Malaysia
[c] Department of Food Science, Faculty of Food Science and Technology, Universiti Putra Malaysia, 43400 UPM, Serdang, Selangor, Malaysia

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ABSTRACT

This study investigated the effect of a coating of chitosan (CH) and cinnamon essential oil (CEO; 0−1 %) on the quality attributes of fresh-cut guava (*Psidium guajaya* L.) during storage at 4 ± 1 °C for 17 days, with uncoated fresh-cut guava used as control. The CH coating significantly ($p < 0.05$) delayed changes in weight loss, firmness, colour, total soluble solids and titratable acidity compared to the control sample. Furthermore, the effects were more prominent with the incorporation of higher CEO concentrations. The bacterial, yeast and mould counts were also significantly lower ($p < 0.05$) in the CH-coated samples than in the control, with the coating containing 1 % CEO exhibiting the best quality preservation effect. In addition, CH and CEO coatings extended the shelf life of fresh-cut guava up to 17 days compared to the control sample (shelf life of only 3 days). In conclusion, combining CH and CEO as a coating matrix effectively preserves the quality and enhances fresh-cut guava's shelf life.

1. Introduction

Fresh-cut guava (*Psidium guajaya* L.) could provide a notable amount of nutrients and bioactive compounds for a balanced diet [1]. This fruit is rich in vitamins such as vitamins A and C, dietary fibres, minerals and antioxidant compounds (carotenoids and polyphenols) [2]. It is available year-round but matures rapidly, with a shelf life varying from 3 to 4 days at room temperature [3]. Meanwhile, storage of guava at a temperature below 8 °C could also cause chilling injury [4] and cutting may also reduce the integrity of the fruit tissue and trigger deterioration processes such as softening, browning, loss of moisture, off-flavour development and microbial growth [5].

Preservation by incorporating synthetic additives or synthetic chemical compounds such as formaldehyde, BHA, BHT and others are not preferable by consumers nowadays due to safety and health issues. Alternative treatments including UV-C [6], non-thermal technologies such as ultrasound and ozone [7] and thermal treatment had been utilised to inactivate microbial growth on guava or maintain the fruit quality. Nonetheless, these processes require specific instruments to execute which may be a hurdle to farmers or small producers. Therefore, to overcome these issues, the research focus has shifted towards a safer yet cheaper method, an active edible coating.

The edible coating is a thin layer of edible materials such as proteins, polysaccharides and lipids that are applied on the surface of

* Corresponding author. Department of Food Technology, Faculty of Food Science and Technology, Universiti Putra Malaysia, 43400, UPM, Serdang, Selangor, Malaysia.
E-mail address: hanani@upm.edu.my (Z.A. Nur Hanani).

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foodstuffs to provide protection [8]. Chitosan (CH) is a linear polysaccharide derived from the deacetylation of chitin and a versatile biopolymer commonly used as an edible coating matrix on fruit due to its excellent film-forming ability and biocompatibility with good mechanical resistance [9,10]. CH also effectively inhibits bacterial growth. Petriccione et al. [11] reported that CH could prolong the shelf life of sweet cherry, whereas Fang et al. [12] showed the effectiveness of CH combined with tea polyphenols on harvested broccoli.

Several researchers have revealed that the protective function of the CH coating can be substantially improved by adding other compounds such as polyphenol [12], nanoemulsion (thymol) [13] or essential oils [14,15]. Cinnamon essential oil (CEO) is well-known for its potent antimicrobial and antioxidant properties. The effective antimicrobial activity of CEO is mostly derived from aldehydes [16,17]. The antimicrobial effect of CEO and cinnamaldehyde has been previously reported [18–21]. Furthermore, incorporating this hydrophobic CEO improves the water barrier properties of the film coating [22]. Previous studies have also demonstrated the effectiveness of CH coating incorporated with CEO in preserving the quality and safety of fruit and vegetables such as China jujube fruit [23], sweet pepper [24] and cucumber [25].

Hasan et al. [4] studied the effect of alginate coatings with black cumin on fresh-cut guava stored at 11 °C. However, to the best of our knowledge, there is a lack of data on the protective function of edible coating on fresh-cut guavas stored at lower temperatures that are more prone to deterioration. Furthermore, most studies have focused on the development of edible coatings and films without proving the functionality of these materials towards food products. Thus, this study determined the effect of CH + CEO coating on the quality attributes of fresh-cut guava during storage at 4 ± 1 °C for 17 days.

2. Materials and methods

2.1. Materials

Chitosan, acetic acid and glycerol were obtained from Sigma-Aldrich (Missouri, USA) while Tween 80 and sodium hypochlorite were purchased from Systerm Chemicals (Selangor, Malaysia) and R&M Chemicals (Selangor, Malaysia), respectively. Food-grade cinnamon essential oil (CEO) derived from *Cinnamomum zeylanicum* bark was obtained from Dru Era (New York, USA). Peptone water, potato dextrose agar and plate count agar were supplied by Oxoid (Hampshire, England).

2.2. Preparation of guava samples

Fresh guavas (*Psidium guajava* L.) of uniform size and degree of maturity with a mass of approximately 300 g were purchased in May one day before the experiment from a local market at Bidor, Perak (Malaysia) and stored at a chilling temperature to maintain the fruit quality. Fruit with any physical damage and visible sign of disease were discarded. The guavas were sanitised by immersion in an aqueous sodium hypochlorite solution (200 mg/L) for 10 min [26]. Then, the fruit was rinsed in distilled water and left to dry at room temperature for 10 min. Finally, the fruit was peeled, deseeded, cut into eight equal parts with a sterile knife and ready to be coated.

2.3. Preparation of the coating solution

The coating solution was prepared using the method of Xing et al. [23] with slight modifications. CH (2 % w/v) solution with 1 % acetic acid (v/v) and 0.75 % (v/v) glycerol as a plasticiser was stirred with a magnetic stirrer (Vision Scientific, Daejeon, Korea) at room temperature for 1 h to ensure complete dispersion. CEO with a concentration of 0.00 %, 0.25 %, 0.50 %, 0.75 % or 1.00 % (v/v) of chitosan solution was mixed with 0.2 % (v/v) Tween 80 (surfactant) and then added to the coating solution. The mixture was stirred continuously with a magnetic stirrer for 30 min before being homogenised with a Heidolph DIAX 900 homogeniser (Heidolph Instruments GmbH & Co., Schwabach, Germany) at 21,600 rpm for 1 min. The homogenate was filtered using filter paper to remove any air bubbles and the emulsion was left to stand for 1 h.

2.4. Coating of fresh-cut guava

The guava slices were dipped into the different coating solutions for 5 min and then drained for 1 min with the control sample dipped in distilled water. Treated samples were subjected to light drying at 30 °C for 20 min in a Mal Chem M-CD0106 cabinet dryer (Malaysian Chemical Engineering Technologies Sdn. Bhd., Selangor, Malaysia) according to the method of Zuraidah et al. [27]. The treated samples were packaged in the polypropylene (PP) pouches and stored at 4 ± 1 °C for 17 days.

2.5. Physical analysis

2.5.1. Weight loss

Weight loss was calculated as the percentage of weight loss from the initial weight. The initial weight (Day 0) and the weight after each storage period (Day 3, 7, 10, 14 and 17) were measured using a Sartorius BS224S weighing balance (Sartorius AG, Göttingen, Germany). The percentage of weight loss was calculated using the following formula Eq. (1), in which W_i refers to the initial weight of the guava and W_f is the weight after the storage period.

$$\text{Weight loss } (\%) = \left[\left(W_i - W_f\right) / W_i\right] \text{x } 100 \quad (1)$$

2.5.2. Firmness

The guava firmness was assessed using a TA-XT2i texture analyser (Stable Micro Systems, Surrey, UK) equipped with a 2 mm diameter cylinder probe (P/2) and a 5 kg load cell. The measurement was conducted using the force-in compression test mode to determine the maximum force required to achieve probe penetration of 5 mm into the guava sample. The result was expressed in Newton (N).

2.5.3. Colour

The colour was determined using a Konica Minolta CR-410 colourimeter (Konica Minolta, Osaka, Japan). The CIE colour system was used to evaluate the L* (luminosity), a* (redness) and b* (yellowness). The hue angle (h^*_{ab}) was calculated from Eq. (2) or Eq. (3), in which 0°, 90°, 180° and 270° represents true red, yellow, green and blue, according:

$$H * ab = \tan^{-1}\frac{b*}{a*} \text{ (For positive b} * \text{ and positive a} * \text{ value)} \quad (2)$$

$$h * ab = 180^\circ + \tan^{-1}\frac{b*}{a*} \text{ (For positive b} * \text{ and negative a} * \text{ value)} \quad (3)$$

2.6. Biochemical analysis

2.6.1. Total soluble solid content

The total soluble solid (TSS) content was measured according to Petriccione et al. [11] using Atago hand-held refractometer (Atago, Tokyo, Japan) and the results were expressed in % Brix.

2.6.2. Titratable acidity

The titratable acidity (TA) was determined according to the method of Jongsri et al. [28]. Guava puree (10 g) was diluted with 90 mL of distilled water before the addition of a few drops of phenolphthalein as an end-point indicator. It was then titrated with 0.1 M sodium hydroxide (NaOH) and the TA was calculated using Eq. (4) and expressed as the percentage of citric acid, which is the major organic acid present in ripe guava fruit [29]:

$$\text{Percentage of citric acid } (\%) = [(0.1 \text{ x V x W}) / (\text{M x } 1000)]\text{x } 100$$

Where V is the volume of titrant; W is the equivalent weight of acid (70); and M is the mass of the sample.

2.7. Microbiological analysis

The microbiological shelf life was determined according to the methods described by Poubol et al. [30] with slight modifications. Guava samples (10 g) were added to 90 mL of 0.1 % peptone water and homogenised for 60 s in an InterScience BagMixer 400-P stomacher (Saint-Nom-la-Bretèche, France). Serial dilutions were prepared by pipetting 1 mL of the solution into 9 mL of 0.1 % peptone water. Then, 0.1 mL of the diluted homogenate was pipetted onto plate count agar and incubated at 7 °C for 10 days for aerobic psychrotrophic bacteria and potato dextrose agar incubated at 35 °C for 5 days for yeast and mould. The number of colonies was determined and the results were expressed as $\log_{10}$ colony forming units per mL ($\log_{10}$ CFU/mL).

2.8. Statistical analysis

All analyses were performed in duplicate (with two sets of fruit per coating formulations) except for the firmness and colour

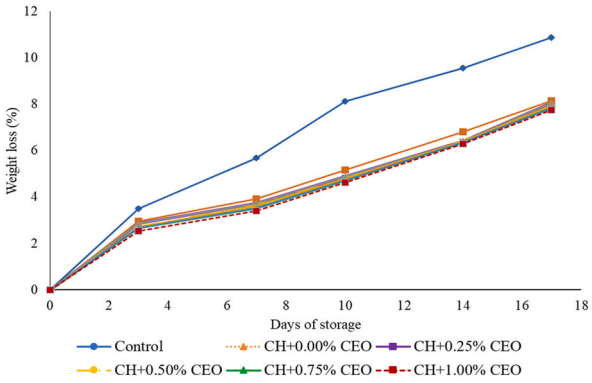

Fig. 1. The weight loss of uncoated (control) and chitosan (CH) and cinnamon essential oil (CEO) coated fresh-cut guavas for 17 days storage.

analysis which were performed in triplicate. The data were reported as the mean ± standard deviation and subjected to the one-way analysis of variance (ANOVA) using Minitab software (Version 16.; Minitab Inc., State College, Pennsylvania, USA). The differences between each formulation and days of storage were determined by using Tukey's multiple-range tests at a 95 % confidence level.

3. Results and discussion

3.1. Physical properties

3.1.1. Weight loss

The guava weight loss results are presented in Fig. 1, showing that there was a significant ($p < 0.05$) increase in the per cent weight loss for all samples throughout the storage period. Weight loss in fresh fruit is mainly due to water loss during respiration and transpiration [31,32]. Dehydration can occur easily especially at the cut surfaces as the removal of peels exposes the internal tissue of the fruit [26]. Also, according to Díaz-Mula et al. [33], the difference in the water vapour pressure gradient between the internal part of the fruit and the external environment will result in the loss of moisture from fresh-cut fruit to the surrounding environment via vapour phase diffusion.

The control sample consistently showed the highest per cent weight loss ($p < 0.05$) compared to the other treatments. Bovi et al. [34] reported that the heat generated during respiration could increase the temperature leading to an increase in the transpiration rate. Samples coated with CH had reduced ($p < 0.05$) weight loss than the control, indicating that CH can form a semi-transparent protective barrier against oxygen and carbon dioxide which eventually reduces the respiration rate [29]. Hence, by lowering the respiration activity, transpiration can be reduced. Rayees et al. [35] also reported that CH acts as a physical barrier to moisture loss, thereby delaying dehydration and fruit shrivelling. These findings were also consistent with the observations of Hasan et al. [4] who studied alginate coatings for guava.

Meanwhile, samples coated with both CH and CEO had significantly ($p < 0.05$) lower per cent weight loss than the control and sample coated with only CH. The value continued to decrease significantly ($p < 0.05$) with higher CEO concentrations. The presence of hydrophobic CEO further improved the water barrier properties of the CH coating, thereby reducing the transpiration rate. This was consistent with the result obtained by Botelho et al. [36], who studied on the whole guava fruit at a room temperature treated with starch and CEO. CH with lemongrass oil also delayed the weight loss of this fruit [37] for 10 days cold storage. However, their weight loss at 10 days was around 20 %; higher than this finding (4.63 % at 1 % CEO).

3.1.2. Firmness

Firmness is a measurement of texture which is important in determining customer acceptability. The initial firmness of all samples on Day 0 ranged from 7.18 to 7.24 N, with no significant difference ($p \geq 0.05$) observed between the samples (Fig. 2). However, all samples exhibited a significant ($p < 0.05$) reduction in firmness throughout the storage period. Softening of fruit can be linked to the metabolism of cell wall carbohydrates due to the action of hydrolytic enzymes, which promotes pectin solubilisation to eventually dismantle the primary cell wall and middle lamella structure [38].

All coated samples were significantly ($p < 0.05$) firmed than the control, irrespective of the storage time. As discussed previously, the CH coating may act as a barrier that limits oxygen permeation to delay respiration and fruit ripening. According to Forato et al. [26], guava softening is affected by the ethylene concentration as it can intensify the enzymatic activity of the cell wall components causing tissue flaccidity. Since the level of ethylene production is strongly related to the respiration rate [26], slowing down the respiration rate is key to preserving fresh-cut guava firmness. The effectiveness of CH coating on the retention of fruit firmness has been reported for strawberries [39], melon [10] and guavas [29].

The incorporation of CEO further improved the firmness retention of the fresh-cut guavas and increased significantly ($p < 0.05$) with CEO concentration. The presence of CEO may prevent microbial infection as well as reduce respiration and other ripening processes during storage. The effectiveness of CEO in lowering the rate of ripening and deterioration has also been reported by Botelho

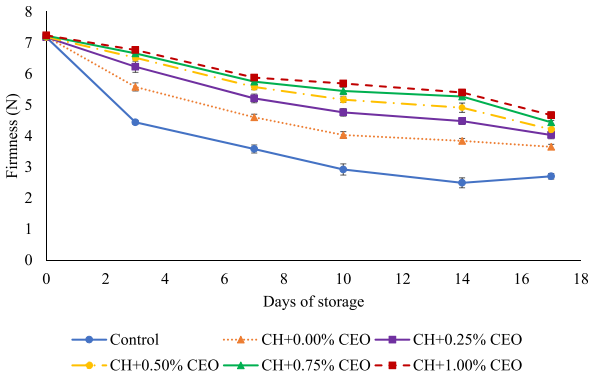

Fig. 2. The firmness of uncoated (control) and chitosan (CH) and cinnamon essential oil (CEO) coated fresh-cut guavas for 17 days storage.

et al. [36]. Also, increasing EO helped to increase the barrier properties of the coating by reducing the respiration rate and increasing the resistance towards water vapour. This is supported by Bhandari et al. [40] who reported that EO forms a thin film around the fruit surface and changes the fruit microclimate, consequently reducing moisture loss, respiration and ethylene production.

3.1.3. Colour

The changes in the colour parameters of fresh-cut guavas are presented in Table 1, showing the L* (lightness) of all the samples decreased significantly ($p < 0.05$), whereas the a* (redness) and b* (yellowness) values significantly ($p < 0.05$) increased throughout storage. This indicates surface browning which can be associated with water-soaking symptoms. The effect was more apparent in the control sample as the colour parameters were significantly ($p < 0.05$) lower in the control sample compared to the other coated fresh-cut guavas. The incorporation of higher concentrations of CEO further improved ($p < 0.05$) the colour retention of fresh-cut guavas. A similar effect was reported by Barreto et al. [41], who observed better colour retention of cherry tomato fruit coated with chitosan and essential oil *Origanum vulgare* L. The visual appearance of coated guava is shown in the Appendix.

The colour changes may be used to indicate the level of maturity as ripening results in the degradation of chlorophylls, leaving only carotenoids that cause the yellowish tinge [26]. According to Hong et al. [29], the CH coating preserves the chlorophyll content in guavas by modifying the internal atmosphere to suppress ethylene production [28]. As the ripening and senescence were delayed, the colour changes will also be retarded. The preservation effect of CH coating on the chlorophyll content had been proven on sweet pepper [24] and guava [29]. The incorporation of CEO further delays the ripening process by slowing down the respiration rate to protect the fruit from being oxidised. Besides, CEO also acts as an anti-browning agent due to the presence of cinnamaldehyde, which exhibits good antioxidant capacities and inhibits the enzymatic activities that may be responsible for physiological deterioration [23, 42]. Furthermore, the antimicrobial properties of both CH and CEO may also prevent any surface discolouration of the fresh-cut fruit.

The results were further confirmed by the rapid decline ($p < 0.05$) of the hue angle (H*) in which the effect was most noticeable in the control sample. The H* values decreased from the green quadrant (180°) towards the yellow quadrant (90°), which represents the characteristic climacteric fruit ripening [43]. The reduction of the H* values may also reflect the development of tissue browning as the H* values towards 0° represent the red quadrant [44]. The lowest H* of the control sample may be attributed to the accelerated ripening process whereas the higher H* value in the CH-CEO coated samples indicates the effectiveness of the coating mixture in delaying ripening and inhibiting browning in guavas [45].

Table 1
The colour properties of uncoated (control) and chitosan (CH) and cinnamon essential oil (CEO) coated fresh-cut guavas.

Sample	Days of storage					
	0	3	7	10	14	17
*L** (lightness)						
Control	82.62 ± 0.19^{aA}	77.99 ± 0.20^{bE}	75.66 ± 0.25^{cF}	74.96 ± 0.07^{dE}	774.06 ± 0.16^{eD}	73.68 ± 0.12^{eD}
CH+0.00 % CEO	83.38 ± 0.12^{aA}	82.08 ± 0.37^{bD}	80.45 ± 0.11^{cE}	79.47 ± 0.27^{cdD}	779.11 ± 0.29^{cdC}	77.72 ± 0.10^{dC}
CH+0.25 % CEO	83.74 ± 0.17^{aA}	83.00 ± 0.20^{bBC}	81.32 ± 0.19^{cD}	80.60 ± 0.21^{dD}	779.35 ± 0.14^{eC}	78.09 ± 0.05^{fC}
CH+0.50 % CEO	83.44 ± 0.12^{aA}	82.76 ± 0.20^{bC}	81.91 ± 0.20^{cC}	81.41 ± 0.13^{cC}	880.76 ± 0.09^{dB}	79.51 ± 0.29^{eB}
CH+0.75 % CEO	84.10 ± 0.08^{aA}	83.43 ± 0.11^{bB}	82.64 ± 0.06^{cB}	81.56 ± 0.29^{dB}	881.67 ± 0.16^{dB}	79.83 ± 0.25^{eB}
CH+1.00 % CEO	83.42 ± 0.25^{aA}	84.08 ± 0.13^{abA}	83.45 ± 0.17^{abA}	82.81 ± 0.25^{bA}	881.80 ± 0.10^{cA}	80.81 ± 0.57^{dA}
*a** (redness)						
Control	-1.63 ± 0.06^{fA}	-0.42 ± 0.05^{eA}	1.28 ± 0.05^{dA}	1.58 ± 0.07^{cA}	1.92 ± 0.13^{bA}	2.13 ± 0.05^{aA}
CH+0.00 % CEO	-1.76 ± 0.05^{fAB}	-1.21 ± 0.06^{eB}	-0.17 ± 0.07^{dB}	0.87 ± 0.04^{cB}	1.56 ± 0.06^{bB}	1.91 ± 0.04^{aB}
CH+0.25 % CEO	-1.82 ± 0.04^{fBC}	-1.43 ± 0.04^{eC}	-0.95 ± 0.10^{dC}	0.27 ± 0.03^{cC}	0.77 ± 0.04^{bC}	1.53 ± 0.05^{aC}
CH+0.50 % CEO	-1.90 ± 0.05^{fBC}	-1.51 ± 0.05^{eC}	-1.08 ± 0.07^{dCD}	0.29 ± 0.04^{cC}	0.67 ± 0.03^{bCD}	1.43 ± 0.04^{aCD}
CH+0.75 % CEO	-1.86 ± 0.07^{fBC}	-1.54 ± 0.06^{eC}	-1.09 ± 0.05^{dCD}	0.23 ± 0.03^{cCD}	0.59 ± 0.02^{bD}	1.35 ± 0.02^{aD}
CH+1.00 % CEO	-1.96 ± 0.07^{fC}	-1.69 ± 0.05^{eD}	-1.26 ± 0.10^{dD}	0.21 ± 0.06^{cCD}	0.55 ± 0.03^{bD}	1.28 ± 0.01^{aE}
*b** (yellowness)						
Control	13.93 ± 0.04^{fA}	15.70 ± 0.05^{eA}	17.83 ± 0.07^{dA}	18.89 ± 0.07^{cA}	20.16 ± 0.04^{bA}	22.79 ± 0.06^{aA}
CH+0.00 % CEO	13.83 ± 0.08^{fA}	15.13 ± 0.03^{eB}	16.71 ± 0.04^{dB}	17.69 ± 0.06^{cB}	18.63 ± 0.07^{bB}	20.80 ± 0.10^{aB}
CH+0.25 % CEO	13.62 ± 0.04^{fB}	14.83 ± 0.06^{eC}	15.82 ± 0.03^{dC}	16.56 ± 0.08^{cC}	17.30 ± 0.05^{bC}	19.32 ± 0.05^{aC}
CH+0.50 % CEO	13.55 ± 0.03^{fBC}	14.74 ± 0.02^{eCD}	15.73 ± 0.04^{dCD}	16.43 ± 0.03^{cC}	17.14 ± 0.08^{bD}	19.02 ± 0.05^{aD}
CH+0.75 % CEO	13.51 ± 0.02^{fBC}	14.73 ± 0.02^{eCD}	15.61 ± 0.08^{dD}	16.21 ± 0.09^{cD}	16.92 ± 0.03^{bE}	18.68 ± 0.06^{aE}
CH+1.00 % CEO	13.47 ± 0.03^{fC}	14.66 ± 0.03^{eD}	15.41 ± 0.09^{dE}	15.95 ± 0.07^{cE}	16.68 ± 0.05^{bF}	18.37 ± 0.08^{aF}
h_{ab} (hue angle)						
Control	96.66 ± 0.22^{aD}	91.53 ± 0.17^{bD}	85.89 ± 0.15^{cD}	85.23 ± 0.23^{dC}	84.57 ± 0.39^{deD}	84.65 ± 0.13^{eE}
CH+0.00 % CEO	97.24 ± 0.21^{aCD}	94.56 ± 0.21^{bC}	90.59 ± 0.24^{cC}	87.18 ± 0.12^{dB}	85.22 ± 0.21^{eC}	84.76 ± 0.12^{eD}
CH+0.25 % CEO	97.61 ± 0.17^{aBC}	95.49 ± 0.15^{bB}	93.44 ± 0.35^{cB}	89.08 ± 0.11^{dA}	87.57 ± 0.31^{eB}	85.48 ± 0.15^{fC}
CH+0.50 % CEO	97.99 ± 0.18^{aBC}	95.85 ± 0.18^{bB}	93.93 ± 0.24^{cB}	88.99 ± 0.15^{dA}	87.76 ± 0.10^{eAB}	85.69 ± 0.11^{fBC}
CH+0.75 % CEO	97.84 ± 0.26^{aB}	95.98 ± 0.20^{bB}	93.99 ± 0.17^{cAB}	89.19 ± 0.10^{dA}	87.99 ± 0.07^{eAB}	85.88 ± 0.05^{fB}
CH+1.00 % CEO	98.26 ± 0.27^{aA}	96.56 ± 0.18^{bA}	94.68 ± 0.35^{cA}	89.25 ± 0.20^{dA}	88.13 ± 0.09^{eA}	86.01 ± 0.04^{fA}

Values are mean ± standard deviation (n = 3). Mean values with different superscript letters are significantly different ($p < 0.05$) based on Tukey's test. Small letter alphabets indicate comparisons horizontally between days of storage. Capital letter alphabets indicate comparisons vertically between samples.

3.2. Biochemical properties

3.2.1. Total soluble solid content

Fig. 3 shows that the TSS content of all samples increased significantly ($p < 0.05$) throughout storage. The ripening of climacteric fruit such as guava may give rise to the TSS content due to polysaccharide degradation [1], whereby starch is broken down into soluble sugar, resulting in a flavour change, especially in terms of sweetness [28]. In general, the coated samples exhibited a significantly ($p < 0.05$) lower TSS than the control sample. According to Foo et al. [46] who applied CH on sapodilla fruit, the CH coating limits gaseous exchange, thereby reducing oxygen and ethylene levels while elevating carbon dioxide. This suppresses respiration and ripening, eventually slowing down the hydrolysis of carbohydrates to sugar [47]. Han et al. [48] reported the effectiveness of the CH coating in reducing respiration as well as the TSS content of sponge gourd (*Luffa cylindrica*) fruit.

This effect of coating was more prominent with the incorporation of CEO as reflected by an even lower ($p < 0.05$) TSS content in samples coated with CH + CEO. The incorporation of essential oils into the CH coating can further enhance the resistance of the coating to gas diffusion due to the lipophilic nature of the essential oils [44]. Hence, the combined function of CH and CEO coating could effectively slow down ripening [49], similar to that reported by Saki et al. [15] who observed a significantly lower TSS content in fresh fig (*Ficus carica* L.) fruit coated with CH and essential oil.

3.2.2. Titratable acidity

The compositional change in terms of the TA is crucial to understand its metabolic processes such as ripening and senescence, which may affect the quality. The TA of all samples (Fig. 4) significantly ($p < 0.05$) decreased throughout storage, with the non-coated sample (control) decreasing the most. These results agree with the findings of Sharma and Saini [1] who investigated on fresh-cut guavas (*Psidium guajava*). The change in the TA of climacteric fruit is typically influenced by its metabolic activities, especially respiration because other than sugar, respiration also consumes organic acids which may decrease the acidity [50].

All coated samples exhibited a greater TA ($p < 0.05$) than the control sample and the values increased significantly ($p < 0.05$) with higher CEO concentration. Similar results were reported in various CH-coated fruit; fresh fig and china jujube fruits [15,23]. As discussed previously, the CH coating, especially in the presence of CEO, may act as a barrier to reduce respiration and ripening, thereby preserving the fruit quality for an extended period. The result obtained was consistent with the TSS results (Fig. 3) which further supported the findings.

3.3. Microbiological properties

Table 2 presents the aerobic psychrotrophic microbial count of all samples at Day 0 which ranged from 3.85 to 3.98 $\log_{10}$ CFU/mL and were not significantly ($p > 0.05$) different between samples. The microbial counts increased significantly ($p < 0.05$) with storage and the control sample exhibited a higher microbial count ($p < 0.05$) than the other coated guavas. The aerobic psychrotrophic microbial count of the control sample exceeded the microbial acceptance limit of 6 $\log_{10}$ CFU/mL [45] after 10 days while the other coated guavas were below the limit for up to 14 or 17 days depending on the CEO concentration. Overall, the microbial resistance of the fresh-cut guavas was significantly ($p < 0.05$) higher when coated with CH and it improved significantly ($p < 0.05$) with the incorporation of higher CEO concentrations.

These results may be due to the antimicrobial properties of CH and CEO which can delay the proliferation of microorganisms, thereby lengthening the shelf life of the fresh-cut guavas. The antimicrobial activity of CH has been widely reported [51,52] and the mechanism of action is closely related to the interaction between the polycationic CH molecules with the anionic microbial cell membranes resulting in molecular cell leakage [53]. The CH molecules can also permeate the microbial cell nucleus to prevent the synthesis of mRNA and protein as well as acting as a metal chelator to inhibit microbial growth [51] The antimicrobial activity of CEO is attributed to the large amount of *trans*-cinnamaldehyde that penetrates the microbial cell wall to cause irreversible structural and

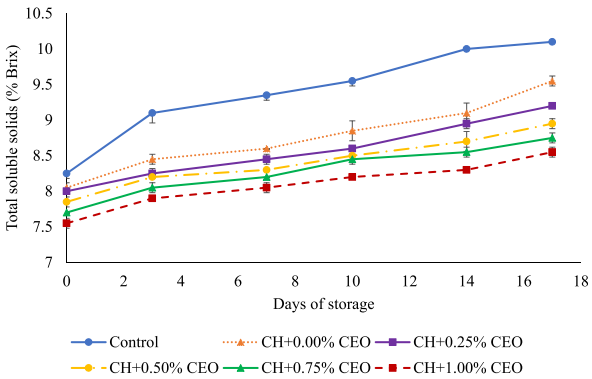

Fig. 3. The total soluble solids of uncoated (control) and chitosan (CH) and cinnamon essential oil (CEO) coated fresh-cut guavas for 17 days storage.

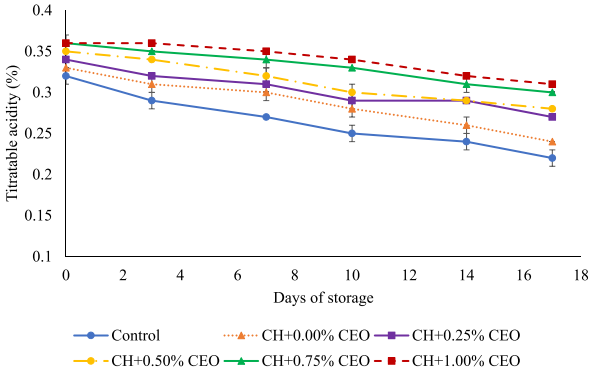

Fig. 4. The titratable acidity of uncoated (control) and chitosan (CH) and cinnamon essential oil (CEO) coated fresh-cut guavas for 17 days storage.

Table 2
The microbiological property of uncoated (control) and chitosan (CH) and cinnamon essential oil (CEO) coated fresh-cut guavas.

Sample	Days of storage					
	0	3	7	10	14	17
Aerobic plate count (log_{10} CFU/ml)						
Control	3.98 ± 0.02^{eA}	4.47 ± 0.01^{dA}	5.32 ± 0.01^{cA}	6.10 ± 0.01^{bA}	6.18 ± 0.01^{aA}	6.14 ± 0.01^{abA}
CH+0.00 % CEO	3.94 ± 0.01^{fAB}	4.20 ± 0.01^{eB}	4.74 ± 0.04^{dB}	5.39 ± 0.01^{cB}	6.05 ± 0.02^{bB}	6.13 ± 0.01^{aA}
CH+0.25 % CEO	3.91 ± 0.01^{fBC}	4.12 ± 0.01^{eC}	4.46 ± 0.01^{dC}	5.09 ± 0.02^{cC}	5.71 ± 0.03^{bC}	6.07 ± 0.01^{aB}
CH+0.50 % CEO	3.89 ± 0.01^{fBC}	4.07 ± 0.01^{eCD}	4.39 ± 0.01^{dCD}	4.98 ± 0.01^{cD}	5.56 ± 0.04^{bD}	5.93 ± 0.01^{aC}
CH+0.75 % CEO	3.87 ± 0.01^{fC}	4.03 ± 0.02^{eDE}	4.34 ± 0.01^{dDE}	4.89 ± 0.03^{cE}	5.45 ± 0.01^{bE}	5.80 ± 0.01^{aD}
CH+1.00 % CEO	3.85 ± 0.01^{fC}	3.98 ± 0.01^{eE}	4.29 ± 0.03^{dE}	4.81 ± 0.02^{cE}	5.33 ± 0.02^{bF}	5.70 ± 0.04^{aE}
Yeast and mould plate count (log_{10} CFU/ml)						
Control	4.38 ± 0.01^{eA}	6.05 ± 0.03^{dA}	6.28 ± 0.01^{cA}	6.36 ± 0.01^{bA}	6.44 ± 0.01^{aA}	6.46 ± 0.01^{aA}
CH+0.00 % CEO	4.17 ± 0.01^{fB}	5.21 ± 0.01^{eB}	5.56 ± 0.03^{dB}	6.03 ± 0.01^{cB}	6.17 ± 0.02^{bB}	6.33 ± 0.01^{aB}
CH+0.25 % CEO	4.12 ± 0.01^{fBC}	5.09 ± 0.01^{eC}	5.34 ± 0.00^{dC}	5.69 ± 0.04^{cC}	5.95 ± 0.02^{bC}	6.11 ± 0.01^{aC}
CH+0.50 % CEO	4.07 ± 0.02^{fC}	5.04 ± 0.01^{eCD}	5.30 ± 0.01^{dC}	5.61 ± 0.02^{cCD}	5.87 ± 0.01^{bD}	6.03 ± 0.01^{aD}
CH+0.75 % CEO	4.02 ± 0.01^{fCD}	4.99 ± 0.02^{eDE}	5.24 ± 0.01^{dD}	5.53 ± 0.02^{cDE}	5.80 ± 0.01^{bD}	5.94 ± 0.01^{aE}
CH+1.00 % CEO	3.97 ± 0.01^{fD}	4.92 ± 0.01^{eE}	5.18 ± 0.01^{dE}	5.45 ± 0.01^{cE}	5.71 ± 0.02^{bE}	5.83 ± 0.03^{aF}

Values are mean ± standard deviation (n = 2). Mean values with different superscript letters are significantly different ($p < 0.05$) based on Tukey's test.
Small letter alphabets indicate comparisons horizontally between days of storage. Capital letter alphabets indicate comparisons vertically between samples.

morphological damage [54]. Zhang et al. [20] and Manso et al. [55] reported the antimicrobial effects of the CEO, respectively.

4. Conclusion

This study determined the effectiveness of CH and CEO coating In extending the shelf life of fresh-cut guavas at a low temperature. The higher CEO concentration (up to 1 %) in the CH coating resulted in better preservation of weight loss, flesh firmness, colour, TSS and TA, quality aspects associated with delayed ripening and characteristic of the CH and CEO components. Moreover, the microbial spoilage of fresh-cut guavas was also delayed due to the effective antimicrobial properties of both CH and CEO, with the CH coating containing the highest CEO concentration best preserving the quality and shelf life (up to 17 days) compared to the control (3 days). These findings revealed the potential of this coating in postharvest production, but further studies are required to determine the organoleptic properties of fresh-cut guava to ensure the coated guava is accepted by consumers.

Data availability statement

All data contained within this article.

Funding declaration

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CRediT authorship contribution statement

Z.A. Nur Hanani: Writing – review & editing, Supervision, Project administration, Conceptualization. **K.L. Soo:** Writing – original draft, Investigation. **W.I. Wan Zunairah:** Visualization. **S. Radhiah:** Visualization, Data curation.

Declaration of competing interest

The authors declare that there is no conflict of interest.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.heliyon.2023.e22419.

References

[1] M. Sharma, C.S. Saini, Postharvest shelf-life extension of fresh-cut guavas (*Psidium guajava*) using flaxseed protein-based composite coatings, Food Hydrocolloids for Health 1 (2021), 100015.
[2] S. Nimisha, D. Kherwar, K.M. Ajay, B. Singh, K. Usha, Molecular breeding to improve guava (*Psidium guajava* L.): current status and future prospective, Sci. Hortic. 164 (2013) 578–588.
[3] C.B. Francisco, M.G. Pellá, O.A. Silva, K.F. Raimundo, J. Caetano, G.A. Linde, N.B. Colauto, D.C. Dragunski, Shelf-life of guavas coated with biodegradable starch and cellulose-based films, Int. J. Biol. Macromol. 152 (2020) 272–279.
[4] K. Hasan, R. Islam, M. Hasan, S.H. Sarker, M.H. Biswas, Effect of alginate edible coatings enriched with black cumin extractfor improving postharvest quality characteristics of guava (*Psidium guajava* L.) fruit, Food Bioprocess Technol. 15 (2022) 2050–2064.
[5] A. Nima, O. Azizah, M.G. Hasanah, C.P. Tan, M.A. Noranizan, Lemongrass essential oil incorporated into alginate-based edible coating for shelf-life extension and quality retention of fresh-cut pineapple, Postharvest Biol. Technol. 88 (2014) 1–7.
[6] M. Guevara, M.S. Tapia, V.M. Gómez-López, Microbial inactivation and quality of guava and passion fruit nectars treated by UV-C light, Food Bioprocess Technol. 5 (2012) 803–807.
[7] N.H. Noguera, D.C. Lima, E.G.H. Filho, T.V. Fonteles, S. Rodrigues, Influence of different non-thermal processing on guava, orange, and tangerine juices and the food matrix effects, Food Bioprocess Technol. 14 (2021) 1662–1672.
[8] B. Yousuf, S. Wu, M.W. Siddiqui, Incorporating essential oils or compounds derived thereof into edible coatings: effect on quality and shelf life of fresh/fresh-cut produce, Trends Food Sci. Technol. 108 (2021) 245–257.
[9] C. Agarwal, Z. Kóczán, Z. Börcsök, K. Halász, Z. Pásztory, Valorization of *Larix decidua* Mill. bark by functionalizing bioextract onto chitosan films for sustainable active food packaging, Carbohydr. Polym. 271 (2021), 118409.
[10] R.L. Carvalho, M.F. Cabral, T.A. Germano, W.M. de Carvalho, I.M. Brasil, M.I. Gallão, C.F.H. Moura, M.M.A. Lopes, M.R.A. de Miranda, Chitosan coating with *trans*-cinnamaldehyde improves structural integrity and antioxidant metabolism of fresh-cut melon, Postharvest Biol. Technol. 113 (2016) 29–39.
[11] M. Petriccione, F.D. Sanctis, M.S. Pasquariello, F. Mastrobuoni, P. Rega, M. Scortichini, F. Mencarelli, The effect of chitosan coating on the quality and nutraceutical traits of sweet cherry during postharverst life, Food Bioprocess Technol. 8 (2015) 394–408.
[12] H. Fang, Q. Zhou, Q. Yang, X. Zhou, S. Cheng, B. Wei, J. Li, S. Ji, Influence of combined edible coating with chitosan and tea polyphenol on the quality deterioration and health-promoting compounds in harvested broccoli, Food Bioprocess Technol. 15 (2022) 407–420.
[13] N. Robledo, L. López, A. Bunger, C. Tapia, L. Abugoch, Effects of antimicrobial edible coating of thymol nanoemulsion/quinoa protein/chitosan on the safety, sensorial properties, and quality of refrigerated strawberries (*Fragaria* × *ananassa*) under commercial storage environment, Food Bioprocess Technol. 11 (2018) 1566–1574.
[14] A. Perdones, L. Sánchez-González, A. Chiralt, M. Vargas, Effect of chitosan-lemon essential oil coatings on storage-keeping quality of strawberry, Postharvest Biol. Technol. 70 (2012) 32–41.
[15] M. Saki, B. ValizadehKaji, A. Abbasifar, I. Shahrjerdi, Effect of chitosan coating combined with thymol essential oil on physicochemical and qualitative properties of fresh fig (*Ficus carica* L.) fruit during cold storage, J. Food Meas. Char. 13 (2019) 1147–1158.
[16] X. Liu, L. Chen, Y. Kang, D. He, B. Yang, K. Wu, Cinnamon essential oil nanoemulsions by high-pressure homogenization: formulation, stability, and antimicrobial activity, LWT 147 (2021), 111660.
[17] W. Chen, D.A. Golden, F.J. Critzer, P.M. Davidson, Antimicrobial activity of cinnamaldehyde, carvacrol, and lauric arginate against *Salmonella tennessee* in a glycerol-sucrose model and peanut paste at different fat concentrations, J. Food Protect. 78 (2015) 1488–1495.
[18] I. Clemente, M. Aznar, F. Silva, C. Nerín, Antimicrobial properties and mode of action of mustard and cinnamon essential oils and their combination against foodborne bacteria, Innovat. Food Sci. Emerg. Technol. 36 (2016) 26–33.
[19] S. Shreaz, W.A. Wani, J.M. Behbehani, V. Raja, M. Irshad, M. Karched, I. Ali, W.A. Siddiqi, L.T. Hun, Cinnamaldehyde and its derivatives, a novel class of antifungal agents, Fitoterapia 112 (2016) 116–131.
[20] Y. Zhang, X. Liu, Y. Wang, P. Jiang, S.Y. Quek, Antibacterial activity and mechanism of cinnamon essential oil against *Escherichia coli* and *Staphylococcus aureus*, Food Control 59 (2016) 282–289.
[21] R. Syafiq, S.M. Sapuan, M.R.M. Zuhri, Antimicrobial activity, physical, mechnical and barrier properties of sugar palm based nanocellulose/starch biocomposite films incorporated with cinnamon essential oil, J. Mater. Res. Technol. 11 (2021) 144–157.
[22] S. Bahram, M. Rezaei, M. Soltani, A. Kamali, S.M. Ojagh, M. Abdollahi, Whey protein concentrate edible film activated with cinnamon essential oil, J. Food Process. Preserv. 38 (2014) 1251–1258.
[23] Y. Xing, H. Lin, D. Cao, Q. Xu, W. Han, R. Wang, Z. Che, X. Li, Effect of chitosan coating with cinnamon oil on the quality and physiological attributes of China jujube fruits, BioMed Res. Int. 2 (2015) 1–10.
[24] Y. Xing, X. Li, Q. Xu, J. Yun, Y. Lu, Y. Tang, Effects of chitosan coating enriched with cinnamon oil on qualitative properties of sweet pepper (*Capsicum annuum* L.), Food Chem. 124 (2011) 1443–1450.
[25] A. Mohammadi, M. Hashemi, S.M. Hosseini, Chitosan nanoparticles loaded with *Cinnamomum zeylanicum* essential oil enhance the shelf life of cucumber during cold storage, Postharvest Biol. Technol. 110 (2015) 203–213.

[26] L.A. Forato, D. de Britto, J.S. de Rizzo, T.A. Gastaldi, O.B.G. Assis, Effect of cashew gum-carboxymethylcellulose edible coatings in extending the shelf-life of fresh and cut guavas, Food Packag. Shelf Life 5 (2015) 68–74.
[27] N. Zuraidah, W.Y. Justine Ng, H. Yusnita, Characteristics of fresh-cut guava coated with aloe vera gel as affected by different additives, Kasetsart J./Nat. Sci. 49 (2015) 111–121.
[28] P. Jongsri, T. Wangsomboondee, P. Rojsitthisak, K. Seraypheap, Effect of molecular weights of chitosan coating on postharvest quality and physicochemical characteristics of mango fruit, LWT–Food Sci. Technol. 73 (2016) 28–36.
[29] K. Hong, J. Xie, L. Zhang, D. Sun, D. Gong, Effects of chitosan coating on postharvest life and quality of guava (*Psidium guajava* L.) fruit during cold storage, Sci. Hortic. 144 (2012) 172–178.
[30] J. Poubol, C. Techavuthiporn, S. Kanlayanarat, Guava fruit treated with hot water on microbiological quality of fresh-cut 'Kimju' and 'Pan Srithong' guava, Int. Food Res. J. 25 (2018) 903–907.
[31] M.A. Rehman, M.R. Asi, A. Hameed, L.D. Bourquin, Effect of postharvest application of aloe vera gel on shelf life,activities of anti-oxidative enzymes, and quality of "gola" guavafruit, Foods 9 (10) (2020) 1–16.
[32] L. Zhang, F. Chen, S. Lai, H. Wang, H. Yang, Impact of soybean protein isolate-chitosan edible coating on the softening of apricot fruit during storage, LWT–Food Sci. Technol. 96 (2018) 604–611.
[33] H.M. Díaz-Mula, M. Serrano, D. Valero, Alginate coatings preserve fruit quality and bioactive compounds during storage of sweet cherry fruit, Food Bioprocess Technol. 5 (2012) 2990–2997.
[34] G.G. Bovi, O.J. Caleb, M. Linke, C. Rauh, P.V. Mahajan, Transpiration and moisture evolution in packaged fresh horticultural produce and the role of integrated mathematical models: a review, Biosyst. Eng. 150 (2016) 24–39.
[35] A.S. Rayees, A.M. Maqsood, A. al-T. Shaeel, A.S. Muneer, Chitosan as a novel edible coating for fresh fruits, Food Sci. Technol. Res. 19 (2013) 139–155.
[36] L.N.S. Botelho, D.A. Rocha, M.A. Braga, A. Silva, C.M.P. de Abreu, Quality of guava cv. 'Pedro Sato' treated with cassava starch and cinnamon essential oil, Sci. Hortic. 209 (2016) 214–220.
[37] L.I.G. De Oliveira, K.Á.R. de Oliveira, E.S. de Medeiros, A.U.D. Batista, M.S. Madruga, M.D.S. Lima, E.L. de Souza, M. Magnani, Characterization and efficacy of a composite coating containing chitosan and lemongrass essenstial oil on postharverst quality of guava, Innovative Food Sci. Emerging Technol. 66 (2020), 102506.
[38] H. Chen, S. Cao, X. Fang, H. Mu, H. Yang, X. Wang, Q. Xu, H. Gao, Changes in fruit firmness, cell wall composition and cell wall degrading enzymes in postharvest blueberries during storage, Sci. Hortic. 188 (2015) 44–48.
[39] M. Petriccione, F. Mastrobuoni, M.S. Pasquariello, L. Zampella, E. Nobis, G. Capriolo, M. Scortichini, Effect of chitosan coating on the postharvest quality and antioxidant enzyme system response of strawberry fruit during cold storage, Foods 4 (2015) 501–523.
[40] N. Bhandari, R. Bika, S. Subedi, S. Pandey, Essential oils amended coatings in citrus postharvest management, Journal of Agriculture and Food research 10 (2022), 100375.
[41] T.A. Barreto, S.C.A. Andrade, J.F. Maciel, N.M.O. Arcanjo, M.S. Madruga, B. Meireles, Â.M.T. Cordeiro, E.L. Souza, M. Magnani, A chitosan coating containing essential oil from *Origanum vulgare* L. to control postharvest mold infections and keep the quality of cherry tomato fruit, Front. Microbiol. 7 (2016) 1–14.
[42] P. Jin, X. Wu, F. Xu, X. Wang, J. Wang, Y. Zheng, Enhancing antioxidant capacity and reducing decay of Chinese bayberries by essential oils, J. Agric. Food Chem. 60 (2012) 3769–3775.
[43] J.R. de Abreu, C.D. dos Santos, C.M.P. de Abreu, A.C.M. Pinheiro, A.D. Corrêa, Ripening pattern of guava cv. Pedro Sato, Food Sci. Technol. 32 (2012) 344–350.
[44] L. Sánchez-González, M. Cháfer, M. Hernández, A. Chiralt, C. González-Martínez, Antimicrobial activity of polysaccharide films containing essential oils, Food Control 22 (2011) 1302–1310.
[45] A.B. de Aquino, A.F. Blank, L.C.L. De Aquino Santana, Impact of edible chitosan-cassava starch coatings enriched with *Lippia gracilis* Schauer genotype mixtures on the shelf life of guavas (*Psidium guajava* L.) during storage at room temperature, Food Chem. 171 (2015) 108–116.
[46] S.Y. Foo, Z.A. Nur Hanani, A. Rozzamri, W.Z.W. Ibadullah, M.R. Ismail-Fitry, Effect of chitosan–beeswax edible coatings on the shelf-life of sapodilla (*Achras zapota*) fruit, J. Packag. Technol. Res. 3 (2019) 27–34.
[47] A. Ali, M.T.M. Muhammad, K. Sijam, Y. Siddiqui, Effect of chitosan coatings on the physicochemical characteristics of Eksotika II papaya (*Carica papaya* L.) fruit during cold storage, Food Chem. 124 (2011) 620–626.
[48] C. Han, J. Zuo, Q. Wang, L. Xu, B. Zhai, Z. Wang, H. Dong, L. Gao, Effects of chitosan coating on postharvest quality and shelf life of sponge gourd (*Luffa cylindrica*) during storage, Sci. Hortic. 166 (2014) 1–8.
[49] Y. Xing, X. Li, Q. Xu, J. Yun, Y. Lu, Extending the shelf life of fresh-cut lotus root with antibrowning agents, cinnamon oil fumigation and moderate vacuum packaging, J. Food Process. Eng. 35 (2012) 505–521.
[50] I. Khalifa, H. Barakat, H.A. El-Mansy, S.A. Soliman, Enhancing the keeping quality of fresh strawberry using chitosan-incorporated olive processing wastes, Food Biosci. 13 (2016) 69–75.
[51] R.-C. Chien, M.-T. Yen, J.-L. Mau, Antimicrobial and antitumor activities of chitosan from shiitake stipes, compared to commercial chitosan from crab shells, Carbohydr. Polym. 138 (2016) 259–264.
[52] Z. Kalaycıoğlu, E. Torlak, G. Akın-Evingür, İ. Özen, F.B. Erim, Antimicrobial and physical properties of chitosan films incorporated with turmeric extract, Int. J. Biol. Macromol. 101 (2017) 882–888.
[53] J. Hafsa, M.A. Smach, M.R. Ben Khedher, B. Charfeddine, K. Limem, H. Majdoub, S. Rouatbi, Physical, antioxidant and antimicrobial properties of chitosan films containing *Eucalyptus globulus* essential oil, LWT–Food Sci. Technol. 68 (2016) 356–364.
[54] Y. Xing, Q. Xu, S.X. Yang, C. Chen, Y. Tang, S. Sun, L. Zhang, Z. Che, X. Li, Preservation mechanism of chitosan-based coating with cinnamon oil for fruits storage based on sensor data, Sensors 16 (7) (2016) 1–23.
[55] S. Manso, F. Cacho-Nerin, R. Becerril, C. Nerín, Combined analytical and microbiological tools to study the effect on *Aspergillus flavus* of cinnamon essential oil contained in food packaging, Food Control 30 (2013) 370–378.