Microbiological Quality and Shelf Life of Enzyme-peeled Fresh-cut Persimmon Slices Stored in High CO₂ Atmospheres

Yukari Murakami, Yoshihiko Ozaki, and Hidemi Izumi¹

Faculty of Biology-Oriented Science and Technology, Kinki University, 930 Nishimitani, Kinokawa, Wakayama, 649-6493 Japan

Additional index words. controlled atmosphere, active modified atmosphere packaging, fresh-cut fruits, enzymatic peeling, microflora

Abstract. The microbiological quality and shelf life of enzyme-peeled fresh-cut persimmon slices were evaluated during storage in a high CO₂ controlled atmosphere (CA) and active modified atmosphere packaging (MAP) at 10 °C. Microbial counts of the enzyme-peeled slices were lower in high CO₂ atmospheres (10%, 15%, and 20%) than in air during CA storage for 6 days at 10 °C with the 20% CO₂ atmosphere being most effective. High CO₂ atmospheres did not affect the number of bacterial and fungal species detected in the persimmon slices. The surface color, expressed as C* values, of the peeled side of enzyme-peeled slices was lower in high CO₂ than in air after 6 days of CA storage. In contrast, C* values at the cut side were higher for slices stored in 20% CO₂ than in air on Day 6. High CO₂ atmospheres did not affect other quality of enzyme-peeled slices such as texture, pH, sugar content, and total ascorbic acid content. Based on the optimum 20% CO₂ concentration in a CA, enzyme-peeled slices were stored in a MAP flushed with either air or 20% CO₂ for 4 days at 10 °C. The CO₂ concentration approached an equilibrium of either 5% or 10% after 3 days of storage in packages flushed with either air or 20% CO₂, respectively, and the O₂ decreased to ≈10% in both packages. Adding 20% CO₂ to the MAP was effective in reducing the growth of mesophiles and coliforms but not fungi in enzyme-peeled persimmon slices throughout 4 days of storage. The diversity of bacterial and fungal flora was partially similar between packages flushed with air and 20% CO₂. Texture, pH, surface color, sugar content, and total ascorbic acid content of enzyme-peeled persimmon slices were unaffected by air or 20% CO₂ as the flushing gas, except that C* values of the enzymatically peeled side on Day 4 were lower for slices flushed with 20% CO₂ than air. A 20% CO₂ atmosphere is recommended for reducing the microbial population of enzyme-peeled persimmon slices stored at 10 °C and the shelf life of persimmon slices in an active MAP with 20% CO₂ is 4 days at 10 °C.

Peeling is an important process to maintain the overall quality of fresh-cut fruits during their production and distribution. However, the common methods of mechanical and chemical peeling often cause the loss and damage of flesh, and sometimes there is deterioration of the visual, physiological, and microbial quality of fresh-cut fruits. As an alternative to these methods, the enzyme-peeling technology began with the first report of a method to remove the peel of grapefruit by dipping scored samples in an enzymatic solution under vacuum (Bruemmer et al., 1978). This method was then applied to various fruits such as grapefruit (Pao et al.,

1996), oranges (Pinnavaia et al., 2006), mangoes (Sakho et al., 1998), apricots, nectarines, peaches (Toker and Bayındırlı, 2003), and Japanese persimmon fruits (Ozaki et al., 2004). We reported that enzyme-peeled persimmon slices resulted in a substantial reduction of microbes in fresh-cut slices, and there was no difference in the physicochemical quality between enzyme-peeled and knife-peeled slices (Murakami et al., 2012).

It is important to maintain the microbiological and physiological quality of fresh-cut fruits during storage. Because cells and tissue of fruits are wounded by peeling and cutting, a deterioration in quality resulting from biochemical changes usually occurs with fresh-cut produce (Watada and Qi, 1999). CA storage and MAP including reduced O₂ and/or elevated CO₂ have been shown to extend the shelf life of fresh-cut fruits as reviewed by Gorny (2003) and Izumi (2005). An atmosphere of 3% to 5% O₂ + 5% to 8% CO₂ is recommended for storing intact persimmon fruit, which maintains its quality at 0 to 5 °C (Kader, 2003). The external appearance of fresh-cut persimmon slices remained unchanged while they were held for 8 d at

5 °C in the presence of a 12% CO₂ atmosphere (Wright and Kader, 1997). With other fresh-cut fruits, Aguayo et al. (2007) reported that a CA of 15% CO₂ alone or 4% O₂ + 15% CO₂ reduced the microbial counts of fresh-cut melon stored at 5 °C. Budu et al. (2007) showed that atmospheres of either 80% O₂ + 15% CO₂ or 5% O₂ + 15% CO₂ reduced the microbial growth on fresh-cut pineapple stored at 5 ± 1 °C. When fresh-cut ‘Carabao’ and ‘Nam Dokmai’ mango cubes were stored under air or high CO₂ atmospheres (3%, 5%, and 10%) at 5 or 13 °C, a 10% CO₂ atmosphere enhanced the bacteriostatic activity (Poubol and Izumi, 2005). These findings indicate that high CO₂ atmospheres appear to be more beneficial for controlling microbial quality than low O₂. The changes in quality of fresh-cut persimmons under high CO₂ atmospheres need to be better understood to ensure quality enzyme-peeled persimmons during storage and distribution.

In this study, we initially determined the optimum ranges of high CO₂ in a CA based on the microbial, physicochemical, and nutrient quality of enzyme-peeled ‘Tone-wase’ persimmon slices during storage at 10 °C. The microbiological quality and shelf life of enzyme-peeled persimmon slices during storage in an active MAP of 20% CO₂ at 10 °C were then evaluated. ‘Tone-wase’ persimmons were used, because we previously reported that an early-maturing cultivar, Tone-wase, was more suitable than a late-maturing cultivar, Fuyu, for the fresh-cut industry in Japan for an optimal microbial and physicochemical quality of enzymatically peeled slices (Murakami et al., 2012).

Materials and Methods

Fruit materials. Ninety-nine fruits of ‘Tone-wase’ persimmon (*Diospyros kaki* Thunb.) were obtained from a commercial grower in Wakayama Prefecture, Japan, from Sept. to Oct. 2011. Fruit were treated to remove astringency by holding them in a closed chamber with a 95% CO₂ atmosphere for 18 h at 25 °C followed by storage for 0 to 2 d at room temperature. Treated fruit were then transported to the laboratory at Kinki University and stored at 20 °C for 2 to 3 d before processing.

Processing. Enzyme-peeled fruit samples were produced according to the method of Ozaki et al. (2004). Calyxes of fruits were removed with a sterilized knife. The enzymatic peeling was then performed as follows. The peel was made porous with a needlepoint holder, and then the fruit were submerged in a hot water bath at 100 °C for 45 s and then cooled in tap water for 1 min. Fruit were infused with enzyme by dipping them in 3% protopectinase (Pectinase-IGA; IGA Bio Research Ltd., Osaka, Japan) produced by *Trichosporon penicillatum* SNO-3 (Sakai, 1988) at 37 °C for 3 h and then rinsed under running tap water for 1 min. The enzyme-peeled fruit was sliced radially into four sections using a sterilized knife. The enzymatic peeling treatment was replicated three times using three fruits for

Received for publication 5 June 2012. Accepted for publication 10 Oct. 2012.

This research was part of the Program for Fostering Regional Innovation (City Area Type) sponsored by the Ministry of Education, Culture, Sports, Science, and Technology of Japan.

We thank Dr. Kathy K. Kamo for reading the manuscript.

¹To whom reprint requests should be addressed; e-mail izumi@waka.kindai.ac.jp.

each treatment of high CO₂ CA storage, and active MAP.

High CO₂ controlled atmosphere storage. Twelve enzyme-peeled slices weighing 400 to 500 g were placed into a 2-L plastic container containing 5 mL of distilled water in a plastic beaker to maintain a high relative humidity. Three replicates were stored under a continuous flow of air or high CO₂ atmosphere (10%, 15%, and 20%) with the balance being air at a flow rate of 15 mL·min⁻¹ for 6 d at 10 °C.

Active modified atmosphere packaging of high CO₂. For active MAP, the optimum gas concentration was based on the results of CA storage. Four enzyme-peeled slices weighing 150 to 180 g were packaged in OPP film (30 µm thick, 21 × 23 cm, O₂ permeability of 1170 mL·m⁻²·d⁻¹·1013 hPa⁻¹; Sumitomo Bakelite Co., Ltd., Tokyo, Japan) flushed with either air or 20% CO₂. In this study, all enzyme-peeled slices flushed with air or 20% CO₂ were found unmarketable after 6 d of storage, so three replicates of each treatment were monitored for 4 d at 10 °C.

Microbial counts. Slices of persimmon fruits during a CA and active MAP storage were taken periodically, and microbial analysis of each sample was performed as previously described (Izumi, 1999). A 10-g sample cut with a sterile scalpel was macerated in 90 mL sterile saline solution (0.85% NaCl in water) in a sterile stomacher bag with an Elmer stomacher (Promedia SH-001; ELMEX, Tokyo, Japan) for 4 min at room temperature. Serial dilutions from each sample were made using sterile saline solution and then poured on the following media: two standard method agar (SMA; Nissui Pharmaceutical, Tokyo, Japan) plates incubated at 37 °C for 48 h for enumeration of mesophiles, two desoxycholate agar (Nissui Pharmaceutical) plates incubated at 37 °C for 24 h for enumeration of coliform groups, and three potato dextrose agar (PDA; Nissui Pharmaceutical) plates with 100 ppm of chloramphenicol incubated at 26 °C for 72 h for enumeration of fungi. The microbiological plate count data were converted to log cfu per gram of fruit.

Microbial isolation and identification. The diluent of each sample was plated onto the surface of solidified SMA and PDA. Bacteria and fungi (molds and yeasts) were aseptically isolated from the SMA plates incubated at 37 °C for 48 h and PDA plates incubated at 26 °C for 72 h, respectively. One hundred thirty-five bacterial and 40 fungal (three mold and 37 yeast) isolates were selected from different-appearing types of colonies on petri plates. A MicroSeq microbial identification system (Applied Biosystems, Foster City, CA) was used to identify the bacteria and fungi. The sequencing data were analyzed using Analysis Software (MicroSeq analysis software Version 2.0, MicroSeq, 16S rDNA sequence databases Version 2.2 for bacteria, and MicroSeq, D2 LSU rDNA sequence databases Version 2.0 for fungi) as previously described (Poubol and Izumi, 2005). A cutoff of the lowest distance score from the sequence

in the database was chosen for species identification.

O₂ and CO₂ analyses. The O₂ and CO₂ concentrations in packages were measured daily during the MAP storage period using a gas chromatography equipped with a thermal conductivity detector (GSC-8AIT-TC; Shimadzu, Kyoto, Japan). The columns used for O₂ and CO₂ analyses were Molecular Sieve SA at 60 °C and Porapak Q at 90 °C, respectively.

Quality evaluation. Subsamples of slices were taken at scheduled time periods during CA storage or active MAP storage for evaluation of quality as previously described (Murakami et al., 2012; Poubol and Izumi, 2005). Surface color (C* value) of the peeled side and cut side of three slices per replication was measured with a Handy Colorimeter (Model NR-3000; Nippon Denshoku, Tokyo, Japan). Surface pH of three slices was determined with a compact pH meter (Model B-113; Horiba, Tokyo, Japan). Texture (N) of the three slices was measured by the force required to shear the slice with a cutter blade using an EZ test texture analyzer (Model AR-228; Shimadzu, Kyoto, Japan). Sugar content of the three slices was determined using a spectral photometer (Model ultraviolet-1600; Shimadzu) based on the method of Somogyi-Nelson (Chachin, 1981). Total ascorbic acid content of the three slices was determined using high-performance liquid chromatography (Model LC-10AD; Shimadzu) equipped with a PLRP-S 100A column (4.6 mm × 25 cm, 5 µm; Polymer Laboratories, Varian, Inc., Amherst, MA) and an electro-chemical detector (Model ECD 300; Eicom, Kyoto, Japan).

Statistical analysis. Statistically significant differences ($P \leq 0.05$) were determined for the microbial population, gas concentration, and quality evaluation data based on an analysis of variance using the SAS system, Release 6.12 (SAS Institute, Cary, NC). The mean values were compared using the Tukey's honestly significant difference method when main effects were significant among the treatments in CA or active MAP storage.

Results and Discussion

Microflora of enzyme-peeled fresh-cut persimmon slices during controlled atmosphere storage. Initially, slices after the peeling and cutting treatment showed a count of 3.0 log cfu·g⁻¹ for mesophiles, and it was below the limit of detection for both coliforms (2.4 log cfu·g⁻¹) and fungi (3.0 log cfu·g⁻¹) (Fig. 1). Because persimmon fruit were submerged in hot water at 100 °C to inactivate the substances in the peel that inhibit the pectolytic enzyme during the enzymatic peeling process, the heating treatment served as hot water pasteurization as shown in our previous report (Murakami et al., 2012). Fan et al. (2008) also reported that hot water treatment at 76 °C for 3 min reduced the microbial population of cantaloupe. During storage in air, counts of mesophiles of persimmon slices increased to 6.4 log cfu·g⁻¹ by Day 4. The high CO₂ (10%, 15%, and 20%) CA reduced

the count increase with the reduction being greatest in 20% CO₂ (4.8 log cfu·g⁻¹) on Day 4. Counts of coliforms and fungi of slices stored in air increased to ≈5.5 log cfu·g⁻¹ by Day 6. In comparison, 20% CO₂ storage showed the lowest count of 3.4 log cfu·g⁻¹ for coliforms and 4.3 log cfu·g⁻¹ for fungi. Elevated CO₂ has been shown to effectively reduce microbial growth on fresh-cut mango cubes (Poubol and Izumi, 2005), fresh-cut pineapple (Antonioli et al., 2007; Budu et al., 2007), and fresh-cut apple slices (Gunes and Hotchkiss, 2002). Inhibition of microbial growth by CO₂ may result from the presence of dissolved CO₂ in the aqueous phase of fresh-cut products, which causes a decrease of the intercellular pH and enzymatically inhibits catalyzed reactions and enzyme synthesis (Molin, 2000).

Poubol and Izumi (2005) reported that the microflora diversity was less for the fresh-cut mango cubes stored in 10% CO₂ rather than in air or CO₂ atmospheres of either 3% or 5%. However, in our study, high CO₂ did not show the desired effects on the microbial diversity of enzyme-peeled slices during storage. No major differences were found in the number of bacterial and fungal species isolated from enzyme-peeled slices stored under either air or high CO₂ atmospheres even after 6 d of storage (Table 1). Isolates from the enzyme-peeled samples included phytopathogenic bacteria such as *Pseudomonas* and *Stenotrophomonas*, soilborne bacteria such as *Bacillus* and *Curtobacterium*, and yeasts living in a plant-soil environment such as *Cryptococcus*, *Pichia*, and *Rhodotorula*. These bacteria and fungi are frequently found in other fruits, and they were mostly epiphytic microorganisms (Izumi et al., 2008a, 2008b). Only enzyme-peeled slices stored under 20% CO₂ contained *Weissella*, lactic acid bacterium, and *Aureobasidium*, a mold.

Quality of enzyme-peeled fresh-cut slices during controlled atmosphere storage. The surface color (C* value) of the peeled side significantly decreased by Day 6. There were no significant differences in the surface color of the peeled side when slices were stored in air or high CO₂ atmospheres, except for Day 6 when C* values of the peeled surface were significantly higher for slices stored in air than in high CO₂ although the cause is unknown (Fig. 2). In contrast, C* values of the cut side were higher for slices stored in high CO₂, particularly 20% CO₂, as compared with samples stored in air on Day 6. The peeled and cut surfaces of all samples became brown or dark-colored during storage as indicated by the decreasing C* values. Brown discoloration of the peeled surface of slices may have resulted from non-enzymatic browning that occurred during the heating treatment (100 °C for 45 s) of the enzyme-peeling process, and browning of the cut surface may have been the result of enzymatic browning when phenolic compounds were exposed to polyphenol oxidase. Thus, high CO₂ atmospheres would be helpful in reducing the development of brown discoloration only on cut surfaces. The texture and pH of all samples

Fig. 1. Counts of mesophiles (A), coliforms (B), and fungi (C) of enzyme-peeled fresh-cut persimmon slices stored under either air or high CO₂ controlled atmospheres at 10 °C. ND (not detectable) means no colonies were detected on a plate of the original culture. Means less than 2.4 or 3.0 were below the level of detection (fewer than 30 bacterial or 10 fungal colonies on a plate of the original culture, respectively). Vertical lines represent SE. Bars with different letters within the same day in each graph are significantly different ($P \leq 0.05$).

Table 1. Bacteria and fungi isolated from enzyme-peeled fresh-cut persimmon slices after 6 d of storage under air or high CO₂ controlled atmosphere at 10 °C.

Treatment	Gram type	Bacteria		Molds		Yeasts	
		Genus	Species	Genus	Species	Genus	Species
Air	Negative	<i>Pseudomonas</i>	<i>monteilii</i>	ND ^a		<i>Bullera</i>	<i>dendrophila</i>
		<i>Serratia</i>	<i>marcescens</i>			<i>Cryptococcus</i>	<i>albidus</i>
		<i>Stenotrophomonas</i>	<i>maltophilia</i>				
10% CO ₂	Positive	<i>Bacillus</i>	<i>altitudinis</i>	ND		<i>Pichia</i>	<i>anomala</i>
	Negative	<i>Stenotrophomonas</i>	<i>maltophilia</i>			<i>Rhodotorula</i>	<i>mucilaginoso</i>
15% CO ₂	Negative	<i>Pectobacterium</i>	<i>betavascularum</i>			<i>Rhodotorula</i>	<i>minuta</i>
		<i>Stenotrophomonas</i>	<i>acidaminiphila</i>				<i>mucilaginoso</i>
			<i>maltophilia</i>				
20% CO ₂	Positive	<i>Curtobacterium</i>	<i>albidum/citream</i>	<i>Aureobasidium</i>	<i>pullulans</i>	<i>Pichia</i>	<i>anomala</i>
		<i>Weissella</i>	<i>paramesenteroides</i>				
	Negative	<i>Leclercia</i>	<i>adecarboxylata</i>				
		<i>Pantoea</i>	<i>ananatis</i>				

^aND = not detectable.

remained constant throughout 6 d of storage and were ≈ 8.0 N and 6.0, respectively (data not shown). The sugar content of all samples was constant at ≈ 10.0 g/100 g fresh weight, and the total ascorbic acid content of all slices significantly decreased to $\approx 50\%$ of the initial value (30 mg/100 g) after 6 d of storage (data not shown). Wright and Kader (1997) reported that a CA of 12% CO₂ was effective in maintaining surface lightness, soluble solids, and pH for fresh-cut persimmon slices stored at 5 °C, and the shelf life was increased by delaying the appearance of black areas on the cut surface. Our study indicated that a 20% CO₂ atmosphere was beneficial in retarding the

microbial growth and color deterioration of the cut side, although high CO₂ did not affect other quality including pH, texture, sugar content, and total ascorbic acid content. The difference in quality between persimmon cultivars may be the result of the difference in each cultivar's characteristics. A 20% CO₂ atmosphere was considered the optimum CO₂ concentration for enzyme-peeled slices in an active MAP from the point of microbiological and visual quality.

CO₂ and O₂ concentration in an active modified atmosphere packaging. When enzyme-peeled persimmon slices were stored in a MAP flushed with either air (0.03% CO₂)

or 20% CO₂ for 4 d at 10 °C, the CO₂ concentration approached a 5% or 10% equilibrium, respectively, after 3 d of storage (data not shown). The O₂ concentration decreased from 17% to 19% to $\approx 10\%$ in the packages regardless of the treatment. Although an active MAP by application of the gas could be helpful in achieving the ideal equilibrium atmosphere readily and quickly, the steady-state atmosphere in the packages was 10% CO₂, probably as a result of low respiration rates of the sample and high gas permeability of the film used in this study.

Microflora of enzyme-peeled fresh-cut persimmon slices in an active modified

Fig. 2. C* value of the peeled side (A) and cut side (B) of enzyme-peeled fresh-cut persimmon slices stored under either air or high CO₂ controlled atmospheres at 10 °C. Vertical lines represent SE. Symbols with different letters within the same day in each graph are significantly different ($P \leq 0.05$).

Fig. 3. Counts of mesophiles (A), coliforms (B), and fungi (C) of enzyme-peeled fresh-cut persimmon slices stored in a modified atmosphere packaging flushed with either air or 20% CO₂ at 10 °C. Means less than 2.4 or 3.0 were below the level of detection (fewer than 30 bacterial or 10 fungal colonies on a plate of the original culture, respectively). Vertical lines represent SE. Bars with different letters within the same day in each graph are significantly different ($P \leq 0.05$).

Table 2. Bacteria and fungi isolated from enzyme-peeled fresh-cut persimmon slices after 4 d of storage in a modified atmosphere packaging flushed with air or 20% CO₂ at 10 °C.

Treatment	Gram type	Bacteria		Molds		Yeasts	
		Genus	Species	Genus	Species	Genus	Species
Air	Negative	<i>Enterobacter</i>	<i>aerogenes</i>	ND ²		<i>Pichia</i>	<i>anomala</i>
			<i>kobei</i>			<i>Rhodotorula</i>	<i>mucilaginosa</i>
		<i>Leclercia</i>	<i>adecarboxylata</i>				
		<i>Pantoea</i>	<i>dispersa</i>				
		<i>Raoultella</i>	<i>ornithinolytica</i>				
20% CO ₂	Positive	<i>Curtobacterium</i>	<i>albidum</i>	ND		<i>Pichia</i>	<i>anomala</i>
	Negative	<i>Enterobacter</i>	<i>cancerogenus</i>				
			<i>cloacae</i>				
			<i>kobei</i>				
		<i>Leclercia</i>	<i>adecarboxylata</i>				

²ND = not detectable.

atmosphere packaging. We previously reported that microbial contamination was much less in enzyme-peeled persimmon slices than in knife-peeled slices (Murakami et al., 2012). Counts of mesophiles, coliforms, and fungi of enzyme-peeled fresh-cut slices stored in a MAP flushed with air increased from a level close to or below the level of detection on Day 0 to ≈ 5 log cfu·g⁻¹ on Day 4 (Fig. 3). Flushing with 20% CO₂ showed 0.4 to 1.6 logs of reduction in the growth of mesophiles and coliforms as compared with flushing with air throughout 4 d of storage, but it did not affect fungal counts.

Fig. 4. C* value of the peeled side (A) and cut side (B) of enzyme-peeled fresh-cut persimmon slices stored in a modified atmosphere packaging flushed with either air or 20% CO₂ at 10 °C. Vertical lines represent SE. Symbols with different letters within the same day in each graph are significantly different ($P \leq 0.05$).

Fresh-cut cantaloupe (Bai et al., 2001) and fresh-cut jackfruit (Saxena et al., 2008) showed a reduction in the growth of bacteria and fungi when flushed with a high CO₂ atmosphere.

Bacteria and fungi isolated from slices on the initial day of MAP storage consisted of three species belonging to three genera and one species belonging to one genus, respectively (data not shown). Although the microbial counts significantly increased during 4 d of storage, the number of bacteria isolated from slices in packages with air or with 20% CO₂ was five species belonging to four genera or five species belonging to three genera, respectively, on 4 d of storage (Table 2). The genera commonly isolated from the samples during storage included Enterobacteriaceae such as *Enterobacter* and *Leclercia*. Fresh-cut slices flushed with either air or 20% CO₂ and stored for 4 d contained no molds and only the yeast genera *Pichia* and *Rhodotorula*. Therefore, no major differences were found in the diversity of microflora of slices stored in packages with either air or 20% CO₂ after 4 d of storage.

Quality of enzyme-peeled slices in an active modified atmosphere packaging. The C* values of enzyme-peeled and cut sides of slices flushed with 20% CO₂ decreased by 4 d of storage (Fig. 4). On the peeled side, slices stored in an active MAP flushed with 20% CO₂ had C* values significantly lower than those flushed with air on Day 4. There were no differences found on the cut side throughout the storage period, between the two treatments, where C* values were reduced similarly in both storage in air and 20% CO₂. A significant loss of total ascorbic acid content was observed in all samples during 4 d of storage and there were no significant differences between air and 20% CO₂. Texture, pH, and sugar content were constant during storage regardless of difference in the MAP method (data not shown). Poubol et al. (2004) reported the similar results in which ascorbic acid content, pH, and firmness of fresh-cut mango cubes were

unaffected by a high CO₂ (5% and 10% CO₂) flush.

In conclusion, when enzyme-peeled fresh-cut persimmon slices were stored in an active MAP of 20% CO₂, the high CO₂ atmosphere reduced the rate of bacterial growth and the shelf life was determined to be 4 d at 10 °C. This technology will be useful for increasing the marketing and consumption of enzyme-peeled fresh-cut persimmon slices in Japan. However, although the storage and transportation temperature of fresh-cut produce is commercially 10 °C in Japan, a storage temperature lower than 10 °C with an active MAP may be necessary to extend the shelf life and delay the surface discoloration of enzyme-peeled slices.

Literature Cited

- Aguayo, E., V.H. Escalona, and F. Artés. 2007. Quality of minimally processed *Cucumis melo* var. *saccharinus* as improved by controlled atmosphere. *Eur. J. Hort. Sci.* 72:39–45.
- Antonioli, L.R., B.C. Benedetti, J.M.M. Sigrist, and N.F.A. Silveira. 2007. Quality evaluation of fresh-cut 'Pérola' pineapple stored in controlled atmosphere. *Ciênc. Tecnol. Aliment. Campinas*. 27:530–534.
- Bai, J.-H., R.A. Saftner, A.E. Watada, and Y.S. Lee. 2001. Modified atmosphere maintains quality of fresh-cut cantaloupe (*Cucumis melo* L.). *J. Food Sci.* 66:1207–1211.
- Bruemmer, J.H., A.W. Griffin, and O. Onayemi. 1978. Sectionizing grapefruit by enzyme digestion. *Proc. Fla. State Hort. Soc.* 91:112–114.
- Budu, A.S., D.C. Joyce, and L.A. Terry. 2007. Quality changes in sliced pineapple under controlled atmosphere storage. *J. Hort. Sci. Biotechnol.* 82:934–940.
- Chachin, K. 1981. Carbohydrates, p. 156–162. In: Nakagawa, S. (ed.). *Experiment and laboratory on horticultural science by Osaka Prefecture Univ. Yokendo, Tokyo, Japan* [in Japanese].
- Fan, X., B.A. Annous, J.C. Beaulieu, and J.E. Sites. 2008. Effect of hot water surface pasteurization of whole fruit on shelf life and quality of fresh-cut cantaloupe. *J. Food Sci.* 73:M91–M98.
- Gorny, J.R. 2003. A summary of CA and MA requirements and recommendations for fresh-cut (minimally processed) fruits and vegetables. *Acta Hort.* 600:609–614.
- Gunes, G.G. and J.H. Hotchkiss. 2002. Growth and survival of *Escherichia coli* O157:H7 on fresh-cut apples in modified atmospheres at abusive temperatures. *J. Food Prot.* 65:1641–1645.
- Izumi, H. 1999. Electrolyzed water as a disinfectant for fresh-cut vegetables. *J. Food Sci.* 64:536–539.
- Izumi, H. 2005. Microbiological quality of fresh-cut produce stored in CA/MAP. *Proc. APEC Symposium on Assuring Quality and Safety of Fresh Produce*. p. 119–124.
- Izumi, H., Y. Tsukada, J. Poubol, and K. Hisa. 2008a. On-farm sources of microbial contamination of persimmon fruit in Japan. *J. Food Prot.* 71:52–59.
- Izumi, H., J. Poubol, K. Hisa, and K. Sera. 2008b. Potential sources of microbial contamination of satsuma mandarin fruit in Japan, from production through packing shed. *J. Food Prot.* 71:530–538.
- Kader, A.A. 2003. A summary of CA requirements and recommendations for fruits other than apples and pears. *Acta Hort.* 600:737–740.
- Molin, G. 2000. Modified atmospheres, p. 214–234. In: Lund, B.M., T.C. Barid-Parker, and G.W. Gould (eds.). *The microbiological safety and quality of food. Vol. 1*. Aspen Publishers, Gaithersburg, MD.
- Murakami, Y., Y. Ozaki, and H. Izumi. 2012. Microbiological and physicochemical quality of enzymatically peeled persimmon fruit for fresh-cut slices. *HortScience* 47:382–385.
- Ozaki, Y., H. Yamanishi, M. Kimura, and M. Nakauchi. 2004. Method for peeling of persimmon fruit and peeled persimmons. *JP Patent No.* 3617042.
- Pao, S., P.D. Petracek, and G.E. Brown. 1996. Effect of infusion method on peel removal and storage quality of citrus. *HortTechnology* 6:409–413.
- Pinnavaia, S., E.A. Baldwin, A. Plotto, J. Narciso, and E. Senesi. 2006. Enzyme-peeling of Valencia oranges for fresh-cut slices. *Proc. Fla. State Hort. Soc.* 119:335–339.
- Poubol, J. and H. Izumi. 2005. Shelf life and microbial quality of fresh-cut mango cubes stored in high CO₂ atmospheres. *J. Food Sci.* 70:M69–M74.
- Poubol, J., Y. Ootani, T. Masada, and H. Izumi. 2004. Physicochemical and microbiological characteristics of fresh-cut 'Carabao' mango stored in active MAP. *Proc. APEC Symposium*

- on Quality Management in Postharvest Systems. p. 183–190.
- Sakai, T. 1988. Protopectinase from yeasts and a yeast-like fungus. *Methods Enzymol.* 161:335–350.
- Sakho, M., D. Chassagne, A. Jaus, E. Chiarazzo, and J. Crouzet. 1998. Enzymatic maceration: Effects on volatile components of mango pulp. *J. Food Sci.* 63:975–978.
- Saxena, A., A.S. Bawa, and P.S. Raju. 2008. Use of modified atmosphere packaging to extend shelf-life of minimally processed jackfruit (*Artocarpus heterophyllus* L.) bulbs. *J. Food Eng.* 87:455–466.
- Toker, İ. and A. Bayındırlı. 2003. Enzymatic peeling of apricots, nectarines and peaches. *Lebensm.-Wiss. U.-Technol.* 36:215–221.
- Watada, A.E. and L. Qi. 1999. Quality of fresh-cut produce. *Postharvest Biol. Technol.* 15:201–205.
- Wright, K.P. and A.A. Kader. 1997. Effect of slicing and controlled-atmosphere storage on the ascorbate content and quality of strawberries and persimmons. *Postharvest Biol. Technol.* 10:39–48.