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Effects of Postharvest Application of 1-MCP and Postcutting Dip Treatment on the Quality and Nutritional Properties of Fresh-Cut Kiwifruit

Maria D. C. Antunes,*,† Susana Dandlen,‡ Ana M. Cavaco,§ and Graça Miguel†

†Faculdade de Ciências e Tecnologia, Universidade do Algarve, IBB, Centro de Biotecnologia Vegetal, Ed. 8, Campus de Gabelas, 8005-139 Faro, Portugal, ‡FCT, Universidade do Algarve, Ed. 8, Campus de Gabelas, 8005-139 Faro, Portugal, and §CEOT, Universidade do Algarve, Ed. 2 da FCT, Campus de Gabelas, 8005-139 Faro, Portugal

Consumption of minimally processed fruit and vegetables has increased significantly in the past few years due to the consumers' life style. The aim of this study was to evaluate the effect of treatment with ascorbic acid or calcium chloride on the quality parameters of fresh-cut kiwifruit prepared from fruit previously stored for 3 months, either treated or not treated with 1-methylcyclopropene (1-MCP) before storage. Harvested fruit were treated with 1 μL L^{-1} 1-MCP for 20 h at room temperature (~20 °C) (MCP) or had no treatment (C) and were then stored at 0 °C. After 3 months, fruit were removed from storage, peeled, and cut longitudinally in quarters, dipped in 2% ascorbic acid (Asc), 2% calcium chloride (Ca), or just water (cont), and kept at 2 °C for 8 days. Measurements of firmness, soluble solids content (SSC) (°Brix), color (CIE L*, a*, b*), electrolyte leakage, sugars, organic acids, total phenolics, and antioxidant activity (DPPH and ABTS) were performed at 0, 4, and 8 days. A taste panel was performed on the seventh shelf life day. It was shown that whole MCP-treated kiwifruit kept better than the control through the 3 months storage, this effect being lost through the fresh-cut shelf life period. Furthermore, the postcut dip on 2% $CaCl_2$ was effective on delaying softening and browning of fresh-cut kiwifruit, which were also the fruit preferred by panelists. Both ascorbic acid and $CaCl_2$ were effective on preserving or improving nutritional properties (phenolics, ascorbic acid, DPPH, and ABTS) mainly in the first 4 days of shelf life. The $CaCl_2$ had a further beneficial effect until 8 shelf life days. It is suggested that $CaCl_2$ is better in keeping overall quality through 8 days of shelf life at 2 °C in fresh-cut kiwifruit followed by Asc, and 1-MCP has negligible effect in the conditions of this experiment.

KEYWORDS: Antioxidant activity; fresh-cut; kiwifruit; organic acids; quality parameters

INTRODUCTION

The consumption of fruit and vegetables is widely accepted as beneficial to health, and current life in modern societies has significantly enhanced the demand for minimally processed (ready-to-eat) commodities (*1*). However, it is difficult to maintain the fresh-like quality and nutritional value of these products through their shelf life, as compared to whole fruit and vegetables. In fact, the procedures used in the fresh-cut industry may induce faster deterioration associated with the physical damage caused by cutting, slicing, peeling, and other mechanical injuries during processing (*2*).

For better preservation of fresh peeled, diced, or sliced commodities, investigation is toward the use of preservatives such as antibrowning and/or firming agents (*1*−*3*). Several studies have been conducted regarding the preservation of these products and their respective quality (*1*−*6*).

*Corresponding author. Tel: ++351289800900. Fax: ++35128981-8419. E-mail: mantunes@ualg.pt.

Kiwifruit (*Actinidia deliciosa* (A. Chev.) C.F. Liang and A.R. Ferguson var. *deliciosa* Hayward) is a commercially important kiwifruit cultivar, which has a relatively long storage life (six months at 0 °C), this being improved under controlled atmosphere (*7*). Kiwifruit is commercially important as fresh-cut fruit and has been targeted by several studies regarding its preservation as sliced fruit, through the application of volatile compounds (methyl jasmonate, ethanol, and other alcohols); treatment with hydrogen peroxide, calcium lactate, and modified atmosphere packaging (MAP); application of 1-methylcyclopropene (1-MCP) prior to cutting, packaging in nonconventional modified atmosphere with argon and nitrous oxide; and utilization of moderate heat treatments to whole kiwifruit (*3*, *4*, *8*).

Although kiwifruit does not produce ethylene at ≤10 °C (*9*), it is very sensitive to this hormone even at very low concentrations (*10*), and it produces ethylene induced by wounding at low temperatures, leading to quality loss (*11*). 1-MCP is an ethylene action inhibitor acting at very low concentration, which has been proved to delay ripening and enhance storage life in some intact and fresh-cut fruit (*2*, *12*, *13*). Despite the rapid adoption of

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1-MCP based technology, little is known about its effect on the nutritional status of kiwifruit as well as its combination with some treatments known to be beneficial for preserving other fresh-cut fruit.

The main goal of the present work was to evaluate the effect of 1-MCP applied after harvest, before storage, on the posterior behavior of ripe fruit prepared as fresh-cut and treated with ascorbic acid or calcium chloride after cutting, and on the overall antioxidant activity as well as other important quality parameters and their possible changes through the shelf life period.

MATERIALS AND METHODS

Fruit and Treatments. Kiwifruit harvested with 6.5 °Brix and firmness of 70 N, were selected for uniformity of size and absence of defects to be used in the experiment. Half of the fruit were treated with 1 μL L^{-1} 1-MCP (SmarthFresh) for 20 h in closed containers with a circulation system and a CO_2 trapping system (NaOH) at room temperature (~20 °C). The weight of 1-MCP powder was calculated for the volume of the fumigation tank, according to the desired concentration, and was put into capped flasks with 2 mL of distilled water at 40 °C and shaken until completely dissolved. The flasks were then opened in the fumigation tanks, which were sealed immediately. The remaining fruit were not treated and used as control (C). All fruit were stored alone in a storage chamber with ethylene scrubbers (potassium permanganate) at 0 °C and 90−95% relative humidity.

After 3 months, all fruit were removed from storage, then selected, peeled, and cut longitudinally in quarters with sharp knives and washed in 0.1 μL L^{-1} sodium hypochlorite. Then, fresh-cut kiwifruit were separated for treatments as follows: one-third was dipped in a solution of 2% ascorbic acid (Asc), another third in calcium chloride at 2% (Ca), and the last third in just water (cont). All reagents were of analytical grade (Sigma Chemical, Co.). Dips lasted for 2 min, and then fruit slices were gently dried with blotting paper and placed in plastic trays which were covered with a 15 μm thick polyethylene film. All treatments were performed at room temperature. Then, fruit were stored at 2 °C for 8 days. All measurements were performed just before packaging (zero time) and after 4 and 8 days of shelf life, except for the sensory evaluation, in which case, fruit were tested on the seventh day of shelf life.

At each storage time, four trays per treatment (4 replicates) were randomly taken for analysis. Firmness, color (CIE L*, a*, b*), and electrolyte leakage were determined immediately. The remaining kiwifruit tissue was ground with an Ultra-Turrax mixer, and juice was extracted by squeezing the fruit mixture through cheesecloth and immediately collected in 20 mL vials which were frozen in liquid nitrogen according to Agar et al. (*14*). Then vials were stored at −20 °C until the following assays. An aliquot was used for SSC (°Brix) measurement before freezing the juice.

Firmness, Soluble Solids Content (SSC) and Color. Flesh firmness was recorded by puncture with a Chatillon Force TCD 200 and Digital Force Gauge DFIS 50, (Jonh Chatillon & Sons, Inc. U.S.A.), fitted with a flat 8 mm diameter tip, on kiwifruit slices, to a depth of 7 mm. The SSC (°Brix) was measured by a digital refractometer, model PR1-Atago Co. LTD, Japan, in kiwifruit juice.

Flesh color was measured on kiwifruit slices with a Chroma meter CR-300 series (CE Minolta, Japan). Color changes were quantified in the CIE L*, a*, and b* color space. The L* value indicates lightness (black = 0 and white = 100), a* changes from green (negative values) to red (positive values), and b* from blue (negative values) to yellow (positive values) (*15*).

Electrolyte Leakage. Electrolyte leakage measurements were made as described previously (*16*) with small modifications: kiwifruit pericarp tissue cylinders were excised with a 19 mm diameter cork borer, and four pieces of 6−7 mm thickness (total weight of 4 g) were used.

Organic Acids and Sugars. After thawing at 4 °C, juice was assayed for both organic acids and sugars, which were measured as described previously (*17*).

Total Phenolics and Antioxidant Activity. Total phenolics were determined on the kiwifruit juice by the Folin−Ciocalteau reagent method using gallic acid (0.024−0.096 mg mL^{-1}) as the standard for the calibration curve (*18*).

The free radical scavenging activity was measured by 2,2-diphenyl-2-picrylhydrazil (DPPH) on the basis of the method of Brand-Williams et al., (*19*) with minor modifications. For this determination, juice was previously diluted 1/5. The DPPH radical concentration was calculated using the following equation: scavenging effect % (IA %) = $(1 - Af/Ao) \times 100$; Ao stands for the absorbance of the control sample and Af for the absorbance in the presence of the sample (t = 15 min). Results were expressed as mM Trolox equivalent antioxidant capacity.

The preformed radical monocation of 2,2′-azinobis-(3-ethylbenzothiazoline-6-sulfonic acid) (ABTS) was generated according to the modified method of Re et al. (*20*). For the assay, 10 μL from a diluted 1/5 kiwifruit juice was added to 1000 μL of ABTS radical cation solution. The absorbance was monitored spectrophotometrically at 750 nm for 6 min (Shimadzu spectrophotometer 160-UV). The antioxidant activity of each sample was calculated using the following equation: scavenging effect % (IA%) = $(1 - Af/Ao) \times 100$, where Ao stands for the absorbance of the control and Af for the absorbance in the presence of the sample. The values were compared with the curve for several Trolox concentrations and the values given as mM Trolox equivalent antioxidant capacity.

Sensory Evaluation. A taste panel was performed with 20 trained panelists. Panel members were asked to evaluate the appearance, texture, sweetness, acidity, and overall flavor on a scale from 1 = bad to 5 = excellent.

Statistical Analysis. Each treatment consisted of 4 replications. Statistical analysis was carried out with the SPSS 13.0 software (SPSS Inc.). Two-way ANOVA and Duncan's Multiple-Range Test ($P < 0.05$) for comparisons among treatments over time was performed.

RESULTS AND DISCUSSION

Firmness. Flesh firmness is one of the best predictors of kiwifruit ripening progress, being accepted as eating-ripe at about 3.9−7.8 N (*7*, *21*). Results showed that, just after dips, 1-MCP treated fruit had higher firmness than nontreated ones, except C + Ca (**Figure 1**). This confirmed previous reports by other authors showing that the application of 1-MCP retarded firmness loss during storage of the whole kiwifruit (*2*, *22*). Actually, 1-MCP is an inhibitor of ethylene action, preventing ripening and senescence of some intact and fresh-cut fruit (ref *12* and references therein). Villas-Boas and Kader (*6*) found that 1-MCP was also able to reduce the softening of fresh-cut kiwifruit, either when applied just before or after processing. In our experiment, 1-MCP had no effect on the fresh-cut kiwifruit firmness retention, despite the dip treatments after processing, during the following shelf life (**Figure 1**). This apparent inefficiency of 1-MCP may be due to a very early application, three months before processing kiwifruit, and/or to the ethylene synthesis induction by wounding, which may overcome the preventive effect by the still existent 1-MCP in kiwifruit. In fact, Mao et al. (*2*) found that 1-MCP prevented wound induced ethylene when the application was performed just before cutting. However, they used unripe fruit (80−90 N firmness), and at the end of shelf life, fruit firmness did not correspond to eating-ripe values. Also, Koukounaras and Sfakiotakis (*22*) found a decreasing effect of 1-MCP in whole kiwifruit as storage time advanced.

Only calcium chloride dips, in fruit with or without 1-MCP, resulted in similar firmness of slices during the shelf life period, confirming the absence of the synergistic effect previously reported by Aguayo et al. (*13*) for fresh-cut strawberries. After processing, a steep decline of firmness in MCP + cont and MCP + Asc samples over time, was observed, attaining results similar to those of C + cont and C + Asc (**Figure 1**). These results show the importance of calcium chloride in fruit firmness maintenance, that its effect is quite fast, while it reveals the loss of the 1-MCP initial protective effect once fruit are processed.

Previous studies have already demonstrated the capacity of calcium to delay softening in kiwifruit (*14*, *23*). Several factors may contribute to this property: the ability of calcium to

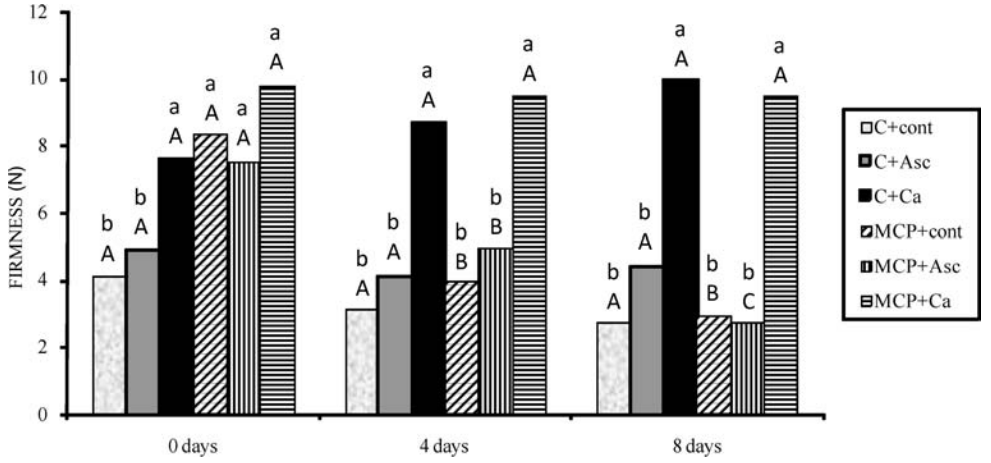

Figure 1. Firmness of fresh-cut Hayward kiwifruit during shelf life at 2 °C. Harvested kiwifruit were treated with 1 μL L^{-1} 1-MCP (MCP) or were untreated (C), stored for 3 months at 0 °C, and then used for fresh-cut produce, and further dipped in 2% ascorbic acid (Asc), 2% calcium chloride (Ca), or just water (cont). Values in the same day followed by the same lower case letter and in the same treatment followed by the same upper case letter are not significantly different by Duncan's multiple range test ($P < 0.05$).

Table 1. Color Coordinates and Electrolyte Leakage of Fresh-Cut Hayward Kiwifruit during Shelf-Life at 2 °C[a]

		without MCP			with MCP		
	days	C + cont	C + Asc	C + Ca	MCP + cont	MCP + Asc	MCP + Ca
lightness (L*)	0	37.9 bA	36.6 bA	39.9 bA	45.3 aA	46.2 aA	47.0 aA
	4	33.5 cB	31.6 cB	41.7 abA	39.3 bB	39.4 bB	45.5 aA
	8	31.9 dB	36.9 bcA	43.0 aA	33.8 cdC	33.0 cdC	40.0 abB
color (a*)	0	−7.4 aB	−7.2 aB	−7.4 aA	−9.2 bC	−8.9 bB	−8.9 bA
	4	−6.5 bAB	−5.2 aA	−8.4 cA	−7.7 bcB	−8.6 cB	−9.0 cA
	8	−5.4 aA	−6.1 abAB	−7.5 abA	−5.7 abA	−6.0 abA	−7.8 bA
color (b*)	0	13.0 bA	13.6 bA	14.3 bA	18.9 aA	19.5 aA	18.8 aA
	4	11.2 bA	9.2 bB	17.1 aA	16.2 aA	17.3 aA	19.7 aA
	8	9.1 cA	12.4 abA	17.9 aA	10.3 bcB	10.1b cB	15.8 aB
electrolyte leakage (%)	0	36.0 bA	39.8 aA	36.1 bA	32.9 cA	33.1 cA	33.2 cA
	4	38.1 aA	35.9 aA	31.1 aB	33.9 aA	33.8 aA	31.6 aA
	8	35.5 aA	37.9 aA	35.4 aAB	38.7 aA	39.4 aA	36.2 aA

[a] Harvested kiwifruit were treated with 1 μL L^{-1} 1-MCP (MCP) or were untreated (C), stored for 3 months at 0 °C, and then used for fresh-cut produce, and further dipped in 2% ascorbic acid (Asc), 2% calcium chloride (Ca), or just water (cont). For each parameter, values in the same row followed by the same lower case letter and in the same column followed by the same upper case letter are not significantly different by Duncan's multiple range test ($P < 0.05$).

cross-link with carboxyl groups of polyuronide chains of pectins (*24*), the possibility of calcium delaying galactolipid breakdown, increasing the rate of sterol conjugation, being important in membrane organization and function (*25*, *26*), and acting on cell turgor pressure (*27*).

As reported previously (*14*), it was shown in our work that ascorbic acid by itself has a weak ability to prevent softening of fresh-cut kiwifruit, particularly when compared to those samples submitted to calcium chloride treatment (**Figure 1**).

Color Coordinates. *Lightness.* At day 0, MCP-fruit were significantly ($P < 0.05$) lighter than nontreated fruit independent of dip treatments (**Table 1**), thus suggesting a role of 1-MCP in what concerns the maintenance of stored kiwifruit luminosity, as reported by Boquete et al. (*28*). This is most probably related to the inhibition/delaying of ripening and/or senescence pathways, associated with this parameter.

Despite the dipping, MCP-fruit exhibited a general and significant decrease in the lightness value (L*) through time, while C-fruit showed such behavior only in C + cont (**Table 1**). After 8 days of shelf life, C + Asc fruit recovered lightness to the initial level suggesting a slower, but nevertheless positive effect of the ascorbic acid. This is probably associated with the antioxidant action of Asc, protecting pigments and avoiding tissue browning caused by oxidation (*29*). Overall, 1-MCP seems to lose its beneficial action through time, becoming antagonistic to the protection roles of Asc and Ca dips after 8 days of shelf life (**Table 1**).

Vilas-Boas and Kader (*29*) found higher lightness values (lower browning) by applying to fresh-cut bananas a dip mixture of 1% $CaCl_2$ + 1% ascorbic acid + 0.5% L-cysteine. A postcutting dip in 2% ascorbic acid + 1% calcium lactate + 0.5% L-cysteine did prevent the cut surface from browning in pears (*30*). Noteworthy, neither the 2% ascorbic acid nor the 1% calcium lactate treatments alone prevented cut surface darkening of fresh-cut pears. In our study, after processing, results show that 2% calcium chloride was effective in maintaining fresh-cut kiwifruit lightness, suggesting that there is a wide variability in responses by different fruit, to the dip treatments, as a result of different antioxidant contents and/or other metabolic features.

Color a Value.* As expected, before processing, 1-MCP was essential for maintaining the greenness of fruit. Indeed, at the beginning of the experiment, the lowest a* values, indicating a greener pulp, were observed in MCP-fruit (**Table 1**). This agrees with results obtained by some authors who found that 1-MCP inhibited chlorophyllase activity, preventing pheophytin formation, either during cold storage or during shelf life at 20 °C in both fruit and vegetables, maintaining a greener color (*31*, *32*). Yet, this effect was lost through shelf life at 2 °C. Indeed, on the eighth

Table 2. Fructose, Glucose, and SSC of Fresh-Cut Hayward Kiwifruit during Shelf-Life at 2 °C[a]

		without MCP			with MCP		
	days	C + cont	C + Asc	C + Ca	MCP + cont	MCP + Asc	MCP + Ca
fructose (g·100 mL^{-1})	0	3.29 aA	2.12 bB	2.43 abA	1.98 bAB	2.16 bA	2.12 bA
	4	3.02 aA	2.07 cdB	2.48 bcA	2.38 bcA	2.67 abA	1.69 dA
	8	4.00 aA	2.94 bA	3.01 bA	1.62 cB	1.78 cA	1.98 cA
glucose (g·100 mL^{-1})	0	2.90 aB	2.14 aB	2.47 aB	2.88 aAB	3.09 aAB	3.54 aA
	4	3.07 bAB	2.15 cB	2.38 cB	3.37 bA	4.13 aA	2.71 bcA
	8	3.92 aA	4.24 aA	4.32 aA	2.20 bB	2.27 bB	2.32 bA
SSC (°Brix)	0	13.5 abcA	13.9 aA	12.9 bcA	13.1 abcA	13.7 abA	12.7 cA
	4	13.7 aA	13.6 aA	13.8 aA	13.0 aA	13.2 aA	13.2 aA
	8	13.1 aA	13.3 aA	13.4 aA	12.9 aA	12.8 aA	12.5 aA

[a] Harvested kiwifruit were treated with 1 μL L^{-1} 1-MCP (MCP) or were untreated (C), stored for 3 months at 0 °C, and then used for fresh-cut produce, and further dipped in 2% ascorbic acid (Asc), 2% calcium chloride (Ca), or just water (cont). For each parameter, values in the same row followed by the same lower case letter and in the same column followed by the same upper case letter are not significantly different by Duncan's multiple range test ($P < 0.05$).

day of shelf life only MCP + Ca was significantly greener (lower a*) than C + cont (**Table 1**).

Dip treatments did not prevent the loss of fresh-cut pulp green color through shelf life, except in Ca dipped fruit (**Table 1**). Those samples maintained the lowest values of a* (greener fruit) through time. The highest increase in a* values was observed in cont kiwifruit.

A decrease in L* and an increase in a* values are browning indicators (*33*, *34*). According to our results, calcium chloride was more effective as antibrowning agent after kiwifruit processing than ascorbic acid. The importance of calcium chloride as an antibrowning agent was also reported by Apintanapong et al. (*35*) for banana slices. These authors indicate that calcium chloride belongs to a strong antibrowning agent group, while ascorbic acid belongs to a medium strength antibrowning agent group. According to these authors, that property may be due to polyphenol oxidase inhibition by the chloride ion.

The lower effect of ascorbic acid suggests that a fast degradation of this vitamin along with its irreversible oxidation during the reaction confers only a short temporary protection as a reducing agent. This temporary action of ascorbic acid has been largely reported by several authors using several fresh-cut fruit (*35*, *36*). Nevertheless, there are some other authors (*37*) who considered that, in general, ascorbic acid showed antibrowning effect in fresh-cut apples, being more noticeable after 9 shelf life days. Apparently, the protective ascorbic acid effect seems to depend on the fruit used and its intrinsic properties, with the results indicating that it is more or less effective as an antioxidation agent in fresh-cut produce.

Color b Value*. The b* value indicates changes from blue (negative values) to yellow color (positive values). At the beginning of the experiment, MCP-fruit showed significantly ($P < 0.05$) higher b* values than the C-fruit group (**Table 1**), which might be associated with a higher carotene content in the former. Indeed, an increase in the content of these pigments was reported in some 1-MCP treated apricot varieties (*38*). However, the b* value decreased significantly from 4 to 8 shelf life days in MCP-fruit, while it did not change in C-fruit. At the end of the experiment, Ca dip fruit showed the least changes in b* color parameter, independent of MCP treatment (**Table 1**).

There is no doubt that $CaCl_2$ was the best dip treatment in keeping the pulp's natural color for a longer time (8 days). Through 3 months of storage and until 4 days as fresh-cut in shelf life, 1-MCP also acted synergistically, with its action being lost thereafter (**Table 1**).

Electrolyte Leakage. Electrolyte leakage was significantly higher in C- than that in MCP-fruit at the beginning of the experiment, with C + Asc exhibiting the highest values (**Table 1**). However, differences become insignificant between the two groups from the fourth day onward.

Electrolyte leakage is generally considered an indirect measure of plant cell membrane damage. This in turn might be an indirect symptom of fruit tissue senescence stage (*16*). Mao et al. (*2*) also indicated that cutting kiwifruit induced an increase of electrolyte leakage, which could be reduced by 1-MCP preapplication. However, Mao et al. (*2*) prepared kiwifruit as fresh-cut and treated them with 1-MCP at an early stage of ripening (≈78 N). In our case, such preapplication was not performed; it was made 3 months before peeling and slicing and, therefore, may not be sufficient to maintain membrane integrity during kiwifruit processing since fruit were prepared as fresh-cut at eating-ripe stage.

Dip treatments did not show any effect in the electrolyte leakage in MCP kiwifruit during the shelf life period (**Table 1**). In C-fruit, however, a transitory calcium-dependent protective effect was observed on the fourth day of shelf life. This effect was fully lost by the eighth shelf life day, with C- and MCP-fruit becoming similar in respect to this parameter (**Table 1**).

Soluble Solids Content (SSC) and Sugars. Of all treatments, only Asc dips showed a significant increase of SSC (°Brix), despite the whole fruit pretreatment (**Table 2**). Yet, this initial effect was lost through shelf life, as expected for ripe fruit.

Fructose and glucose comprised the most prominent sugars in kiwifruit exhibiting approximately equal amounts (**Table 2**), as expected from the previous report by Wang and Buta (*4*). Sucrose was present at residual levels, being undetected in many of the samples assayed (data not shown). Similar results have been reported by Soliva-Fortuny and Martin-Beloso (ref *1* and references therein) in many fresh-cut fruit under cold storage (**Table 2**).

Glucose increased significantly from the fourth to the eighth day in C-fruit, despite the dip treatment, while fructose behaved similarly only in C + Asc samples (**Table 2**). Apparently, this increase is a result of the ripening process. Esti et al. (*39*) found higher levels of fructose and glucose at eating-ripe stage than at commercial maturity in diverse genotypes of kiwifruit. In fact, kiwifruit were ripe when used for fresh-cut, according to the SSC and firmness (**Table 2** and **Figure 1**).

At the beginning of the experiment, fructose was significantly ($P < 0.05$) lower in MCP- than in C-fruit, while glucose was similar in both fruit groups (**Table 2**). However, at the end of the experiment both hexoses had higher values in C-fruit. These results might at least partially be related to the role of 1-MCP in delaying kiwifruit ripening (*2*, *12*). In any case, the effect of this compound on sugars or SSC is controversial since remarkable differences among a wide number of fruit have been reported. In fact, the addition of 1-MCP did not alter the SSC in apricots,

Table 3. Citric, Quinic, Oxalic, and Ascorbic Acids of Fresh-Cut Hayward kiwifruit during Shelf-Life at 2 °C[a]

		without MCP			with MCP		
	days	C + cont	C + Asc	C + Ca	MCP + cont	MCP + Asc	MCP + Ca
citric acid (mg·100 mL^{-1})	0	341.31 abA	334.95 abA	217.90 cA	420.57 aA	414.32 aA	273.31 bcAB
	4	341.46 aA	223.23 abA	292.44 abA	242.38 abB	178.35 bcB	339.81 aA
	8	188.61 abA	224.55 aA	194.67 aA	109.64 cB	156.25 bcB	147.11 bcB
quinic acid (mg·100 mL^{-1})	0	104.36 abA	127.39 aAB	100.77 abA	112.94 aA	97.18abA	75.68bB
	4	115.26 aA	109.66 aB	117.92 aA	81.18 bB	81.65 bA	95.49 abAB
	8	101.03 bcA	145.28 aA	81.94 bcA	76.78 cB	75.93 cA	127.25 abA
oxalic acid (mg·100 mL^{-1})	0	12.56 aA	9.99 abA	7.53 bB	8.68 bA	7.92 bB	8.84 bB
	4	10.11 aAB	10.92 aA	8.00 aAB	7.88 aA	7.81 aB	9.30 aB
	8	6.69 cB	11.95 bA	8.79 bcA	9.92 bcA	11.12 bA	15.52 aA
ascorbic acid (mg·100 mL^{-1})	0	16.47 bA	43.09 aA	14.12 bA	13.67 bA	45.48 aA	12.97 bA
	4	11.32 abB	14.61 abB	12.80 abAB	9.72 bB	15.13 aB	10.08 abB
	8	8.62 cB	11.85 aB	8.55 cB	8.45 cB	10.33 bB	9.34 bcB

[a] Harvested kiwifruit were treated with 1 μL L^{-1} 1-MCP (MCP) or were untreated (C), stored for 3 months at 0 °C, and then used for fresh-cut produce, and further dipped in 2% ascorbic acid (Asc), 2% calcium chloride (Ca), or just water (cont). For each parameter, values in the same row followed by the same lower case letter and in the same column followed by the same upper case letter are not significantly different by Duncan's multiple range test ($P < 0.05$).

plums, and apples (*40*, *41*), decreased this attribute in pineapple and papaya (*42*, *43*), and increased it in strawberries (*44*).

Organic Acids. Citric and quinic acids are the more representative organic acids present in kiwifruit (**Table 3**) as expected from data previously reported by other authors (*45*−*47*). However, other organic acids could also be detected, namely, oxalic and ascorbic (**Table 3**) as well as tartaric and malic acids at trace amounts (data not shown).

Citric Acid. Citric acid was higher in MCP-fruit just after cutting than in the C-fruit (**Table 3**). This pattern tended to reverse after 8 days of shelf life, with MCP + cont exhibiting the lowest content (**Table 3**).

Higher levels of organic acids are expected in less ripe fruit, and a decrease is expected through ripening and senescense; additionally, 1-MCP is known to delay ripening (*2*, *12*). Then, the initial higher citric acid contents present in MCP-fruit was probably the result of less ripe tissue, the effect of 1-MCP being lost after 8 shelf life days.

In most cases, there was a decrease of citric acid through storage, although values were significant only in MCP + cont and MCP + Asc (**Table 3**). Agar et al. (*14*) also found that citric acid decreased with time in fresh-cut kiwifruit when subjected to some controlled atmospheres. In contrast, when Wang and Buta (*4*) studied the effect of volatile compounds on the quality of fresh-cut kiwifruit, they reported an increase of citric acid.

The $CaCl_2$ dips led to a significantly lower content of citric acid than the other treatments just after the procedure. However, this effect was lost through shelf life, which was not different from the other dip treatments at the end of the experiment.

Quinic Acid. In respect to the content of quinic acid, its values were significantly lower only in the MCP + Ca than that in C + Asc at the beginning of the experiment (**Table 3**). This organic acid increased in C + Asc and MCP + Ca kiwifruit, while it decreased in MCP + cont during the shelf life at 2 °C. The other treatments did not cause any significant change through time (**Table 3**). Marsh et al. (*45*) found no differences in the quinic acid content during storage at different temperatures, which agrees with our results for C + cont fruit. Nevertheless, these authors worked with whole kiwifruit. Agar et al. (*14*) found a decrease or an increase in quinic acid of fresh-cut kiwifruit stored at 0 °C for 12 days according to the atmosphere compositions used.

Although the physiological and nutritional importance of quinic acid has not been established, it has attracted great interest because this organic acid putatively could serve as a precursor for the biosynthesis of polyphenols, such as chlorogenic acids and flavonoids in plants (*48*). In this sense, treatments C + Asc and the MCP + Ca may be of importance since they resulted in the highest values by the eighth shelf life day.

Oxalic Acid. Oxalic acid was significantly higher ($P < 0.05$) in C + cont just after dips than that in the other treatments, except in C + Asc (**Table 3**). It decreased significantly through shelf life time in C + cont kiwifruit slices, remained constant in C + Asc and MCP + cont, and increased in both Ca treatments as well as in MCP + Asc (**Table 3**). After 8 shelf life days, MCP + Ca treated fruit had higher oxalic acid than the other treatments, attaining the lowest level in C + cont. These results might, at least partially, be related to the role of 1-MCP and Ca in delaying kiwifruit ripening (*2*, *12*).

However, oxalic acid is often suggested as a breakdown product of ascorbic acid (vitamin C) (*49*). Rassan and Laing (*50*) reported that in kiwifruit the oxalate production is regulated by and not a sink for excess ascorbic acid. In the present work, it is noteworthy to mention that, in Asc and Ca treated samples, the increment in oxalic acid observed through shelf life coincides with a parallel decline in ascorbic acid (**Table 3**) and enlightens the relationship between these two organic acids in the treated samples.

Ascorbic Acid. In what concerns ascorbic acid, just after dips, and as expected, Asc dipped kiwifruit had significantly higher ascorbic acid content than the other treatments (**Table 3**).

Fawbush et al. (*51*) found slightly lower ascorbic acid in apples treated with 1-MCP only after 2 and 3 months storage but not after 5 months. In our case, the influence of 1-MCP was not visible (**Table 3**). None of the treatments (1-MCP or dips) prevent the decline of ascorbic acid content during storage (**Table 3**). Interestingly, there was a great decrease in ascorbic acid within 4 days of shelf life at 2 °C. After 4 and 8 days, Asc treated fresh-cut kiwifruit still had the highest values of ascorbic acid content compared with the other treatments, except for MCP + Ca. Cocci et al. (*52*) found similar results in minimally processed apples when treated with ascorbic plus citric acid.

Agar et al. (*14*) reported higher retention of ascorbic acid levels in kiwifruit slices treated with Ca when compared to that of the control. In our case, Asc treatment as well as MCP + Ca were efficient in keeping ascorbic acid content higher than the other treatments through shelf life at 2 °C.

Total Phenolics. Total phenolics were significantly ($P < 0.05$) higher in C + Asc, followed by MCP + Ca, MCP + Asc, and C + cont than in the other treatments at the beginning of the experiment (**Figure 2**). Fawbush et al. (*51*) reported a slightly lower phenolic concentration in 1-MCP treated whole apples through 5 months of storage. In our study, there was no influence

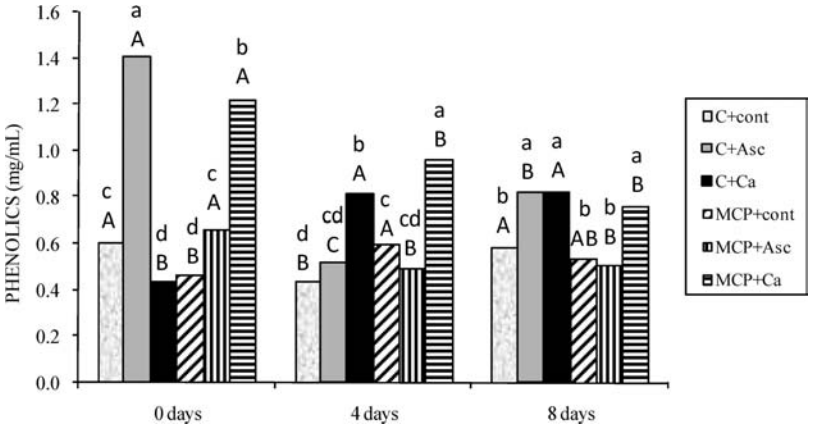

Figure 2. Total phenolic content of fresh-cut Hayward kiwifruit during shelf life at 2 °C. Harvested kiwifruit were treated with 1 μL L^{-1} 1-MCP (MCP) or were untreated (C), stored for 3 months at 0 °C, and then used for fresh-cut produce, and further dipped in 2% ascorbic acid (Asc), 2% calcium chloride (Ca), or just water (cont). Values in the same day followed by the same lower case letter and in the same treatment followed by the same upper case letter are not significantly different by Duncan's multiple range test ($P < 0.05$).

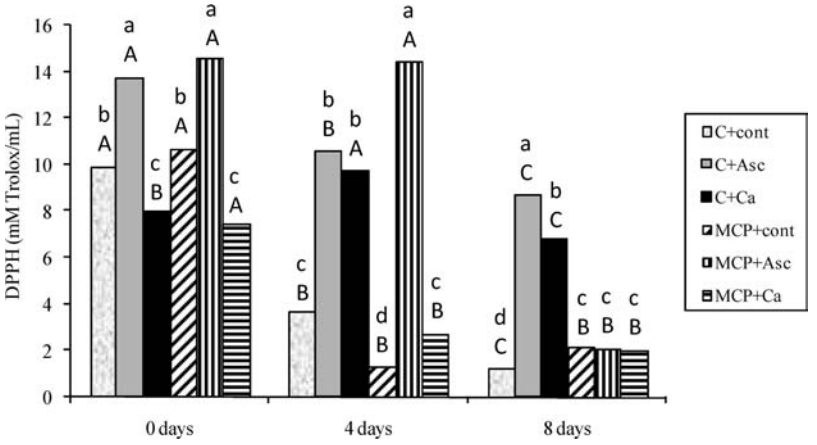

Figure 3. Capacity for scavenging free radicals measured by the DPPH (2,2-diphenyl-1-picrylhydrazyl) method in fresh-cut Hayward kiwifruit during shelf life at 2 °C. Harvested kiwifruit were treated with 1 μL L^{-1} 1-MCP (MCP) or were untreated (C), stored for 3 months at 0 °C, and then used for fresh-cut produce, and further dipped in 2% ascorbic acid (Asc), 2% calcium chloride (Ca), or just water (cont). Values in the same day followed by the same lower case letter and in the same treatment followed by the same upper case letter are not significantly different by Duncan's multiple range test ($P < 0.05$).

of 1-MCP on the phenolics content, but we worked with fresh-cut kiwifruit. If any effect occurred, then it was lost after cutting.

The first 4 days of shelf life led to a significant decrease of total phenolics content in C+Asc and MCP+Ca treatments (**Figure 2**). Phenolics content of C + Ca increased and, by the eighth shelf life day, together with C + Asc and MCP + Ca had the highest values.

Kalt (*53*) and Tavarini et al. (*54*) reported that phenolics content may increase or decrease in fruit and vegetables, depending on the storage conditions. Indeed, phenolics content remained unaltered in whole kiwifruit stored for 2 months, while it increased after 6 months of storage (*54*). Also, as for control slices in our experiments, Gil et al. (*55*) found no changes in phenolics of entire or fresh-cut kiwifruit during 9 days of shelf life. Cocci et al. (*52*) reported a decrease in total phenolic levels after 2 shelf life days, remaining constant until 8 days, in ascorbic acid + citric acid dipped apple slices, as in our study. The same authors also have found at the end of shelf life (8 days) a significantly higher poliphenolic content in C + Asc fresh-cut fruit compared to that in the control. They attributed this behavior to the reducing action of ascorbic acid that prevented a high level of total phenolic degradation. However, that effect was not observed in MCP-fruit, which raises the question on the limitation imposed by the ethylene dependent processes. Furthermore, we have found that as for C + Asc, fresh-cut kiwifruit treated with calcium showed higher phenolics content after 8 days of storage in either C- or MCP-fruit.

Antioxidant Capacity. Two methods were used for the evaluation of antioxidant capacity in kiwifruit: trolox equivalent antioxidant capacity (TEAC) or ABTS$^{\bullet}$ [2,2-azino-bis(3-ethylbenzthiazoline-6-sulfonic acid) method and the DPPH$^{\bullet}$ (2,2′-diphenyl-1-picrylhydrazyl) method.

Antioxidant Capacity Determined by the DPPH Method. Despite the similarity among the several fruit groups just after dipping, suggesting the inefficiency of 1-MCP to improve the capacity of kiwifruit to scavenger free radicals, by the eighth shelf life day at 2 °C, this capacity was significantly ($P < 0.05$) lower, being quite evident in all MCP-fruit, despite the different fresh-cut dips (**Figure 3**).

Fruit dipped in Asc showed the highest DPPH values followed by cont and Ca (**Figure 3**). A progressive decrease in DPPH through storage was observed, as also reported by Cocci et al. (*52*) for fresh-cut apples.

The highest activity observed for MCP + Asc samples at the fourth day of shelf life is not easily explained (**Figure 3**). Indeed, the antioxidant activity measured by DPPH decreased

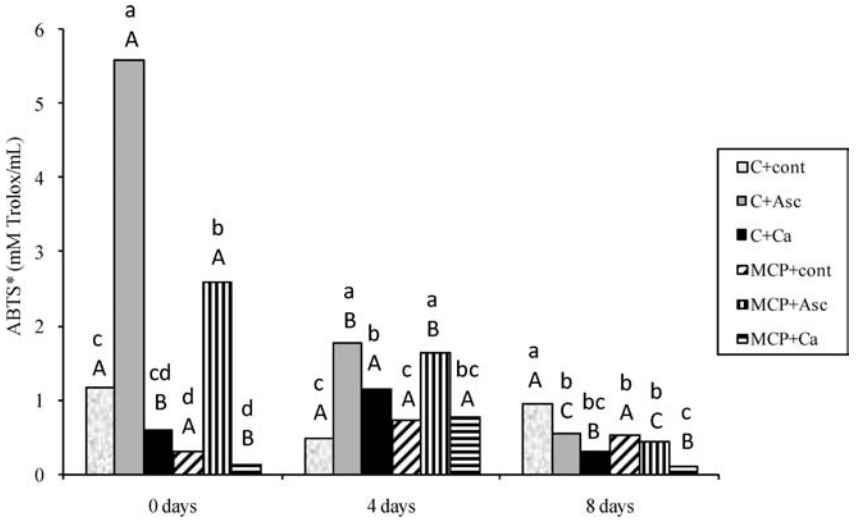

Figure 4. Capacity for scavenging free radicals measured by the ABTS [2,2-azino-bis(3-ethylbenzthiazoline-6-sulfonic acid) method in fresh-cut Hayward kiwifruit during shelf life at 2 °C. Harvested kiwifruit were treated with 1 μL L^{-1} 1-MCP (MCP) or were untreated (C), stored for 3 months at 0 °C, and then used for fresh-cut produce, and further dipped in 2% ascorbic acid (Asc), 2% calcium chloride (Ca), or just water (cont). Values in the same day followed by the same lower case letter and in the same treatment followed by the same upper case letter are not significantly different by Duncan's multiple range test ($P < 0.05$).

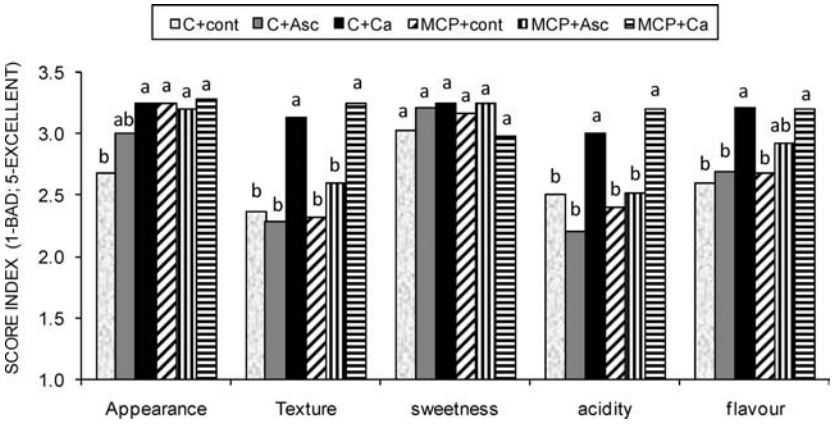

Figure 5. Score index of fresh-cut Hayward kiwifruit after 7 days of shelf life at 2 °C. Harvested kiwifruit were treated with 1 μL L^{-1} 1-MCP (MCP) or were untreated (C), stored for 3 months at 0 °C, and then used for fresh-cut produce, and further dipped in 2% ascorbic acid (Asc), 2% calcium chloride (Ca), or just water (cont). Values in the same day followed by the same lower case letter and in the same treatment followed by the same upper case letter are not significantly different by Duncan's multiple range test ($P < 0.05$).

dramatically only after the fourth day of shelf life in the MCP + Asc, suggesting that 1-MCP might have an indirect protective effect with respect to the total scavenging activity in Asc kiwifruit.

In C-fruit, however, Asc was shown to be the most effective for maintaining the antioxidant ability of kiwifruit, followed by Ca (**Figure 3**). The highest decreases in DPPH were observed for controls and MCP + Ca mainly after 4 days of shelf life. Although significantly reduced, Asc and Ca treatments, in the absence of 1-MCP, have prevented such a dramatic loss of scavenging activity in kiwifruit even after 8 shelf life days (**Figure 3**). Overall, MCP had a counter effect on the activity of both ascorbic acid and calcium. It is possible that the climacteric delay effect imposed by 1-MCP (*28*) can, through the limitation imposed on the respiratory pathway, also limit the scavenging capacity associated with this pathway. This needs further studies.

Antioxidant Capacity Determined by the ABTS Method. The radical scavenging activity measured by the ABTS method gave lower values than those measured by DPPH as reported by Du et al. (*56*).

The capacity for scavenging free radicals measured by the ABTS method was significantly higher in C-fruit than in the MCP at the beginning of the experiment (**Figure 4**). The highest values were observed after dip in C + Asc followed by MCP + Asc fresh-cut kiwifruit.

Although showing a significant decrease, after 4 shelf life days, Asc dipped fruit, with or without MCP, showed significantly higher ABTS values followed by the C + Ca. However, contrary to the DPPH method, the effect of treatment was not significant for antioxidant capacity as measured by the ABTS method, after 8 days of shelf life (**Figures 3** and **4**).

Du et al. (*56*) found lower but proportional values for antioxidant capacity measured by ABTS than DPPH in different kiwifruit genotypes. In our experiment, similar results were obtained except after the eighth day, when a significant effect promoted by some treatments was observed only in DPPH.

Sensory Analysis. The taste panel is of great importance as dip treatments can change the edible quality and taste of fresh-cut products. After 7 shelf life days, the taste panel showed that all fresh-cut kiwifruit had a reasonable appearance (> 3 in a scale of 1−5),

except for C + cont (**Figure 5**). Texture and acidity were significantly ($P < 0.05$) higher in Ca samples, despite the pretreatment with or without 1-MCP. Sweetness was unchanged by any of the treatments, with values close to 3 in a scale of 1−5 (**Figure 5**). Flavor was highest in Ca dipped fruit (values >3) in C- or MCP-fruit, followed by MCP + Asc, and then the other treatments.

The results of the taste panel do agree with the instrumental measurements giving preference for Ca dips independent of the prestorage treatment, although 1-MCP helped to preserve the appearance of fruit before processing.

Conclusions. It is important to have eating-ripe fruit kept with their fresh-like quality for as long as possible. It seems that 1-MCP affects the main characteristics related to the ripening/senescense process during storage of whole fruit, with its effect being reduced through fresh-cut shelf life at 2 °C. On the basis of our data, we suggest that 1-MCP does not significantly affect quality and nutritional properties in fresh-cut kiwifruit through 8 days of shelf life at 2 °C. Its effect was resumed to lower fructose and glucose content at the end of experiments but have no effect on SSC. This apparent inefficiency of 1-MCP may be due to a very early application, three months before processing, and/or to the ethylene synthesis induction by wounding, which may overcome the preventive effect by the still existent 1-MCP in kiwifruit.

Dips of kiwifruit slices in 2% $CaCl_2$ delayed their softening and browning and maintained L and a* color values better, with the respective fruit being preferred by panellists.

Either ascorbic acid applied to fresh-cut kiwifruit or $CaCl_2$, mainly in the first 4 days of shelf life, had a positive effect in preserving or improving the nutritional characteristics, namely, phenolics, ascorbic acid content, and antioxidant activity (DPPH and ABTS). $CaCl_2$ had a longer beneficial effect until 8 days of shelf life at 2 °C.

It is suggested from our work that $CaCl_2$ generally behaves better in keeping overall quality through 8 days of shelf life at 2 °C in fresh-cut kiwifruit, followed by ascorbic acid. 1-MCP has a negligible effect when applied to whole fruit 3 months before processing.

LITERATURE CITED

(1) Soliva-Fortuny, R. C.; Martín-Belloso, O. New advances in extending the shelf-life of fresh-cut fruits: a review. *Trends Food Sci. Technol.* **2003**, *14*, 341–353.

(2) Mao, L.; Wang, G.; Que, F. Application of 1-methylcyclopropene prior to cutting reduces wound responses and maintains quality in cut kiwifruit. *J. Food Eng.* **2007**, *78*, 361–365.

(3) Beirão-da-Costa, S.; Steiner, A.; Correia, L.; Empis, J.; Moldão-Martins, M. Effects of maturity stage and mild heat treatments on quality of minimally processed kiwifruit. *J. Food Eng.* **2006**, *76*, 616–625.

(4) Wang, C. Y.; Buta, J. G. Maintaining quality of fresh-cut kiwifruit with volatile compounds. *Postharvest Biol. Technol.* **2003**, *28*, 181–186.

(5) Martín-Diana, A. B.; Rico, D.; Frías, J. M.; Barat, J. M.; Henehan, G. T. M.; Barry-Ryan, C. Calcium for extending the shelf life of fresh whole and minimally processed fruits and vegetables: a review. *Trends Food Sci. Technol.* **2007**, *18* (4), 210–218.

(6) Vilas-Boas, E. V. B.; Kader, A. A. Effect of 1-methylcyclopropene (1-MCP) on softening of fresh-cut kiwifruit, mango and persimmon slices. *Postharvest Biol. Technol.* **2007**, *43*, 238–244.

(7) Antunes, M. D. C.; Sfakiotakis, E. M. Ethylene biosynthesis and ripening behaviour of 'Hayward' kiwifruit subjected to some controlled atmospheres. *Postharvest Biol. Technol.* **2002**, *26*, 167–179.

(8) Beirão-da-Costa, S.; Steiner, A.; Correia, L.; Leitão, E.; Empis, J.; Moldão-Martins, M. Influence of moderate heat pre-treatments on physical and chemical characteristics of kiwifruit slices. *Eur. Food Res. Technol.* **2008**, *226*, 641–651.

(9) Antunes, M. D. C.; Pateraki, I.; Kanellis, A. K.; Sfakiotakis, E. M. Differential effects of low temperature inhibition on the propylene induced autocatalysis of ethylene production, respiration and ripening of 'Hayward' kiwifruit. *J. Hortic. Sci. Biotechnol.* **2000**, *75* (5), 575–580.

(10) Crisosto, C. H.; Mitcham, E. J.; Kader, A. A. Produce facts kiwifruit. Management of fruit ripening. *Postharvest Hortic. Serv.* **2000**, *9*, 40–41.

(11) Sfakiotakis, E.; Antunes, M. D.; Stavroulakis, G.; Niklis, N. Ethylene Biosynthesis. Its Role in Ripening and Quality of 'Hayward' Kiwifruit after Harvest, during Storage and in Shelf Life. In *Crop Management and Postharvest Handling of Horticultural Products. Vol. 1: Quality Management*; Dris, R., Niscanan, R. Jain, M., Eds.; Oxford & IBH Publishing Co. Pvt. Ltd.: New Delhi, India, 2001; pp 263−287.

(12) Blankenship, S. M.; Dole, J. M. 1-Methylcyclopropene: a review. *Postharvest Biol. Technol.* **2003**, *28*, 1–25.

(13) Aguayo, E.; Jansasithorn, R.; Kader, A. A. Combined effects of 1-methylcyclopropene, calcium chloride dip, and/or atmospheric modification on quality changes in fresh-cut strawberries. *Postharvest Biol. Technol.* **2006**, *40*, 269–278.

(14) Agar, I. T.; Massantini, R.; Hess-Pierce, B.; Kader, A. A. Postharvest CO_2 and ethylene production and quality maintenance of fresh-cut kiwifruit slices. *J. Food Sci.* **1999**, *64*, 433–440.

(15) McGuire, R. G. Reporting of objective color measurements. *Hortscience* **1992**, *27*, 1254–1255.

(16) Antunes, M. D. C.; Sfakiotakis, E. M. Changes in fatty acid composition and electrolyte leakage of 'Hayward' kiwifruit during storage at different temperatures. *Food Chem.* **2008**, *110* (4), 891–896.

(17) Miguel, G.; Dandlen, S.; Antunes, D.; Neves, A.; Martins, D. The effect of two methods of pomegranate (*Punica granatum* L.) juice extraction on quality during storage at 4 °C. *J. Biomed. Biotechnol.* **2004**, *5*, 332–337.

(18) Singleton, V. L.; Rossi, J. A. Colorimetry of total phenolics with phosphomolybdic-phosphotungstic acid reagents. *Am. J. Enol. Vitic.* **1965**, *16*, 144–158.

(19) Brand-Williams, W.; Cuvelier, M. E.; Berset, C. Use of a free radical method to evaluate antioxidant activity. *LWT-Food Sci. Technol.* **1995**, *28* (1), 25–30.

(20) Re, R.; Pellegrini, N.; Proteggente, A.; Pannala, A.; Yang, M.; Rice-Evans, C. Antioxidant activity applying an improved ABTS radical cation decolorization assay. *Free Radical Biol. Med.* **1999**, *26*, 1231–1237.

(21) Stec, M. G. H.; Hodgson, J. A.; McRae, E. A.; Triggs, C. M. Role of fruit firmness in the sensory evaluation of kiwifruit (*Actinidea deliciosa cv. Hayward*). *J. Sci. Food Agric.* **1989**, *47*, 417–433.

(22) Koukounaras, A.; Sfakiotakis, E. Effect of 1-MCP prestorage treatment on ethylene and CO_2 production and quality of 'Hayward' kiwifruit during shelf-life after short, medium and long term cold storage. *Postharvest Biol. Technol.* **2007**, *46*, 174–180.

(23) Antunes, M. D. C.; Panagopoulos, T.; Rodrigues, S.; Neves, N.; Curado, F. The effect of pre- and postharvest calcium applications on 'Hayward' kiwifruit storage ability. *Acta Hortic.* **2005**, *682*, 909–916.

(24) Lara, I.; García, P.; Vendrell, M. Modifications in cell wall composition after cold storage of calcium-treated strawberry (*Fragraria x ananassa* Duch.) fruit. *Postharvest Biol. Technol.* **2004**, *34*, 331–339.

(25) Watada, A. E.; Qui, L. Quality of fresh-cut produce. *Postharvest Biol. Technol.* **1999**, *15*, 201–205.

(26) Picchioni, G. A.; Watada, A. E.; Conway, W. S.; Whitaker, B. D.; Sams, C. E. Phospholipid, galactolipid, and steryl lipid composition of apple fruit cortical tissue following postharvest $CaCl_2$ infiltration. *Phytochemistry* **1995**, *39*, 763–769.

(27) Mignani, I.; Greve, L. C.; Ben-Arie, R.; Stotz, H. U.; Li, C.; Shackel, K.; Labavitch, J. M. The effects of GA_3 and divalent cations on aspects of pectin metabolism and tissue softening in ripening tomato pericarp. *Physiol. Plant.* **1995**, *93*, 108–115.

(28) Boquete, E. J.; Trinchero, G. D.; Fraschina, A. A.; Vilella, F.; Sozzi, G. O. Ripening of 'Hayward' kiwifruit treated with 1-methylcyclopropene after cold storage. *Postharvest Biol. Technol.* **2004**, *32*, 57–65.

(29) Vilas-Boas, E. V. B.; Kader, A. A. Effect of atmosphere modification, 1-MCP and chemicals on quality of fresh-cut banana. *Postharvest Biol. Technol.* **2006**, *39*, 155–162.
(30) Gorny, J. R.; Hess-Pierce, B.; Cifuentes, R. A.; Kader, A. A. Quality changes in fresh-cut pear slices as affected by controlled atmospheres and chemical preservatives. *Postharvest Biol. Technol.* **2002**, *24*, 271–278.
(31) Gong, Y.; Matheis, J. P. Effect of ethylene and 1-methylcyclopropene on chlorophyll catabolism of broccoli florets. *Plant Growth Reg.* **2003**, *40*, 33–38.
(32) Hershkovitz, V.; Saguy, S. I.; Pesis, E. Postharvest application of 1-MCP to improve the quality of various avocado cultivars. *Postharvest Biol. Technol.* **2005**, *37*, 252–264.
(33) Monsalve, G. A.; Barbosa, C. G. V.; McEvily, A. J.; Iyengar, R. Inhibition of enzymatic browning in apple products by 4-hexilresorcinol. *Food Technol.* **1995**, *49*, 110–118.
(34) Rocha, A. M. C. N.; Morais, A. M. M. B. Shelf-life of minimally processed apple (cv. Jonagored) determined by color changes. *Food Control* **2003**, *14*, 13–20.
(35) Apintanapong, M.; Cheachumluang, K.; Suansawan, P.; Thongprasert, N. Effect of agents on banana slices and vacuum-fried slices. *J. Food, Agric. Environ.* **2007**, *5*, 151–157.
(36) Rojas-Graü, M. A.; Soliva-Fortuny, R.; Martín-Belloso, O. Effect of natural antibrowning agents on color and related enzymes in fresh-cut Fuji apples as an alternative to the use of ascorbic acid. *J. Food Sci.* **2008**, *73*, S267–S272.
(37) Zuo, L.; Seog, E. J.; Lee, J. H. Effects of ascorbic and citric acids on CIE color values of fresh-cut Apple cubes. *J. Food Technol.* **2008**, *6* (1), 20–24.
(38) Marty, I.; Bureau, S.; Sarkissian, G.; Gouble, B.; Audergon, J. M.; Albagnac, G. Ethyylene regulation of carotenoid accumulation and carotogenic gene expression in colour-contrasted apricot varieties (*Prunus armeniaca*). *J. Exp. Bot.* **2005**, *56*, 1877–1886.
(39) Esti, M.; Messia, M. C.; Bertocchi, P.; Sinesio, F.; Moneta, E.; Nicotra, A.; Fantechi, P.; Palleschi, G. Chemical compounds and sensory assessment of kiwifruit (*Actinidia chinensis* (Planch.) var. *chinensis*): electrochemical and multivariate analyses. *Food Chem.* **1998**, *61*, 293–300.
(40) DeEll, J. R.; Murr, D. P.; Porteous, M. D.; Rupasinghe, H. P. V. Influence of temperature and duration of 1-methylcyclopropene (1-MCP) treatment on apple quality. *Postharvest Biol. Technol.* **2002**, *24*, 349–353.
(41) Dong, L.; Kurie, S.; Zhou, H. Effect of 1-methylcyclopropene on ripening of 'Canino' apricots and 'Royal Zee' plums. *Postharvest Biol. Technol.* **2002**, *24*, 135–145.
(42) Hofman, P. J.; Jobin-Décor, M.; Meiburg, G. F.; Macnish, A. J.; Joyce, D. C. Ripening and quality responses of avocado, custard apple, mango and papaya fruit to 1- methylcyclopropene. *Aust. J. Exp. Agric.* **2001**, *41*, 567–572.
(43) Selvarajah, S.; Bauchot, A. D.; John, P. Internal browning in cold-stored pineapples is suppressed by a postharvest application of 1-methylcyclopropene. *Postharvest Biol. Technol.* **2001**, *23*, 167–170.
(44) Tian, M. S.; Prakash, S.; Elgar, H. J.; Young, H.; Burmeister, D. M.; Ross, G. S. Responses of strawberry fruit to 1- methylcyclopropene (1-MCP) and ethylene. *Plant Growth Regul.* **2000**, *32*, 83–90.
(45) Marsh, K.; Attanayake, S.; Walker, A.; Gunson, H.; Boldingh, E.; MacRae, E. Acidicity and taste in kiwifruit. *Postharvest Biol. Technol.* **2004**, *32*, 159–168.
(46) Amodio, M. L.; Colelli, G; Hasey, J. K.; Kader, A. A. A comparative study of composition and postharvest performance of organically and conventionally grown kiwifruits. *J. Sci. Food and Agric.* **2007**, *87*, 1228–1238.
(47) Nishyama, I.; Tetsuo, F.; Shimohashi, A.; Oota, T. Sugar and organic acid composition in the fruit juice of different *Actinidia* varieties. *Food Sci. Technol. Res.* **2008**, *14*, 67–73.
(48) Leuschner, C.; Hermann, K. M.; Schultz, G. The metabolism of quinate in pea roots: purification and partial characterization of a quinate hydrolyase. *Plant Physiol.* **1995**, *108*, 319–325.
(49) Keates, S. E.; Tarlyn, N. M.; Loewus, F. A.; Franceschi, V. R. L-Ascorbic acid and L-galactose are sources for oxalic acid and calcium oxalate in *Pistia stratiotis*. *Phytochemistry* **2000**, *53*, 433–440.
(50) Rassan, M.; Laing, W. Variation in ascorbic acid and oxalate levels in the fruit of *Actinidia chinensis* tissues and genotypes. *J. Agric. Food Chem.* **2005**, *53*, 2322–2326.
(51) Fawbush, F.; Nock, J. F.; Watkins, C. B. Antioxidant contents and activity of 1-methylcyclopropene (1-MCP)-treated 'Empire' apples in air and controlled atmosphere storage. *Postharvest Biol. Technol.* **2009**, *52*, 30–37.
(52) Cocci, E; Rocculi, P.; Romani, S.; Rosa, M. D. Changes in nutritional properties of minimally processed apples during storage. *Postharvest Biol. Technol.* **2006**, *39*, 265–271.
(53) Kalt, W. Effects of production and processing factors on major fruit and vegetable antioxidants. *J. Food Sci.* **2005**, *70* (1), R11–R19.
(54) Tavarini, S.; Innocenti, E. D.; Remorini, D.; Massai, R.; Guidi, L. Antioxidant capacity, ascorbic acid, total, phenols and carotenoids changes during harvest and after storage of Hayward kiwifruit. *Food Chem.* **2008**, *107*, 282–288.
(55) Gil, M. I.; Aguayo, E.; Kader, A. A. Quality changes and nutrient retention in fresh-cut versus whole fruits during storage. *J. Agric. Food Chem.* **2006**, *54*, 4284–4296.
(56) Du, G.; Li, M.; Ma, F.; Liang, D. Antioxidant capacity and the relationship with polyphenol and vitamin C in *Actinidia* fruits. *Food Chem.* **2009**, *113*, 557–562.

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