

# Maintaining quality of fresh-cut kiwifruit with volatile compounds

Chien Y. Wang\*, J. George Buta

Produce Quality and Safety Laboratory, Plant Sciences Institute, ARS, US Department of Agriculture, Bg. 002, BARC-W, 10300  
Baltimore Avenue, Beltsville, MD 20705-2350, USA

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## Abstract

Kiwifruit (*Actinidia deliciosa*) were cut into 5 mm slices and placed in polystyrene trays. Various volatile compounds were introduced inside the trays before the lids were covered. The development of decay and the shelf life of the slices were evaluated during storage at 10 °C. Kiwifruit slices treated with 2.24, 11.2, or 22.4  $\mu\text{l l}^{-1}$  methyl jasmonate maintained good quality after 3 weeks at 10 °C compared to the control slices. Comparable results were obtained with absolute ethyl alcohol (300  $\mu\text{l l}^{-1}$ ) or isopropyl alcohol (300  $\mu\text{l l}^{-1}$ ). However, 1-propanol was less effective and methyl alcohol was not effective in maintaining the quality of kiwifruit slices. Methods of application affected the efficacy of the volatile compounds. In general, suspension of the source of volatile compounds within the trays yielded better results compared to volatilization of the volatile compounds from beakers placed inside the trays. In addition to having less decay, kiwifruit slices treated with methyl jasmonate also maintained higher levels of sugars and organic acids compared to the untreated slices. Measurement of oxygen and carbon dioxide concentrations in the trays indicated that oxygen never dropped below 19.5% and carbon dioxide remained at approximately 0.8% in all treatments during the 3 weeks at 10 °C. No differences in respiration rates between methyl jasmonate treatment and control were detected. Ethylene production increased during the first 7 days and then decreased gradually. However, no differences in ethylene production between methyl jasmonate treatment and control were found.

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## 1. Introduction

Kiwifruit slices do not store well because of their susceptibility to infections by gray mold (*Botrytis cinerea*), blue mold (*Penicillium expansum*), and

phomopsis (*Phomopsis actinidiae*). In addition to microbial growth, fresh-cut kiwifruit also break-down rapidly because of their high water content and soft texture. Therefore, it is difficult to maintain the quality of kiwifruit slices once they have been cut. A 9–12-day shelf life at 0–2 °C has been reported with the combination of calcium treatment and modified atmosphere packaging (Agar et al., 1999). However, kiwifruit slices remain an attractive item in the salad bars of

\* Corresponding author. Tel.: +1-301-504-5981; fax: +1-301-504-5107

E-mail address: wangc@ba.ars.usda.gov (C.Y. Wang).

many restaurants and food service entrepreneurs. There is a need for better techniques in maintaining quality and extending shelf life of fresh-cut kiwifruit.

Several volatile compounds have shown promise in reducing postharvest diseases and disorders in horticultural crops. Methyl jasmonate vapor or emulsion inhibits the microbial contamination of fresh-cut celery and peppers (Buta and Moline, 1998), inhibits the gray mold infection in strawberries (Moline et al., 1997), suppresses green mold decay in grapefruit (Droby et al., 1999), inhibits aflatoxin production by *Aspergillus flavus* (Goodrich-Tanrikulu et al., 1995), and suppresses *B. cinerea* rot in cut rose flowers (Meir et al., 1998). When used as a co-fumigant with thymol or carvacrol, methyl jasmonate decreases the severity of postharvest brown rot in sweet cherries (Tsao and Zhou, 2000). In addition, methyl jasmonate also delays decay and pitting development caused by chilling injury in zucchini squash (Wang and Buta, 1994), avocados, grapefruit and peppers (Meir et al., 1996), and mangoes (Gonzalez-Aguilar et al., 2001). Use of vinegar vapor has been reported to effectively prevent conidia of brown rot, gray mold, and blue mold from germinating in stone fruits, strawberries, and apples (Sholberg et al., 2000). Exposure of whole or half-peeled avocado fruit to acetaldehyde vapor delays fruit softening and inhibits ethylene production (Pesis et al., 1998). Control of superficial scald in 'delicious' apples was achieved by treating the fruit with ethanol, butan-1-ol, or propan-1-ol (Ghahramani et al., 2000). Ethanol vapor was also effective in reducing postharvest leaf blackening in cut flower *Protea* 'Pink Ice' stems (Crick and McConchie, 1999). This study was initiated to determine the effectiveness of several volatile compounds including methyl jasmonate, ethanol, and other alcohols in maintaining the quality and shelf life of kiwifruit slices.

## 2. Materials and methods

### 2.1. Plant material

Kiwifruit (*Actinidia deliciosa* cv. Hayward) were obtained from the Maryland Wholesale Market in

Jessup, MA. Care was taken to select only fruit with uniform size and shape and no external defects. Fruit used for the experiments had a firmness of 10–14 N and a soluble solids content of 9–11%.

### 2.2. Reagents

Methyl ( $\pm$ )-jasmonate was obtained from Aldrich Chemical Co. (Milwaukee, WI). Ethyl alcohol was obtained from Aaper Alcohol and Chemical Co. (Shelbyville, KY). Methyl alcohol, 1-propanol, and isopropanol were obtained from Sigma Chemical Co. (St. Louis, MO).

### 2.3. Slice preparation and treatments

Before slicing, kiwifruit were washed with a 200 ppm solution prepared from 5% sodium hypochlorite (Chlorox). After rinsing with deionized water and air-drying, the fruit were cut into 5 mm slices with a commercial slicing machine (Model 827, Berkel, Inc., La Porte, IN). The slices were randomized and placed into 1 l polystyrene containers with snap-on lids commonly used for fresh-cut products.

Two methods of application were used for supplying the volatile compounds inside the plastic containers. One method was to place the specified volume of the volatile compounds into small beakers which were subsequently placed inside the plastic containers and allowed to vaporize spontaneously. The second method was to spot the desired volume of the volatile compounds onto filter paper strips hanging inside the containers before the lids were covered.

Three concentrations (2.24, 11.2, and 22.4  $\mu\text{l l}^{-1}$ ) of methyl jasmonate were applied, whereas only one concentration (300  $\mu\text{l l}^{-1}$ ) was used for ethyl alcohol, methyl alcohol, 1-propanol or isopropyl alcohol based on the preliminary experiments. Three containers were used for each treatment and all containers were stored at 10 °C.

### 2.4. Decay evaluation

The severity of decay was visually evaluated daily during storage at 10 °C. The degree of

infection on slices was rated using a scale of 1–5, where 1—clean, no infection, 2—trace, 3—slight, 4—moderate, and 5—severe infection. The experiments were replicated two times.

### 2.5. Measurements of ethylene, O<sub>2</sub>, and CO<sub>2</sub>

To analyze the accumulation of ethylene and CO<sub>2</sub> and the depletion of O<sub>2</sub> inside the containers during storage, 10 ml of headspace gas was taken from each container twice each week for analysis. Ethylene was determined with a Carle flame ionization gas chromatograph (Carle Instruments, Inc., Fullerton, CA) equipped with an alumina column. Carbon dioxide and oxygen were measured with a CO<sub>2</sub> and O<sub>2</sub> analyzer (AMETEK Applied Electrochemistry, Pittsburgh, PA, Model CD-3A for CO<sub>2</sub> and S-3A for O<sub>2</sub>). For ethylene production and respiration measurements, samples were weighed and then enclosed in quart jars. A 10 ml gas sample was collected in a gas syringe from each treatment at the end of the 1 h enclosure and the accumulated ethylene and CO<sub>2</sub> were determined with the instruments described above.

### 2.6. Analysis of sugars and organic acids

Two grams of kiwifruit tissue were homogenized with a Polytron homogenizer (Brinkmann Instruments, Westbury, NY) in imidazole buffer (20 mM, pH 7.0). The extracts were centrifuged and the supernatants were dried in vacuo in derivatizing vials. Procedures described by Li and Schuhmann (1980) were modified for the derivatization of sugars and organic acids. A known amount of  $\beta$ -phenyl-D-glucopyranoside was included in all samples as an internal standard. One milliliter of Trisil reagent (Pierce, Rockford, IL) was mixed vigorously with each sample and then heated at 75 °C for 30 min. After silylation, 1  $\mu$ l of each derivatized sample was injected into a Hewlett Packard 5890 gas chromatograph (Hewlett Packard, Palo Alto, CA) equipped with a flame ionization detector and a 25 m crosslinked methyl silicon gum capillary column (0.2 mm ID, 0.33  $\mu$ m film thickness). Temperatures were as follows: injector 250 °C, detector 275 °C, and column temperature was programmed to increase from

Table 1

Effect of various volatile compounds on the severity of decay in fresh-cut kiwifruit stored at 10 °C for 3 weeks

Volatile compounds	Concentration ( $\mu$ l l <sup>-1</sup> )	Score <sup>a</sup>
Methyl jasmonate	22.4	1.0 ± 0.0
Methyl jasmonate	11.2	1.0 ± 0.0
Methyl jasmonate	2.24	1.3 ± 0.4
Ethyl alcohol	300	1.3 ± 0.4
Isopropyl alcohol	300	1.3 ± 0.4
1-Propanol	300	3.3 ± 0.5
Methyl alcohol	300	5.0 ± 0.0
Control	–	4.7 ± 0.6

<sup>a</sup> Scoring represents a visual rating of decay severity on kiwifruit slices using a scale of 1–5 with 1—no infection, 2—trace, 3—slight, 4—moderate, and 5—severe infection.

100 to 250 °C at 10 °C min<sup>-1</sup>, then holding at 250 °C for 23 min. Organic acids were analyzed after extraction with imidazole buffer and purification with a Baker-10 solid-phase extraction system. Supernatants from the extract were passed through the quaternary amine columns, which were previously conditioned with hexane and methanol. The samples were then eluted from the columns with 0.1 N HCl. The eluates were concentrated to dryness in vacuo in derivatized vials. Procedures of derivatization and chromatography for organic acids were the same as those for sugars except that column temperature was held at 180 °C for 3 min, then increased to 250 °C at 10 °C min<sup>-1</sup> and held at 250 °C for 12 min. The sugars and organic acids were quantified by comparison with the derivatized standards.

## 3. Results and discussion

### 3.1. Effect of volatile compounds on the severity of decay

Preliminary experiments have shown that spotting the volatile compounds onto hanging filter paper strips produced more profound effects compared to putting the volatile compounds into small beakers placed inside the trays. Apparently, the former method facilitated the vaporization of the volatile compounds. Therefore, only data from hanging filter paper strip method are shown in the

Table 2

Oxygen and carbon dioxide concentrations (%) inside containers of kiwifruit slices during storage at 10 °C

Days	Control		Methyl jasmonate (22.4 $\mu\text{l l}^{-1}$ )		Methyl jasmonate (11.4 $\mu\text{l l}^{-1}$ )	
	O <sub>2</sub>	CO <sub>2</sub>	O <sub>2</sub>	CO <sub>2</sub>	O <sub>2</sub>	CO <sub>2</sub>
0	20.41	0.47	20.12	0.78	20.34	0.56
3	20.31	0.55	19.87	1.03	20.18	0.76
6	20.29	0.57	19.92	1.07	20.22	0.81
9	20.36	0.61	19.93	1.09	20.23	0.81
12	20.47	0.71	20.19	1.05	20.48	0.76
15	20.17	0.85	19.92	1.13	20.20	0.80

present report. A striking difference in the severity of decay between control and methyl jasmonate treatments was observed after 3 weeks of storage at 10 °C (Table 1). Fresh-cut kiwifruit developed severe fungal infection and decay when they were not exposed to any volatile compounds. Kiwifruit slices exposed to 11.2 or 22.4  $\mu\text{l l}^{-1}$  methyl jasmonate remained fresh-looking and had no infection even after 3 weeks at 10 °C. Those treated with 2.24  $\mu\text{l l}^{-1}$  methyl jasmonate or with 300  $\mu\text{l l}^{-1}$  absolute ethyl alcohol or isopropyl alcohol also maintained good quality and had only trace amounts of mold growth. However, 1-propanol was less effective in inhibiting the mold growth. Slices exposed to 1-propanol had slight to moderate infection. All of the slices in methyl alcohol treatment exhibited severe decay and did not appear to be different from those in the untreated control.

Suppression of decay by methyl jasmonate treatment has been shown in other horticultural commodities. Postharvest application of methyl jasmonate effectively inhibited green mold decay and reduced chilling injury symptoms after 6 weeks of storage at 2 °C plus 4 days at 20 °C in grapefruit (Droby et al., 1999). Methyl jasmonate at very low concentration (2.24  $\mu\text{l l}^{-1}$ ) also was effective in decreasing microbial growth and prolonging storage life of fresh-cut celery and peppers at 10 °C (Buta and Moline, 1998). Suppression of *Botrytis* rot in cut rose flowers by postharvest treatment of methyl jasmonate has also been reported (Meir et al., 1998). While 22.4  $\mu\text{l l}^{-1}$  methyl jasmonate was found to be the most effective concentration for reducing chilling injury

and decay of mango fruit, a lower concentration (2.24  $\mu\text{l l}^{-1}$ ) was shown to produce a more desirable effect on color, soluble solids, sugars, and organic acids (Gonzalez-Aguilar et al., 2001). The enhancement of the resistance to decay and chilling injury by methyl jasmonate might be linked to the increased accumulation and expression of stress proteins, such as heat shock proteins and pathogenesis-related (PR) proteins in the treated tissues (Ding et al., 2001). The use of various alcohol vapors to inhibit decay was apparently due to their antimicrobial activity.

### 3.2. Changes of O<sub>2</sub> and CO<sub>2</sub> in the containers

One of the factors which may influence the quality and storage life of harvested fruits and vegetables is the atmosphere surrounding them. Depending on the type of commodity and the length of exposure, most fruits and vegetables are injured by the high concentrations of CO<sub>2</sub> and low concentrations of O<sub>2</sub> (Lidster et al., 1990). In kiwifruit, accumulation of fermentative metabolic products such as acetaldehyde and ethanol which cause off-flavor can be enhanced by oxygen levels at 0.5% or lower and internal discoloration can be induced by carbon dioxide at 10% or higher (Agar et al., 1999). To ascertain that the CO<sub>2</sub> concentrations did not accumulate to the injurious levels and the O<sub>2</sub> concentrations did not deplete to a suboxidation level, the changes of these gases in the headspaces of the containers were analyzed twice weekly. Very little change was found in CO<sub>2</sub> or O<sub>2</sub> levels during the 3 weeks of storage at 10 °C (Table 2). Oxygen concentrations fluctuated be-

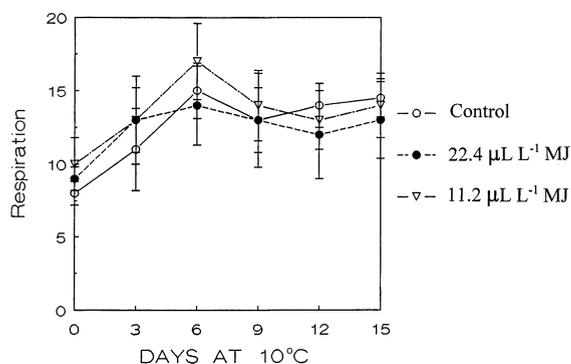


Fig. 1. Respiration ( $\text{CO}_2 \text{ mg kg}^{-1} \text{ h}^{-1}$ ) of methyl jasmonate (MJ)-treated kiwifruit slices during storage at  $10^\circ\text{C}$ .

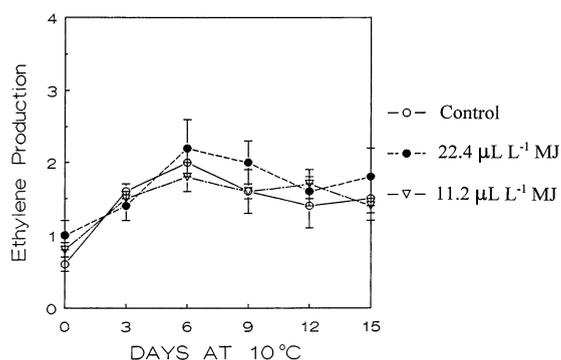


Fig. 2. Ethylene production ( $\text{C}_2\text{H}_4 \mu\text{l kg}^{-1} \text{ h}^{-1}$ ) of methyl jasmonate (MJ)-treated kiwifruit slices during storage at  $10^\circ\text{C}$ .

tween 20.4 and 19.5% in all the treatments, but never dropped below 19.5%. Carbon dioxide concentrations stayed around 0.8% most of the

time, but never increased more than 1.3%. The levels of oxygen and carbon dioxide inside the containers in all the treatments in our study, thus, remained in the safe range throughout the experiment.

### 3.3. Respiration and ethylene production

Respiration rates of kiwifruit slices in all the treatments increased slightly during the first 6 days (Fig. 1). These increases might have been the result of tissue damage or wounding created by slicing of the fruit. Thereafter, the respiration rates remained stable for the duration of the experiment. No significant differences in  $\text{CO}_2$  production between methyl jasmonate treatment and control were detected. Ethylene production in kiwifruit slices was low (Fig. 2). However, all slices exhibited a gradual increase in ethylene production during the first 6 days and a slight decrease during the remainder of the experiment. Comparable levels of ethylene were produced by all the treatments measured, indicating that ethylene production was neither stimulated nor inhibited by any of the treatments.

### 3.4. Sugar and organic acid levels as affected by volatile compounds

Fructose and glucose are the main sugars in kiwifruit (Table 3). These two sugars were present in the kiwifruit slices in approximately equal

Table 3

Effect of methyl jasmonate treatment on sugar and organic acid levels in kiwifruit slices stored at  $10^\circ\text{C}$

Treatment	Storage duration (days)	Sugars ( $\text{g kg}^{-1}$ fresh wt.)			Organic acids ( $\text{g kg}^{-1}$ fresh wt.)	
		Fructose	Glucose	Sucrose	Malic	Citric
Control	0	46±3	38±2	8±0.6	9±0.5	6±0.2
	7	54±5	47±3	11±0.8	5±0.4	8±0.3
	14	50±2	42±3	13±1.1	3±0.2	10±0.9
Methyl jasmonate (22.4 $\mu\text{l l}^{-1}$ )	0	46±3	38±2	8±0.6	9±0.5	6±0.2
	7	72±6	64±4	17±1.5	8±0.7	11±0.7
	14	66±5	57±3	15±1.2	6±0.9	14±1.1
Methyl jasmonate (11.2 $\mu\text{l l}^{-1}$ )	0	46±3	38±2	8±0.6	9±0.5	6±0.2
	7	61±4	54±2	13±0.8	6±0.3	10±0.6
	14	57±2	52±3	15±1.7	7±1.0	12±0.8

amounts. Sucrose was also found, but in smaller quantities. Fructose and glucose levels increased slightly during the first 7 days and then declined. Fruit treated with methyl jasmonate tended to maintain higher levels of sugars compared with the control fruit. The initial increase of sugars possibly was the result of the ripening process. Much higher levels of soluble sugars have also been reported at eating ripeness stage than at commercial maturity in various kiwifruit genotypes (Esti et al., 1998).

Malic acid and citric acid are the two predominant organic acids in kiwifruit (Table 3). As the storage progressed, malic acid decreased and citric acid increased. Thus, the ratio of malic acid to citric acid decreased with time. Total organic acid levels remained higher in methyl jasmonate-treated slices than in the control slices, especially at the end of storage. The lower levels of sugars and organic acids were probably related to the breakdown of tissues in the control slices.

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