Effects of citrus essential oils incorporated in alginate coating on quality of fresh-cut Jintao kiwifruit

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Summary

The effects of lemon (*Citrus lemon* L.), orange *(Citrus sinensis* L.*)* and grapefruit (*Citrus paradisi* L.) essential oils incorporated in sodium alginate edible coating on the shelf-life of fresh-cut Jintao kiwifruits was investigated for the first time. Samples were packed in polylactic acid trays and were stored at 0 °C for 7 days. Changes in headspace gas composition, colour, firmness, total phenolic content, vitamin C, visual quality and microbial growth were evaluated. Results showed a significant reduction in the rates of O_2 consumption and CO_2 production in samples treated with essential oils, in particular lemon and orange essential oils. Moreover, these treatments with coating and essentials oil helped to maintain firmness and vitamin C content during storage of kiwifruits. On the contrary, the treatments did not have a notable effect on the weight loss and on colour evolution. Finally, coating and essential oils treatments significantly inhibited the growth of yeasts and, furthermore, orange essential oil inhibited growth of moulds.

Keywords

kiwi fruit; grapefruit; lemon; orange; post-harvest quality

Consumption of ready-to-eat fruits and vegetables has significantly increased in recent years, due to the growing demand for low-energy foods with fresh-like characteristics. Offer of these products is growing in the food market, however, peeling and cutting operations accelerate the metabolic activities making fresh-cut products more perishable than whole fruits [1]. Moreover, the presence of microorganisms on the fruit surface may compromise the safety of fresh-cut fruit during processing and shelf-life [2]. Therefore, fresh-cut fruits require the use of suitable post-harvest technologies and treatments to extend the shelf-life and to reduce surface contamination as well as spoilage that affect the quality [3–6].

The use of edible coatings enriched with antimicrobial or antioxidant agents was found to be efficient in preserving and improving the quality during storage of many fruits [7–9]. The coatings act as obstacles to water loss and gas exchange, being able to create a modified atmosphere around fruits.

Essential oils were studied for their antimicrobial and antioxidant effects in food protection according to their chemical composition [10, 11]. Essential oils are designated as Generally Regarded as Safe (GRAS) by the United State Food and Drug Administration (FDA) [12] and can be used as alternatives to chemical additives, as reviewed by BURT [13]. The genus *Citrus* includes 16 species and essential oils derived from fruits of this genus make up the largest share of the world production of these products [14]. *Citrus* essential oils contain 85–99 % of volatile constituents, in particular monoterpene hydrocarbons (limonene), sesquiterpene hydrocarbons and their oxygenated derivatives that include aldehydes (citral), esters, alcohols (linalool), acids and ketones [15]. These constituents have antifungal properties against numerous postharvest phytopathogens [16]. For these reasons, citrus essential oils appear to be promising natural compounds to control post-harvest decay in fruits.

The objective of this study was to determine the effect of lemon, grapefruit and orange essential oils incorporated into edible coatings based on alginate on quality, safety and shelf-life of fresh-cut Jintao kiwifruit.

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MATERIALS AND METHODS

Plant material

Samples of *Actinidia chinensis* cv Jintao (marketed as Jingold; from the Italian Kiwigold consortium, Cesena, Italy) were used. Kiwifruit samples were harvested from a commercial orchard located in the north-west of Italy (Scarnafigi, Italy). Samples were stored at 0 °C for 7 days and then they were used in the study, to reduce the respiration rate and the chemical as well as physiological variations. Only fruits with uniform size, shape, maturity stage and no external defects were used.

Preparation of edible coatings

The coating-forming solutions based on sodium alginate (SA, 20 g·l^{-1}; Sigma-Aldrich, St. Louis, Missouri, USA) were formulated as described by Rojas-Graü et al. [17]. The coating solution was previously prepared by dissolving alginate in distilled water and heating at 70 °C while stirring until the solution became clear. Glycerol (1%, Sigma-Aldrich) was added to edible coatings as a plasticizer agent, and $CaCl_2$ (Sigma-Aldrich) at 50 g·l^{-1} was used as the last dip for cross-linking [18].

Essential oils from lemon (*Citrus lemon* L.), grapefruit (*Citrus paradisi* L.), and orange (*Citrus sinensis* L.; all from Erboristica Magentina, Poirino, Italy) were added to the edible coating solution at 5 g·l^{-1}. These solutions were homogenized for 3 min using the homogenizer Ultra Turrax T25 (IKA-Werke, Staufen im Breisgau, Germany) and degassed under vacuum. Edible coatings without essential oils were evaluated as control.

Kiwifruits were manually peeled with a sharp knife, washed in tap water and cut to 8 mm slices using a commercial slicing machine. Best sanitary conditions were followed during all the processing and handling operations. From each fruit, 5 slices were obtained. Then, the slices were immersed into individual solutions for 2 min, allowed to drip for 30 s, dipped in $CaCl_2$ solution for 1 min and then dripped again [19, 20]. The control samples did not have any kind of treatment but were sliced and dipped in tap water.

Afterwards, kiwifruit slices were placed in polylactic acid (PLA) trays (14 cm × 7 cm × 9 cm), 8 slices per tray, and were machine-enveloped with a 40 μm film (Compac, Castelnovo di Sotto, Italy) of the following permeability characteristics: O_2 transmission rates of 480·10^5 ml·m^{-2}·d^{-1}·Pa^{-1}, water vapour transmission rate of 15.3 g·m^{-2}·d^{-1} at 39 °C and 90 % relative humidity (RH). Trays with samples were then stored in darkness at 0 ± 0.5 °C and 95% RH. On every day of analyses, three trays per treatment (replicates) were taken for quality evaluation.

Headspace gas composition

The CO_2 and O_2 values of the atmosphere in the sample trays were determined using a Checkmate Gas Analyzer (PBI Dansensor, Segrate, Italy). A syringe was introduced into the tray through a self-adhesive rubber septum positioned on the film. The percent of gases was determined using a paramagnetic sensor for O_2 and an infrared sensor for CO_2. The gas analyser was calibrated towards air. Three measurements were taken for each treatment at days 1, 2, 3, 6 and 7 of cold storage.

Weight loss

Weight loss was calculated in each sample tray during cold storage. The results (in percent) were expressed as the weight loss with respect to the initial weight.

Quality parameters

Colour of the fruits was measured by a calibrated Chroma meter with a D65 standard illuminant (CR-400, Konica Minolta, Tokyo, Japan). The colour of ten slices per treatment was determined in CIE $L^*a^*b^*$ colour space by measuring the lightness L^* (+100 = white, –100 = black), a^*(+60 = red, –60 = green), b^*(+60 = yellow, –60 = blue), $h°$ (hue angle) and C^* (chroma or saturation) [21] at days 0, 1, 2, 3, 6 and 7 of cold storage.

The flesh firmness was determined with a puncture test using a Texture Analyzer TA-XT2i (Stable Micro Systems, Godalming, United Kingdom) fitted with a cylindric probe (P/4, 4 mm diameter) and interfaced to a personal computer. The test conditions used for the measurement were: pre-test speed 5 mm·s^{-1}, test speed 1 mm·s^{-1}, post-test speed 5 mm·s^{-1}, trigger force 5 g and penetrating distance 3 mm into the slice. All the measurements were carried out at room temperature (20 ± 2 °C) and at days 0, 1, 2, 3, 6 and 7 of cold storage, 30 slices for each treatment being evaluated. Results were expressed in Newtons.

The total soluble solids (*TSS*) value, pH and titratable acidity (*TA*) were measured at days 0, 1, 2, 3, 6 and 7 of cold storage for each treatment. *TSS* (in degrees Brix) was measured by refractometry using a PR1 digital refractometer (Atago, Tokyo, Japan) in filtered juice extracted from 10 kiwifruit slices from each sample. *TA* and pH were determined by adding 50 ml deionized water to 10 ml of filtered juice and analysis with 0.1 mol·l^{-1} NaOH up to pH 8.1 with an automatic titrator (Compact

44–00; Crison Instruments, Barcelona, Spain). The results were expressed as milliequivalents of 0.1 mol·l^{-1} NaOH per litre.

Microbiological analyses

Moulds and yeasts were determined at the start and at the end of the study. The analyses were performed according to the standard ISO 21527-2 [22] using dichloran rose-bengal chloramphenicol agar (Biokar Diagnostics, Beauvais Cedex, France). Ten grams of fruits were homogenized with 90 ml of peptone water (Oxoid, Basingstoke, United Kingdom). Decimal dilutions were prepared using the same diluent. The incubation temperature for yeasts and moulds was 25 ± 1 °C during 48–72 h. Results were expressed as decadic logarithm of colony-forming units per gram of fresh weight.

Evaluation of appearance

To measure the effect of edible coatings on fresh-cut kiwifruit visual quality, each slice on a tray was scored by 5 laboratory panelists, using a photographic scale in which: 9 = excellent quality; 7 = good quality; 5 = fair quality (limit of marketability); 3 = poor quality (limit of edibility); 1 = very bad quality [23].

Total phenolics content

The extraction of fruit samples for the determination of total phenolics content (*TPC*) was performed under reduced light conditions by weighing 10 g of kiwifruit, adding 25 ml of methanol and homogenizing the extract for 1 min. Extracts were then centrifuged (30000 ×*g* for 15 min), the clear supernatant was collected and stored at –26 °C. Three replicates were performed at day 0 and at the end of storage period (after 7 days) for each treatment. *TPC* was measured by using the Folin–Ciocalteu phenol reagent method [24]. Absorbance was read at 765 nm using a U-5100 Spectrophotometer (Hitachi, Tokyo, Japan). A mixture of water and reagents was used as a blank. *TPC* was expressed as milligrams of gallic acid equivalents (GAE) per kilogram of fresh weight of kiwifruit. All standards and reagents were of analytical purity “pro-analysis” and were purchased from Sigma-Aldrich.

Vitamin C determination

An amount of 10 g of kiwifruits (fresh weight) was homogenized with an Ultra-Turrax T25 homogenizer for 2 min with 10 ml of MeOH/H_2O (5:95, v/v), citric acid (0.1 mol·l^{-1}), ethylenediaminetetraacetic acid (0.5 g·l^{-1}) and sodium fluoride (0.004 mol·l^{-1}). The homogenate was filtered and pH adjusted to 2.2–2.4 by adding HCl (4 mol·l^{-1}). Acidified extract was centrifuged for 5 min at 4 °C and the supernatant was passed through a C18 Sep-Pak cartridge (Waters, Milford, Massachusetts, USA) and a Titan3 polytetrafluoroethylene membrane filter (pore size 0.45 μm, diameter 17 mm; Thermo Fisher Scientific, Waltham, Massachusetts, USA). Then, 250 μl of freshly prepared *o*-phenylenediamine dihydrochloride solution (OPDA, 18.8 mmol·l^{-1}) was added to 750 μl of extract. After 37 min in the dark, ascorbic acid (AA) and dehydroascorbic acid (DHAA) contents were determined by high-performance liquid chromatography (HPLC) as described by GONZALEZ-MOLINA et al. [25] using an Agilent HPLC 1200 Series system (Agilent Technologies, Santa Clara, California, USA) consisting of manual injection valve, G1311A quaternary pump, 20 μl sample loop, diode array detector GI315D UV-Vis and controlled by Agilent ChemStation software B.03.02. Separations of DHAA and AA were realized in a column Eclipse XDB-C18 (150 mm × 4.6 mm; 5 μm particle size; Sigma-Aldrich). The mobile phase was MeOH/H_2O (5:95, v/v), 0.005 mol·l^{-1} cetrimide and 0.05 mol·l^{-1} potassium dihydrogenphosphate (pH 4.5). The total run time was 10 min with a flow rate of 0.9 ml·min^{-1} and the wavelengths being 348 nm for fluorophore 3-(1,2-dihydroxyethyl)furo[3,4-*b*]quinoxaline-1-one (DFQ) detection and 261 nm for AA detection. The vitamin C content was expressed as milligrams per kilogram of fresh kiwifruit weight. Reported values were mean ± standard deviation (*SD*) of three replicates at day 0 and at the end of storage period (after 7 days) for each treatment. All standards and reagents were of analytical purity “pro-analysis” and were purchased from Sigma-Aldrich.

Statistical analysis

One-way analysis of variance (ANOVA) was performed to compare mean values with Tukey’s honestly significant difference (HSD) test for different coatings and control samples. Differences were considered significant when the *p*-values were lower than 0.05. Statistica software (Statistica 7.0, Statsoft, Tulsa, Oklahoma, USA) was used.

RESULTS AND DISCUSSION

Headspace gas composition

Without filling the packaging with other gas, the atmosphere depends on the gas permeability of the packaging material and on respiration of the preserved product. In this work, the percent of O_2 inside the trays decreased in all samples

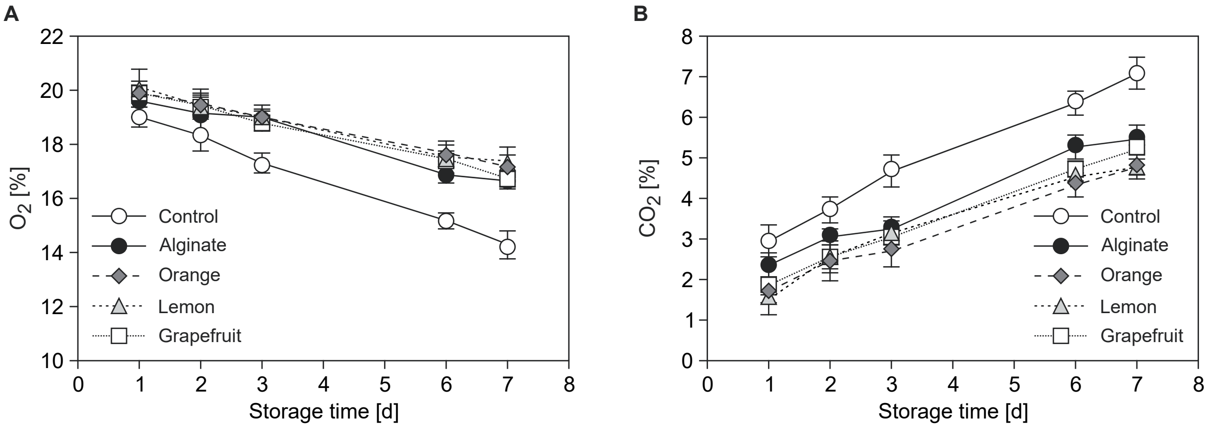

Fig. 1. Changes in internal atmosphere of fresh-cut kiwifruit packed in trays.

A – changes in percentage of O_2, B – changes in percentage of CO_2.
Data shown are mean ± standard deviation (means marked with * are significantly different (Tukey's HSD test, $p < 0.05$). Coating: control – uncoated, alginate – sodium alginate (20 g·l^{-1}), orange – sodium alginate (20 g·l^{-1}) + orange essential oil (5 g·l^{-1}), lemon – sodium alginate (20 g·l^{-1}) + lemon essential oil (5 g·l^{-1}), grapefruit – sodium alginate (20 g·l^{-1}) + grapefruit essential oil (5 g·l^{-1}).

during storage (Fig. 1A). There were significant differences between all the coated samples (sodium alginate-coated samples and samples coated with essential oils) and control ($p < 0.05$) from the third day of storage and onwards. A lower respiration rate was detected in coated slices compared to control, and these differences could be attributed to the influence of the coating on oxygen diffusion between the fruit and environment [26]. Similar results were previously obtained for fresh-cut apples and mango coated with alginate [27, 28]. Meanwhile, the change in the percent of CO_2 showed an opposite pattern (Fig. 1B). CO_2 values increased progressively during storage with significant differences ($p < 0.05$) between coated and control samples. The final partial pressure of CO_2 did not exceed 8 %, which is in the range recommended for fresh-cut kiwifruit conservation (5–10 % CO_2) [29]. The action of the coating alone or of the coating with incorporated essential oils had the same reduction effect on the respiration rate.

Weight loss

Fresh-cut fruits are very susceptible to weight loss, hence evaluation of this parameter is very important, also because it is an indicator of fruit freshness [26]. In this study, results showed that weight loss significantly ($p < 0.05$) increased for all samples during 7 days of storage at 0 °C (data not shown) but without significant differences between treatments. The same result was obtained in the study of Rojas-Graü et al. [17], in which the authors observed that lemongrass essential oil did not influence positively the weight loss of fruits probably because its incorporation into an edible film did not significantly affect water vapour permeability of the coating.

Quality parameters

The initial values of L^*, $h°$ and C^* colour parameters of the kiwifruit flesh were 57.03 ± 4.77, 106.09 ± 2.61 and 23.16 ± 1.62, respectively. The colour values of fresh-cut kiwifruits during storage for 7 days at 0 °C are shown in Tab. 1. Generally, edible coatings with or without essential oils were not significantly effective in maintaining L^* values if compared to uncoated samples (control), probably due to the increase in opacity of the coating. This takes place as a result of oil droplets aggregation during the drying process, which may reduce absorption of light by the surface of the fruits. To sum up, during storage for 7 days, samples became more opaque and had a less vivid colour. The essential oils had no notable effect on this development, except those containing grapefruit essential oil, which gave rise to a more intense colour when compared to the other treatments.

Fruit firmness is an important quality characteristic that influences the consumer acceptability of the fresh-cut products. Results showed that the lemon and orange essential oils could significantly ($p < 0.05$) maintain higher fruit firmness during storage (Tab. 2). The obtained values of the fruit firmness are in agreement with the weight loss results. The lower the water loss, the greater the fruit turgor, and so the greater values of fruit firmness [17]. The other samples (control, coated samples without essential oils and coated samples with grapefruit essential oil) showed significantly lower firmness values even after 1 day of storage. At the end of storage, control fruits had significantly lower firmness values compared to the rest of the coated samples. This could be due to beneficial effects of edible coating and $CaCl_2$ dip on firmness retention of fresh-cut kiwifruit slices, which is in agreement with other authors [30]. The effect of calcium dip in reduction of firmness loss of fresh-cut kiwifruits during storage may be due to stabilization of membranes and establishment of Ca-pectates, which improve the rigidity of the middle lamella [31]. Similar results were obtained for fresh-cut apples coated with sodium alginate [17], for fresh-cut melon [32], for raspberries treated with chitosan-based coating [33] and for fresh-cut Gala apples [34].

TSS values summarized in Tab. 3 showed lower

Tab. 1. Colour evaluation of fresh-cut kiwifruit.

Coating	Storage time					
	0 days	1 day	2 days	3 days	6 days	7 days
	Chroma *C**					
Control	23.16 ± 1.62 aA	18.26 ± 1.72 abB	17.38 ± 2.82 bB	16.78 ± 2.12 aC	15.94 ± 2.03 aC	15.87 ± 2.42 bC
Alginate	23.16 ± 1.62 aA	18.23 ± 4.05 abB	16.54 ± 3.77 bC	15.66 ± 4.22 aC	15.96 ± 4.58 aC	15.53 ± 4.13 bC
Orange	23.16 ± 1.62 aA	15.33 ± 4.21 bB	15.36 ± 2.16 bB	15.40 ± 3.22 aB	15.55 ± 3.54 aB	14.85 ± 3.77 cB
Lemon	23.16 ± 1.62 aA	16.55 ± 2.78 bB	17.32 ± 2.34 bB	16.33 ± 3.64 aB	14.14 ± 2.77 bC	13.63 ± 3.88 cC
Grapefruit	23.16 ± 1.62 aA	19.46 ± 1.98 aB	18.16 ± 3.61 aB	16.06 ± 1.62 aC	14.65 ± 3.8 abC	16.14 ± 2.68 aC
	Hue angle *h*°					
Control	106.09 ± 2.61 aA	106.34 ± 1.89 bA	106.13 ± 1.39 bA	106.35 ± 2.28 bA	106.00 ± 2.12 bA	107.50 ± 1.76 bA
Alginate	106.09 ± 2.61 aB	108.65 ± 2.80 abA	107.05 ± 1.45 bB	107.24 ± 3.94 bB	108.31 ± 2.02 aA	106.91 ± 4.56 bB
Orange	106.09 ± 2.61 aB	107.71 ± 1.84 bA	106.36 ± 2.28 bB	108.21 ± 2.44 abA	109.38 ± 2.24 aA	106.09 ± 2.98 bB
Lemon	106.09 ± 2.61 aB	110.22 ± 3.02 aA	109.00 ± 2.67 aA	109.37 ± 2.18 aA	109.43 ± 1.67 aA	109.10 ± 3.08 aA
Grapefruit	106.09 ± 2.61 aB	109.41 ± 2.84 aA	106.86 ± 4.08 bB	107.01 ± 2.01 bB	106.77 ± 2.83 bB	108.80 ± 2.85 aA
	Lightness *L**					
Control	57.03 ± 4.77 aA	56.26 ± 2.77 aA	55.43 ± 4.13 aA	52.00 ± 3.42 aB	50.39 ± 3.31 aB	50.85 ± 3.04 aB
Alginate	57.03 ± 4.77 aA	53.85 ± 5.34 bB	49.45 ± 6.78 bB	49.77 ± 4.96 bB	48.37 ± 3.41 bB	48.23 ± 5.57 bB
Orange	57.03 ± 4.77 aA	49.38 ± 4.73 bB	48.13 ± 4.16 bB	48.86 ± 5.01 bB	50.09 ± 2.47 aB	47.67 ± 4.87 bB
Lemon	57.03 ± 4.77 aA	52.55 ± 3.48 bB	52.87 ± 3.75 bB	52.32 ± 5.29 aB	51.20 ± 2.85 aB	51.51 ± 2.68 aB
Grapefruit	57.03 ± 4.77 aA	53.38 ± 2.74 bB	52.19 ± 5.84 bB	49.24 ± 3.12 bB	47.69 ± 4.18 bB	48.84 ± 3.76 bB

Data shown are mean ± standard deviation. Means sharing the same letters in rows (A, B, C) and in column (a, b, c) are not significantly different (Tukey's HSD test, $p < 0.05$).
Coating: control – uncoated, alginate – sodium alginate (20 g·l^{-1}), orange – sodium alginate (20 g·l^{-1}) + orange essential oil (5 g·l^{-1}), lemon – sodium alginate (20 g·l^{-1}) + lemon essential oil (5 g·l^{-1}), grapefruit – sodium alginate (20 g·l^{-1}) + grapefruit essential oil (5 g·l^{-1}).

Tab. 2. Firmness evaluation of fresh-cut kiwifruit.

Coating	Storage time					
	0 days	1 day	2 days	3 days	6 days	7 days
	Firmness [N]					
Control	8.27 ± 1.62 aA	7.27 ± 0.93 bB	7.09 ± 0.80 bB	6.62 ± 1.12 bC	6.23 ± 1.62 bC	6.00 ± 0.42 bC
Alginate	8.27 ± 1.62 aA	7.29 ± 1.18 bB	7.08 ± 1.11 bC	6.98 ± 1.14 bC	7.51 ± 1.58 bC	6.94 ± 0.96 abC
Orange	8.27 ± 1.62 aA	8.31 ± 0.87 aB	7.99 ± 1.93 aB	7.54 ± 1.14 aB	7.81 ± 1.03 aB	7.08 ± 1.18 aB
Lemon	8.27 ± 1.62 aA	8.33 ± 0.62 aB	7.31 ± 1.98 aB	7.18 ± 1.10 aB	7.24 ± 0.98 bC	7.32 ± 1.07 aC
Grapefruit	8.27 ± 1.62 aA	7.36 ± 0.81 bB	6.84 ± 1.12 bB	6.69 ± 1.15 bC	6.84 ± 1.35 bC	6.87 ± 1.47 abC

Data shown are mean ± standard deviation. Means sharing the same letters in rows (A, B, C) and in column (a, b, c) are not significantly different (Tukey's HSD test, $p < 0.05$).
Coating: control – uncoated, alginate – sodium alginate (20 g·l^{-1}), orange – sodium alginate (20 g·l^{-1}) + orange essential oil (5 g·l^{-1}), lemon – sodium alginate (20 g·l^{-1}) + lemon essential oil (5 g·l^{-1}), grapefruit – sodium alginate (20 g·l^{-1}) + grapefruit essential oil (5 g·l^{-1}).

values for untreated samples. However, although with some statistically significant differences, the *TSS* values ranged between 9.5–11.4 °Brix for all treatments and were not significantly different from those determined immediately after fruit cutting. Fisk et al. [35] suggested that *TSS* values in kiwifruits were more affected by the different package and storage conditions than by the coating treatments. Only samples treated with orange essential oil-containing coating showed particularly higher values compared to other samples. This trend could be due to the possible effect of essential oil components on the fruit metabolic activity and the consequent reduction of respiration rate as well as reduction of other vital processes.

TA values are shown in Tab. 3. Acidity of all samples decreased after one day of storage, increased slightly after 2 days of storage and then remained stable until the end of storage. Control samples showed significantly lower values from the third day of storage onwards. This trend indicated that coating and essential oil treatments limited the loss of acidity during the storage period due to the possible effect of essential oil components on the metabolic activity of fruits. A similar effect was found in coated longan fruit and interpreted as being due to a lower respiration of the fruit [36].

Microbiological evaluation

Minimally processed fruits have a large area of cut surface with high moisture and a source of nutrients for development of microorganisms [37]. Tab. 4 presents the results of the analysis of yeasts and moulds on coated and uncoated sliced kiwifruits. In samples treated with essential oils, significant reduction ($p < 0.05$) in yeasts was observed

Tab. 3. Total soluble solids and titratable acidity evaluation of fresh-cut kiwifruit.

Coating	Storage time					
	0 days	1 day	2 days	3 days	6 days	7 days
	Total soluble solids [°Brix]					
Control	9.89 ± 0.75 aA	9.53 ± 0.28 aA	10.33 ± 0.28 aA	10.06 ± 0.10 bA	10.50 ± 0.31 aA	10.53 ± 0.62 aA
Alginate	9.89 ± 0.75 aB	9.90 ± 0.32 aB	10.36 ± 0.29 aB	11.30 ± 0.47 aA	10.53 ± 0.10 aB	11.20 ± 0.15 aA
Orange	9.89 ± 0.75 aB	10.26 ± 0.33 aB	10.96 ± 0.36 aAB	11.33 ± 0.31 aA	10.96 ± 0.83 aAB	11.36 ± 0.52 aA
Lemon	9.89 ± 0.75 aA	10.05 ± 0.05 aA	9.80 ± 0.09 aA	10.40 ± 0.63 aA	10.86 ± 0.44 aA	10.66 ± 0.21 aA
Grapefruit	9.89 ± 0.75 aA	10.00 ± 0.32 aA	10.30 ± 0.08 aA	10.93 ± 0.27 aA	10.73 ± 0.13 aA	10.43 ± 0.54 aA
	Titratable acidity [meq·l^{-1}]					
Control	191.33 ± 13.03 aA	151.72 ± 10.36 aB	160.84 ± 1.81 aB	159.43 ± 2.56 bB	159.89 ± 2.56 bB	153.53 ± 4.38 cB
Alginate	191.33 ± 13.03 aA	151.25 ± 6.15 aC	161.14 ± 2.69 aC	171.34 ± 4.99 aB	167.21 ± 6.01 aB	173.63 ± 2.62 aB
Orange	191.33 ± 13.03 aA	156.07 ± 1.02 aC	173.17 ± 0.88 aB	168.55 ± 2.81 abB	167.56 ± 7.43 aB	176.03 ± 7.52 aB
Lemon	191.33 ± 13.03 aA	156.85 ± 3.73 aB	168.99 ± 5.31 abB	174.67 ± 4.77 aB	169.26 ± 1.79 aB	163.36 ± 5.62 bB
Grapefruit	191.33 ± 13.03 aA	158.35 ± 4.05 aC	174.04 ± 5.77 aB	164.49 ± 1.31 abB	164.10 ± 3.55 aB	163.06 ± 5.41 bB

Data shown are mean ± standard deviation. Means sharing the same letters in rows (A, B, C) and in column (a, b, c) are not significantly different (Tukey's HSD test, $p < 0.05$). Titratable acidity is expressed in milliequivalents of 0.1 mol·l^{-1} NaOH per litre. Coating: control – uncoated, alginate – sodium alginate (20 g·l^{-1}), orange – sodium alginate (20 g·l^{-1}) + orange essential oil (5 g·l^{-1}), lemon – sodium alginate (20 g·l^{-1}) + lemon essential oil (5 g·l^{-1}), grapefruit – sodium alginate (20 g·l^{-1}) + grapefruit essential oil (5 g·l^{-1}).

Tab. 4. Counts of yeasts and moulds in fresh-cut kiwifruit.

Coating	Storage time			
	0 days	7 days	0 days	7 days
	Yeasts [log CFU·g^{-1}]		**Moulds** [log CFU·g^{-1}]	
Control	< 1.60 a	2.70 a	2.28 a	2.40 a
Alginate	< 1.60 a	2.51 a	2.28 a	2.40 a
Orange	< 1.60 a	< 1.00 b	2.28 a	< 1.00 b
Lemon	< 1.60 a	< 1.00 b	2.28 a	2.43 a
Grapefruit	< 1.60 a	< 1.60 b	2.28 a	2.40 a

Means sharing the same letters are not significantly different (Tukey's HSD test, $p < 0.05$).
Coating: control – uncoated, alginate – sodium alginate (20 g·l^{-1}), orange – sodium alginate (20 g·l^{-1}) + orange essential oil (5 g·l^{-1}), lemon – sodium alginate (20 g·l^{-1}) + lemon essential oil (5 g·l^{-1}), grapefruit – sodium alginate (20 g·l^{-1}) + grapefruit essential oil (5 g·l^{-1}).

Tab. 5. Appearance scores of fresh-cut kiwifruit.

Coating	Storage time				
	1 day	2 days	3 days	6 days	7 days
	Appearance score				
Control	7.60 ^{bA}	5.80 ^{cB}	4.20 ^{bBC}	3.20 ^{cC}	3.00 ^{cC}
Alginate	9.00 ^{aA}	9.00 ^{aA}	7.60 ^{aA}	4.80 ^{bcB}	4.80 ^{bB}
Orange	9.00 ^{aA}	9.00 ^{aA}	7.20 ^{aB}	6.80 ^{bB}	6.20 ^{aB}
Lemon	9.00 ^{aA}	8.20 ^{abA}	7.80 ^{aB}	7.00 ^{aB}	6.80 ^{aB}
Grapefruit	9.00 ^{aA}	7.40 ^{bAB}	6.80 ^{abB}	5.20 ^{bBC}	4.20 ^{bC}

Means sharing the same letters in rows (A, B, C) and in column (a, b, c) are not significantly different (Tukey's HSD test, $p < 0.05$).
Coating: control – uncoated, alginate – sodium alginate (20 g·l^{-1}), orange – sodium alginate (20 g·l^{-1}) + orange essential oil (5 g·l^{-1}), lemon – sodium alginate (20 g·l^{-1}) + lemon essential oil (5 g·l^{-1}), grapefruit – sodium alginate (20 g·l^{-1}) + grapefruit essential oil (5 g·l^{-1}).

Tab. 6. Vitamin C and total polyphenols contents of fresh-cut kiwifruit.

Coating	Storage time			
	0 days	7 days	0 days	7 days
	Total phenolics content [mg·kg^{-1}]		**Vitamin C** [mg·kg^{-1}]	
Control	5.89 ± 2.50 ^{aB}	6.43 ± 0.61 ^{bA}	6.69 ± 1.87 ^{aA}	4.94 ± 1.96 ^{bB}
Alginate	5.89 ± 2.50 ^{aB}	6.36 ± 1.27 ^{bA}	6.69 ± 1.87 ^{aA}	4.67 ± 2.05 ^{cB}
Orange	5.89 ± 2.50 ^{aB}	6.71 ± 0.91 ^{aA}	6.69 ± 1.87 ^{aA}	5.04 ± 1.21 ^{aB}
Lemon	5.89 ± 2.50 ^{aB}	6.83 ± 1.21 ^{aA}	6.69 ± 1.87 ^{aA}	4.88 ± 1.34 ^{bB}
Grapefruit	5.89 ± 2.50 ^{aB}	6.99 ± 0.73 ^{aA}	6.69 ± 1.87 ^{aA}	5.17 ± 1.66 ^{aB}

Data shown are mean ± standard deviation. Means sharing the same letters in rows (A, B, C) and in column (a, b, c) are not significantly different (Tukey's HSD test, $p < 0.05$). Total phenolics content is expressed as milligrams of gallic acid equivalents per kilogram of fresh fruit.
Coating: control – uncoated, alginate – sodium alginate (20 g·l^{-1}), orange – sodium alginate (20 g·l^{-1}) + orange essential oil (5 g·l^{-1}), lemon – sodium alginate (20 g·l^{-1}) + lemon essential oil (5 g·l^{-1}), grapefruit – sodium alginate (20 g·l^{-1}) + grapefruit essential oil (5 g·l^{-1}).

during storage. Moreover, the incorporation of orange essential oil in the alginate-based coating formulation significantly ($p < 0.05$) reduced the mould counts (Tab. 4). Rojas-Graü et al. [17] observed similar effects with lemongrass essential oils and Periago et al. [38] with oregano and thyme essential oils.

Appearance evaluation

As expected, appearance of kiwifruit slices negatively changed during storage (Tab. 5). Treatments with lemon and orange essential oils maintained very good appearance, as evaluated using the photographic scale, until 3 days of storage and displayed fruits with good appearance also after 7 days, while the general appearance of coated samples negatively changed after 6 days of storage, dropping to „poor" level at the end of storage. On the other hand, control samples were evaluated as "poor in appearance" already after 3 days of storage at 0 °C. At the end of storage, the higher appearance values were attributed to orange and lemon essential oils samples, followed by coating alone and grapefruit essential oil samples, and the worst appearance was recorded for untreated samples (3, which corresponded with the limit of edibility).

Total phenolics content

A significant increase in *TPC* was observed during storage for 7 days in all samples (Tab. 6). *TPC* of the three samples treated with coatings containing essential oils demonstrated higher values after 7 days of storage compared to control and coated samples without any essential oil. The increase in *TPC* observed in all samples might have been stimulated by phenylalanine ammonia-lyase (PAL) activity. Oms-Oliu et al. [39] observed activation of PAL in response to various stresses including CO_2 treatment, higher O_2 content and cutting operations.

Vitamin C content

TPC and vitamin C are the main influencing factors of the total antioxidant capability in *Actinidia* fruits. It was clearly shown from the investigations that essential oils incorporated in the coating may have a positive impact on vitamin C and *TPC*. Vitamin C content was significantly affected by the composition of the coating and by the storage time ($p < 0.05$). The use of essential oils significantly reduced the loss of vitamin C, in particular in case of coatings containing orange or grapefruit essential oils (Tab. 6). The initial vitamin C content of kiwifruits was 6.69 $mg \cdot kg^{-1}$. At the end of storage, samples of kiwifruits treated with essential oils preserved approximately 69–77 % of the initial vitamin C content, while control samples preserved only 64 % of the initial vitamin C content. This result may be due to a lower amount of O_2 in the package headspace of coated samples compared to uncoated. Lower partial pressure of oxygen delays the deteriorative oxidation reactions of vitamin C. Previous studies showed that the lower the package headspace percent of O_2 was, the higher the vitamin C content could be found in the fruits [27]. Moreover, Jayaprakasha et al. [40] found that addition of essential oils might inhibit the vitamin C losses due to its protection by antioxidant phenolics contained in the oils.

CONCLUSIONS

Sodium alginate coatings with incorporated citrus essential oils seem to be suitable treatments for enhancing the quality of fresh-cut kiwifruits during storage, and a promising alternative method to the application of chemical agents to control microbial spoilage. Results obtained in this study showed that edible coating and edible coatings with incorporated essential oils reduced respiration rate, *TSS* and *TA* losses, as well as yeast and mould counts, while maintaining the firmness, contents of vitamin C and *TPC*. In particular, edible coating with incorporated grapefruit essential oil preserved external colour, edible coatings with incorporated lemon or orange essential oil maintained *TPC* and vitamin C content, as well as appearance and acceptability of the fruits. Furthermore, these essential oil-containing coatings seemed to slightly diminish the metabolic pattern of the fruits, as deduced by certain differences induced in the mechanical properties and in some quality parameters, such as acidity. In conclusion, the maintenance of quality of sliced kiwifruit by the use of citrus essential oils incorporated in alginate coating presented here revealed that these treatments can be considered for commercial application during storage and shelf-life. Considering the intense aroma of essential oils and the layer of the coating used, future research on the effect of these treatments on the sensory and organoleptic characteristics of the fruits are needed.

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