Postharvest CO_2 and Ethylene Production and Quality Maintenance of Fresh-Cut Kiwifruit Slices

I. T. Agar, R. Massantini, B. Hess-Pierce and A. A. Kader

ABSTRACT

The quality attributes and gas production of fresh-cut kiwifruit slices (Actinidia deliciosa cv. Hayward) were studied to identify the optimum ranges of storage temperature, relative humidity, and atmospheric composition. Also the effects of wounding, C_2H_4 addition or removal, and chemical treatments (calcium, ascorbic acid, citric acid) on deterioration rate were investigated. Flesh softening was the major quality loss of stored fresh-cut kiwifruit slices. Fresh-cut kiwifruit slices had a shelf-life of 9-12 days if treated with 1% $CaCl_2$ or 2% Ca lactate, and stored at 0-2°C and >90% relative humidity in an C_2H_4-free atmosphere of 2 to 4 kPa O_2 and/or 5 to 10 kPa CO_2.

Key Words: ascorbic acid, controlled atmosphere, freshcut, kiwifruit, ethylene

INTRODUCTION

PHYSICAL DAMAGE OR WOUNDING CAUSED by slicing, peeling, and/or other mechanical injuries in minimally processed fruits results in increased rates of respiration and ethylene (C_2H_4) production within minutes (Abe and Watada, 1991). Increases occur in biochemical reactions related to changes in color, flavor, texture, nutritional quality and susceptibility to dehydration. During storage such products have a very limited shelf-life (Brackett, 1994; O'Connor-Shaw et al., 1994). These responses occur in disrupted tissues where cellular decompartmentation leads to intermixing of enzymes and substrates, as well as release of acids and hydrolyzing enzymes (Watada et al., 1990).

Minimally processed products should be refrigerated (0-5°C) to prolong their quality and safety (Watada et al., 1996). Removal of C_2H_4 from the storage environment of lightly processed fruits and vegetables can retard tissue softening (Abe and Watada, 1991). Controlled atmospheres can reduce the effects of C_2H_4 on fruit tissues and retard senescence (Kader, 1980), delay softening (Knee, 1980) and help extend the postharvest life (Kader, 1986; Huxsoll and Bolin, 1989). Exogenous treatments with calcium chloride ($CaCl_2$) dips have been reported to reduce browning (Drake and Spayd, 1983), delay ripening (Poovaiah, 1986) and retard flesh softening of whole (Bangerth et al., 1972; Garcia et al., 1996) and sliced fruits (Rosen and Kader, 1989) and vegetables (Izumi and Watada, 1995). However, $CaCl_2$ may also cause detectable off-flavors when used at >0.5% (Guzman, 1996).

Kiwifruits are high in vitamin C (Mitchell, 1994). However, little has been reported about the physiological, microbiological and nutritional changes which may occur in fresh-cut kiwifruit slices (Varoquaux et al., 1990; Watada et al., 1990; Abe and Watada, 1991; O'Connor-Shaw et al., 1994; Massantini and Kader, 1995; Watada et al., 1996). Our objective was to determine the optimum ranges of storage temperatures, relative humidity, and concentrations of oxygen, carbon dioxide, and ethylene for maintaining appearance, texture, flavor, and nutritional quality of fresh-cut kiwifruit slices. Pre-storage dips of kiwifruit slices in calcium solutions, ascorbic acid and/or citric acid were also evaluated.

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MATERIALS & METHODS

Material

Kiwifruits (*Actinidia deliciosa* (A. Chev.) C.-F. Liang et A.R. Ferguson var. *deliciosa* cv Hayward) were harvested from a commercial vineyard in Winters, CA, during 1996 and 1997 and transported to the Dept. of Pomology Postharvest Laboratory at the Univ. of California, Davis within 1h of harvest in an air conditioned vehicle. Initial firmness of whole kiwifruit was 53 to 66N. The average diameter and mass of the fruit were 40 mm and 70-85g, respectively. Kiwifruits were stored at 0°C and ventilated with 90-95% relative humidity, C_2H_4-free air for various durations before they were used in experiments. Additionally, $KMnO_4$ impregnated on aluminum oxide was placed inside each storage tank to absorb C_2H_4.

Ripening

Kiwifruits were sorted to eliminate damaged or defective fruit and partially ripened at 20°C and 90-95% RH in air + 1 Pa C_2H_4 (10 $\mu L \cdot L^{-1}$) in a flow through system. This provided whole fruit flesh firmness values of 15 to 20N. Fruits within this range were matched and used for experiments.

Slice preparation

Kiwifruits were peeled with a sharp vegetable peeler and sliced perpendicularly to the blossom end-stem scar axis with a meat slicer. From each kiwifruit 5 slices (7 mm thick) were obtained. For each treatment, 20 slices from 20 fruits were used for each replicate. Kiwifruit slices in colanders were dipped in 10-L solution containing chlorinated (1.3 mM NaOCl) distilled water at 4°C. Slices were drained, blotted dry with cheesecloth and placed in jars.

Storage

Slices (20) were placed in 1.9-L jars which were ventilated with a flow of humidified air or a specified gas mixture at 20 $mL \cdot min^{-1}$ to ensure that CO_2 concentrations in the air-control jars were maintained below 0.25 kPa. Gas mixtures were maintained ±10% of required concentrations throughout storage.

Flesh firmness

Firmness of whole fruit and slices was determined with a Univ. of California Firmness Tester (Western Industrial Supply Co., San Francisco, CA) by measuring force required for an 8-mm probe to penetrate the cut surface in two opposite locations in mesocarp tissue to a depth of 5 mm. Whole fruit firmness was determined by the force required for an 8-mm probe to penetrate the mesocarp of a whole fruit, with skin removed, to a depth of 10-mm.

Soluble solids (SSC), titratable acidity (TA) and mass loss

One wedge was cut from each slice, and all wedges from 20 slices were juiced together for a composite sample analyzed for SSC using a refractometer (Abbe model 10450;

American Optical Corp, Buffalo, NY) and TA using an automatic titrator (Radiometer, Copenhagen, Denmark). Titration was conducted with 0.1N NaOH to pH 8.1 and percentage citric acid equivalents were determined. The mass of fruit slices in each replicate was recorded initially and after treatments and storage.

Color and visual quality evaluation

Color on opposite sides of each slice was measured with a Minolta Chromameter (Model CR-300, Minolta, Ramsey, NJ) in the CIE L*a*b* mode. Changes in hue angle (h°) were calculated to indicate color change during storage. The visual quality of each fruit slice was determined based on a hedonic scale: 1=inedible; 2=limit of usability; 3=limit of marketability; 4=very good; and 5=excellent. A color photograph of slices so-rated was used by 3 judges to score slices on color, visible structural integrity, and general visual appeal. A weighted average of 20 slice quality scores was calculated to determine the mean visual quality score for each replicate.

Respiration and C_2H_4 production rates

Carbon dioxide and C_2H_4 production rates were measured daily at 20°C and 101 kPa for each replicate and treatment. Slices (20) (200g) were sealed in a 1.9-L jar for 15-30 min and the headspace was sampled with a 10-mL syringe. An infrared CO_2 analyzer (model PIR-2000R, Horiba Instruments, Irvine, CA) was used for CO_2 measurements. A gas chromatograph (model 211 Carle Instruments, Anaheim, CA) with FID detector and alumina column was used to analyze for C_2H_4.

Calcium content

Fresh fruit samples were vacuum dehydrated at –100 kPa at 70°C for 24h. Samples (0.5g) were weighed into 30 mL porcelain crucibles and ashed at 300°C for 1h followed by 500°C for 12h. Ashed samples were allowed to cool to room temperature, digested with 10 mL of 1M HNO_3 at 80°C for 20 min, filtered through Whatman No.1, and made up to 50 mL with double deionized water. Samples were analyzed on a Techtron AA 120 Atomic Absorption Spectrophotometer. A Varian Techtron D 1-30 digital indicator was used; samples were compared to a standard curve and results were expressed as $\mu g \cdot g^{1}$ dry weight.

Ethanol and acetaldehyde

Juice from slices was immediately frozen in liquid N_2 and stored at –80°C until analysis. Samples were thawed and centrifuged in an Eppendorf (5,000 × gn) for 2 min, and 1 µL of supernatant was injected directly to determine acetaldehyde and ethanol in each sample. A HP 5890 GC (Hewlett Packard, Palo Alto, Calif.) equipped with an autosampler, controller (Hewlett Packard model 7673), and FID detector fitted with a Carbopack glass column (2 mm × 1.8m containing 5% Carbowax on 60/80 Carbopack stationary phase; Supelco, Bellefonte, PA) was used. Injector and detector temperatures were 200 and 250°C, respectively. Oven temperature was 75°C for 2 min, followed by a gradient of 7.5°C/min to 100°C and a second gradient of 25°C/min to 160°C, held for 5 min at the final temperature. Compounds were quantified by comparison with known standard retention times and peak areas.

Sugars and organic acids

The method was based on van Gorsel et al. (1992) with some modifications. Juices were prepared by squeezing wedges of fresh slices through cheesecloth, filling vials and immediately freezing in liquid N_2. Juice samples were stored at –80°C until analyses were performed. Juice samples were thawed and centrifuged at 25,000 × *gn* for 15 min at 4°C. The supernatant was adjusted to pH 8-9 with 58% NH_4OH [16.5M], and 2 mL of sample was passed through a column with 2g of anion-exchange resin (Bio-Rex 5 analytical grade, 100-200 mesh, chloride form). The column was rinsed with 2 × 4 mL double deionized water, and the eluate was collected, filtered through a 0.45-µm filter, and analyzed by HPLC for sugar. Next, 2 mL of 10% H_2SO_4 [1.0M] was added to the resin column, and this was rinsed through the column with 2 × 4 mL double deionized water. The eluate was collected, filtered through a 0.45-µm filter and 20 µL of the extract was injected into the HPLC system (Series 1050; Hewlett Packard, Palo Alto, CA).

Individual sugars were separated with a 250 mm × 4 mm HPX-87C column (Bio-Rad) at 85°C and detected with a RI monitor. Double deionized water was used as the mobile phase at 0.6 $mL \cdot min^{-1}$. Sucrose, glucose and fructose (Sigma Chemical Co.) were standards. Organic acids were separated with a reverse phase C_{18} Nucleosil column (150 mm × 4.6 mm, particle size 5 µm) at 25°C with a C18 guard column (Safeguard). All organic acids were determined with a photodiode array detector (DAD, Series II), at 210 nm. The mobile phase was 0.2N $NH_4H_2PO_4$ (pH 3.5) at 1 $mL \cdot min^{-1}$. Citric, malic and quinic acids (Sigma Chemical Co.) were standards.

Ascorbic and dehydroascorbic acid

The method was based on Zapata and Dufour (1992) with some modifications. Subsamples of wedges were frozen in liquid N_2 and stored at –80°C for analysis of L-ascorbic acid and dehydroascorbic acid concentrations. Frozen samples (15g) were crushed with a pestle and homogenized in a 185 mL extraction solution of 0.1M citric acid and 0.05% ethylenediaminetetraacetic acid (EDTA) in 5% aqueous methanol (MeOH) for 2 min at high speed in an Oster Blender. An internal standard of isoascorbic acid was added at 50 $mg \cdot 100\ g^{-1}$ of fruit. The homogenate was filtered through 4 layers of cheesecloth and centrifuged for 10 min at 11,950 × *gn* at 2°C. After calibrating the pH meter with cold buffer solution, the pH of the supernatant was adjusted to 2.35-2.40 with HCl. The sample was passed through a Sep-Pak C_{18} cartridge (Waters Assoc.) which had been preconditioned with 10 mL HPLC grade methanol followed by 10 mL of ultrapure water. Before use, the residual water in the cartridge was expelled with air. The first 5 mL of eluent was discarded and the next 3 mL retained for analysis. We added 1 mL of 1,1-phenylendiamine ($3.3\ mg \cdot mL^{-1}$) in methanol-water (5:95, v/v) 37 min before injection. The mixture was immediately filtered through a 0.45-µm filter into an amber vial, sealed and stored in darkness at 20°C. After 37 min, 20 µL were injected into the HPLC system using a Waters µBondapak C_{18} reverse-phase column (300 mm × 3.9 mm i.d.) with a BioRad Biosil Micro-Guard column (ODS-5S 30-mm × 4.6 mm i.d.). The eluent was methanol:water (5:95, v/v) containing hexadecyltrimethylammonium bromide (CTAB) and 50 mM potassium dihydrogen phosphate, with the pH adjusted to 4.55–4.60. The flow rate was 1.6 $mL \cdot min^{-1}$ at 20°C. Prior to analysis, the column was equilibrated by pumping the eluent at 0.2 $mL \cdot min^{-1}$ for 3h at 20°C and column function was reproducible from lot to lot. Detection was at 261 nm, and retention times were 7.3 and 8.3 min for reduced L-ascorbate and isoascorbate, respectively, and 4.2 min at 348 nm for L-dehydroascorbate. Solutions of standards were prepared in methanol:water (5:95, v/v). Standards of L-ascorbate and isoascorbate were supplied by Sigma and L-dehydroascorbate by Aldrich Chemical Co.

Effects of storage temperature and wounding

Kiwifruit slices were held at 0, 2, 5, and 20°C in the 1996 and at 0, 5, 10 and 20°C in the 1997 to study the effects of temperature on quality retention and physiology. To study the rate of mass loss and effects of wounding on CO_2 and C_2H_4 production, whole peeled fruit, unpeeled slices and peeled slices were compared to whole fruit (control) kept at 2°C for 3 days or at 20°C for 6h.

Effects of C_2H_4 in storage atmosphere

The effects of C_2H_4 on slice firmness and titratable acidity were studied by storing slices in air, air + 0.1 Pa C_2H_4 ($1\ \mu l \cdot L^{-1}$), air + 1 Pa C_2H_4 ($10\ \mu l \cdot L^{-1}$), and air with/without C_2H_4 scrubbing with $KMnO_4$ in a flow-through system at 2°C.

Effects of chemical treatments

Kiwifruit slices were dipped in aqueous solutions of 1% [0.068M] and 2% $CaCl_2$ [0.136M] (m/v) at 4°C for 5 min and compared to controls (water). Calcium content of slices was analyzed with an Atomic Absorption Spectrophotometer. In a second test, slic-

es were dipped in aqueous solutions of 1 and 2% (m/v) $CaCl_2$, 1% (m/v) ascorbic acid [0.056 M], 1% (m/v) citric acid [0.0047M] and 1% ascorbic acid + 1% citric acid, all at 4°C and compared to slices which had not been dipped (dry control) or had been dipped in distilled water (wet control) for 5 min. Firmness was evaluated initially and after 5 days at 2°C. In a third test, slices were dipped in aqueous solutions of 1% $CaCl_2$ [0.068M] (m/v) and then stored at 2°C for 10 days in air with or without C_2H_4, scrubbing with $KMnO_4$, to determine how $CaCl_2$ treatment and C_2H_4 scrubbing affected firmness retention. In a fourth test, Ca lactate was used to replace $CaCl_2$ to prevent the off-flavor problems reported by Guzman (1996) at >0.5% in cantaloupes. Therefore, we compared the efficacy of various concentrations of $CaCl_2$ with Ca lactate on firmness retention. In order to have the equivalent amount of calcium in both treatments, Ca lactate was used at double the concentration of $CaCl_2$ (2% Ca Lac [0.064M] m/v= 1% $CaCl_2$ [0.068M] m/v). Kiwifruit slices were dipped in aqueous solutions of 0.25, 0.5 and 1% (m/v) [0.017, 0.034, 0.068M] $CaCl_2$, or 0.5, 1 and 2% (m/v) [0.016, 0.032, 0.064M] Ca lactate, or distilled water at 4°C for 2 min. Treated kiwifruit slices were stored at 0 and 10°C. Firmness and color were evaluated immediately after dipping and after 3 and 6 days storage.

Effects of atmospheric modification

The quality and gas production of kiwifruit slices were evaluated after storage (0°C) in atmospheres of low O_2 (0.5, 1, 2 or 4 kPa, balance N_2) or elevated CO_2 (air + 2.5, 5, 10, or 20 kPa) concentrations. Subsequently, the following O_2/CO_2 combinations were tested: 2/5, 2/10, 4/5, 4/10 kPa (balance N_2). Slices were evaluated initially, and after 3, 6, 9, and 12 days at 0, 5, and 10°C. Slices were dipped in chlorinated (1.3 mM NaOCl) distilled water with 1% $CaCl_2$ at 4°C as a standard treatment.

Statistical analysis

Three replicates per treatment and 20 slices per replicate were used in the experiments. All data points represent the mean ± SD of the three replicates. Analysis of variance (ANOVA), followed by Duncan's Multiple Range Test with a significance level of $P<0.05$, and correlation tests were performed on the data using CoStat Statistical Software, Ver. 5.01 (CoHort Software, Minneapolis, MN).

RESULTS & DISCUSSION

Effects of storage temperature and relative humidity

At 5°C and higher we noted rapid deterioration of slice quality. Softening increased as storage temperature and time increased (Fig. 1A). Slices kept at 0°C for 12 days exhibited a reduced rate of softening and were above 3N flesh firmness after 12 days. The L* value of kiwifruit slices (surface darkening) was greater at higher storage temperatures and longer durations (Fig. 1B). The cut surface darkening was due to induction of a translucent water-soaked tissue and not to enzymatic browning. Okuse and Ryugo (1981) reported that kiwifruit did not exhibit browning due to low tannin content, low polyphenoloxidase and high ascorbic acid.

Table 1—Changes in the reduced ascorbic acid (AA), dehydroascorbic acid (DHA), and total ascorbic acid (vitamin C) content of fresh-cut kiwifruit slices as related to storage conditions (means ± SD of three replicates)

	mg·100g^{-1} FW		
	AA	DHA	Total
Initial	59.6±0.3	5.3±0.3	64.9
After 6 days at			
0°C	51.6±2.0	8.1±1.0	59.7
5°C	46.8±4.4	9.8±1.0	56.6
10°C	39.4±2.9	12.1±1.8	51.5
$LSD_{Temperature}$ 0.05=	2.90	1.20	1.56
LSD_{Time} 0.05=	2.37	0.98	1.27

Kiwifruit slices stored at 5 and 10°C exhibited a gradual decrease in ascorbic acid (AA) and an increase in dehydroascorbic acid (DHA) (Table 1). The total vitamin C (AA+DHA) was 8, 13 and 21% lower than initial values in slices kept at 0, 5, and 10°C, respectively, after 6 days storage. Mass loss of slices kept in 60% r.h. was 1.2% after 3 days at 2°C, double that of slices kept in 95% r.h.

Effects of wounding

Peeling and slicing caused an increase in mass loss (Fig. 2) which was highest in peeled slices and lowest in intact whole fruit stored 3 days at 2°C. Fresh-cut slices had more water loss than intact fruits because the protective epidermal cells were removed, and surface area/mass rate was increased. Physical tissue damage or wounding caused by slicing and/or peeling resulted in increased CO_2 and C_2H_4 production rates within 2 to 6h at 20°C (Fig. 3) and 1 to 3 days at 2°C (Fig. 4). The C_2H_4 and CO_2 production rates of peel were about 2 to 4 times higher than those of unpeeled slices, which were the next highest source. Peeled fruit and slices had double the C_2H_4 and CO_2 production rates of whole fruit, which remained unchanged during 6h at 20°C or 3 days at 2°C. Respiration and C_2H_4 production rates increased with temperature. The C_2H_4 and CO_2 production rates were 5× higher in peeled slices at 20°C, than in those kept at 2°C (Fig. 3, 4).

Effect of C_2H_4 in the storage atmosphere.

All treatments resulted in loss of firmness

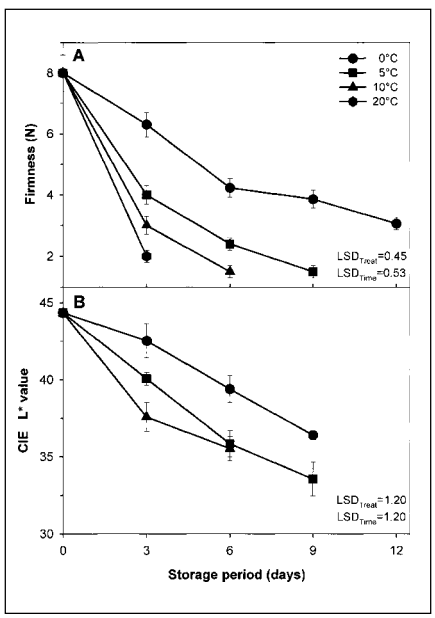

Fig. 1—Effect of storage conditions on firmness (A) and L* value=brightness (B) of fresh-cut kiwifruit slices. For all figures, data points are means of three replicates ± SD and LSDs at 5% level for treatment and time are shown.

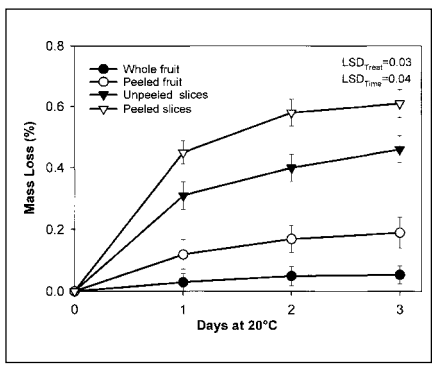

Fig. 2—Effect of wounding on mass loss of whole kiwifruit, whole-peeled fruit, peeled slices and unpeeled slices stored at 20°C for 3 days.

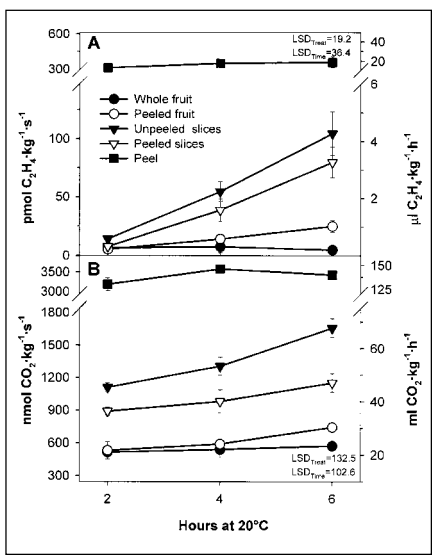

Fig. 3—Effect of wounding on the C_2H_4 (A) and CO_2 (B) production rates of whole kiwifruit, whole-peeled fruit, peel, peeled and unpeeled fruit slices stored at 20°C for 6h.

Table 2—Effects of $CaCl_2$,C_2H_4 scrubbing (with $KMnO_4$), controlled atmosphere, and their combinations on reduced ascorbic acid (AA) content of kiwifruit slices stored at 2°C (means ± SD of three replicates)

mg·100g-1 FW after indicated days at 2°C					
	0	3	5	7	10
Air	55±6	34±5	30±3	20±2	6±4
Air + 1% CaCl2		34±4	28±2	29±4	23±5
Air + KMnO4		35±4	22±8	22±2	20±4
1% CaCl2 + KMnO4		38±3	36±3	28±3	22±3
CA (2 kPaO2+ 5 kPaCO2)		45±7	30±6	30±6	31±4
CA + 1% CaCl2		40±5	40±7	38±3	38±2
$LSD_{Treatment}$ 0.05= 3.51	LSD_{Time} 0.05=	4.49			

and TA. Removal of C_2H_4 from the storage atmosphere reduced the rates of firmness (Fig. 5A) and TA (Fig. 5B) losses of fresh-cut slices stored at 2°C for 5 days. The softening rate was increased by storage in air + 1 Pa (10 $\mu L \cdot L^{-1}$) C_2H_4, whereas storage in air + 0.1 Pa (1 $\mu L \cdot L^{-1}$) C_2H_4 had no effect after 5 days at 2°C. When C_2H_4 was removed, slices were 62%, 27% and 18% firmer than those kept in air + 1 Pa C_2H_4, air + 0.1 Pa C_2H_4 and air (control) treatments, respectively. TA was 18% lower in air (control) and in ethylene-treated slices than in those kept in ethylene-free atmospheres. Slices stored in ethylene-free air contained 3-fold more ascorbic acid than controls (Table 2). When dipped in 1% $CaCl_2$ after cutting and kept in an ethylene-free atmosphere, slices had a slightly higher ascorbic acid content than those treated with 1% $CaCl_2$ only. Results confirmed those of Watada et al. (1990) and Abe and Watada (1991), that the softening rate of kiwifruit slices was reduced by C_2H_4 scrubbing (charcoal

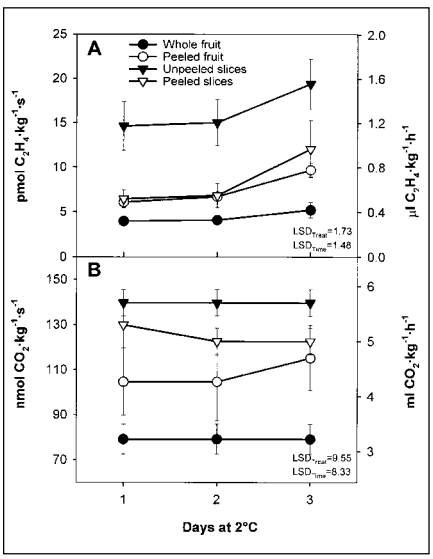

Fig. 4—Effect of wounding on the C_2H_4 (A) and CO_2 (B) production rates of whole kiwifruit, whole-peeled fruit, peeled and unpeeled fruit slices stored at 2°C for 3 days.

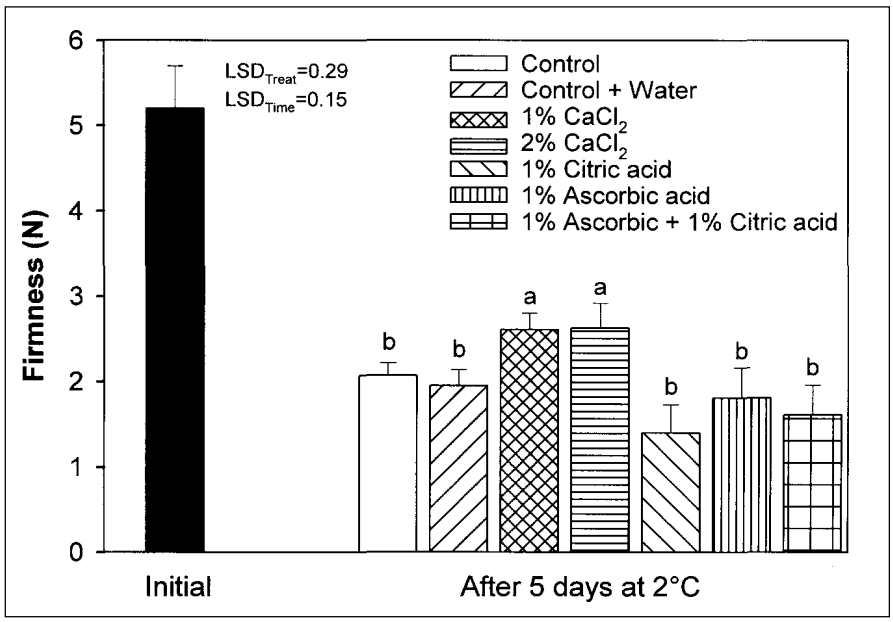

Fig. 6—Effect of $CaCl_2$, citric and ascorbic acid and their combination dips on firmness of fresh-cut kiwifruit slices initially and 5 days at 2°C.

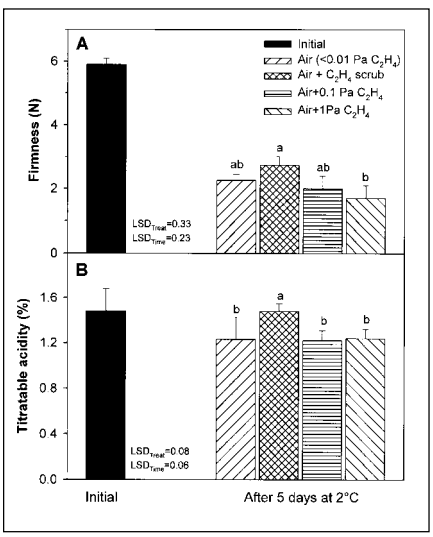

Fig. 5—Effect of exogenous C_2H_4 application and removal of endogenously produced C_2H_4 with $KMnO_4$ on firmness (A) and titratable acidity (B) of fresh-cut slices initially and after 5 days at 2°C.

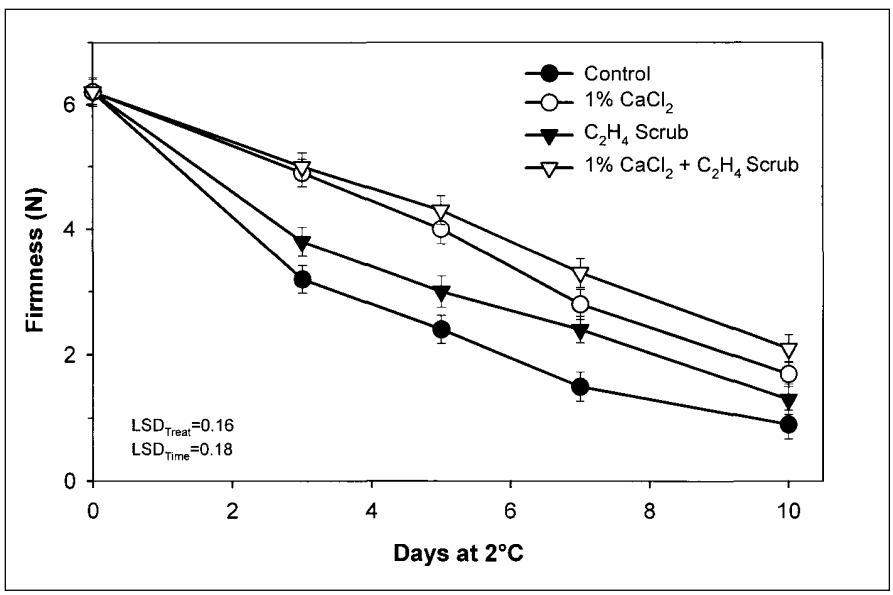

Fig. 7—Effect of CaCl2, C2H4 scrubbing with KMnO4 and their combination on firmness of fresh-cut kiwifruit slices during storage at 2°C for 10 days.

Table 3—Changes in reduced ascorbic acid (AA), dehydroascorbic acid (DHA), and total ascorbic acid (vitamin C) contents of fresh-cut kiwifruit slices as related to O_2 and CO_2 concentrations at 0°C (means±SD of three replicates)

	mg 100g^{-1} FW after 6 days			mg 100g^{-1} FW after 12 days		
	AA	DHA	Total	AA	DHA	Total
Initial	55.0±2.6	6.8±1.2	61.8	55.0±2.6	6.8±1.2	61.8
Air	44.6±5.5	8.7±2.6	53.3	36.2±1.2	14.1±1.1	50.3
0.5% O_2 (balance N_2)	50.7±4.9	7.8±0.6	58.5	49.7±3.3	7.8±0.6	57.6
2% O_2 (balance N_2)	47.7±5.5	12.9±08.	60.6	44.2±5.2	10.3±1.2	54.5
4% O_2 (balance N_2)	51.6±6.8	9.8±1.8	61.4	39.9±2.0	11.2±1.7	51.1
Air + 5 kPa CO_2	46.4±2.1	11.1±1.3	57.5	40.7±2.3	12.4±1.4	53.1
Air + 10 kPa CO_2	41.1±3.1	10.5±0.8	51.6	36.9±1.6	11.4±1.8	48.3
Air + 20 kPa CO_2	36.0±0.4	10.2±0.6	46.4	33.7±0.6	7.6±0.5	41.3
$LSD_{Treatment}$ 0.05 =	3.24	1.23	2.49	3.24	1.23	2.49
LSD_{Time} 0.05 =	2.12	0.80	1.63	2.12	0.80	1.63

with palladium chloride) and enhanced by 2 and 20 $\mu L \cdot L^{-1}$ C_2H_4. Arpaia et al. (1986) determined that C_2H_4 levels of air + 0.005-0.5 Pa accelerated kiwifruit softening, and the response was accelerated by increasing temperatures.

Effect of chemical treatments

Ca concentrations of the slices which had been dipped in 1 and 2% $CaCl_2$ were at levels of 2967±16 $\mu g \cdot g^1$ and 3907±13 $\mu g \cdot g^1$ Ca, respectively, as compared to 2000±16 $\mu g \cdot g^1$ Ca(dry mass basis) in controls. The firmness of slices decreased during 5 days at 2°C in all treatments except the 1 and 2% $CaCl_2$ dipped fruit which were 25% firmer than controls (Fig. 6). The effects of 1 and 2% $CaCl_2$ treatments, were similar. Citric acid, ascorbic acid and their combination treatments did not affect firmness retention.

Kiwifruit slices treated with 1% $CaCl_2$ and then stored in C_2H_4-free air were firmer and had higher ascorbic acid after 3-5 days at 2°C than treatments of 1% $CaCl_2$ or ethylene scrubbing alone (Fig. 7, Table 2). $CaCl_2$ and C_2H_4 scrubbing treatments had an additive effect on firmness and ascorbic acid content until 5 days at 2°C.

Slices treated with 0.5 or 1% $CaCl_2$ and 1 or 2% Ca lactate immediately after cutting had a higher flesh firmness than those treated with 0.25% $CaCl_2$ or 0.5% Ca lactate and controls (Fig. 8). Firmness in all treatments declined after 3 d at 0°C. Slices treated with 0.25 and 0.5% $CaCl_2$ were firmer after 3 days at 0°C than those treated with 0.5 and 1% Ca lactate, although the solutions had equivalent amounts of Ca. The greatest firmness loss occurred between 0 days and 3 days, whereas differences between 3 and 6 d were minimal. The two higher concentrations of $CaCl_2$ (0.5 and 1%) and Ca lactate (1 and 2%) resulted in similar firmness. The 'L*' values decreased less rapidly in Ca-treated slices than in untreated slices, and there was no visible cut surface browning in fresh-cut slices (data not shown).

Varoquaux et al. (1990) reported that the most obvious change in kiwifruit slices was a rapid loss of firmness, which was noticeable after a few hours. They hypothesized that texture loss during storage was due to enzymatic hydrolysis of cell wall components. Calcium chloride treatments firm fruit tissue by reacting with pectinic acid to form calcium pectate (King and Bolin, 1989). Bangerth et al. (1972) and Poovaiah (1986) hypothesized that the main effect of Ca was maintaining the structural integrity of membranes and cell walls. Retention of ascorbic acid levels in kiwifruit slices treated with calcium was similar to results reported for apples (Bangerth, 1976; Drake and Spayd, 1983).

Effect of atmospheric modification

The firmness of slices, initially about 7-8N, decreased rapidly during the first 3 days storage to about 4N irrespective of atmosphere. Thereafter, rates of softening were slower. Treatments with 2 kPa or 4 kPa O_2 (balance N_2) atmospheres (Fig. 9A), as well as air + 5 kPa and air + 10 kPa CO_2 (Fig. 9B), resulted in higher firmness than controls. Slices stored in 4 kPa O_2 tended to have a slightly higher firmness than those kept in 2 kPa O_2. Slices stored in air + 10 kPa CO_2 resulted in slightly higher firmness than in air + 5 kPa CO_2. However, we noted a slight brown discoloration in slices exposed to 10 kPa or higher CO_2 in the first year but not in the second year. Firmness levels were slightly higher for up to 6 d storage in two CA combinations than for those in only low O_2 or only elevated CO_2 atmospheres. However, we did not observe a clear additive effect of low O_2 and elevated CO_2 concentrations on firmness retention (Fig. 9C). Kiwifruit slices stored in low O_2, elevated CO_2 or their combinations tended to retain their initial SSC and TA, while control slices exhibited an increase in SSC and decline in TA during 12 days storage (data not shown).

The visual quality of air (control) stored slices deteriorated (appeared water soaked and macerated around the edges) faster than did those from the other treatments during 12 days storage (Fig. 9 D, E, F). The 2 and 4 kPa O_2 and air + 5 and 10 kPa CO_2 atmospheres resulted in better visual quality (no differences among treatments) of slices compared to controls. Slices stored in low O_2 plus elevated CO_2 atmospheres were similar in visual quality to those held in either low O_2 or elevated CO_2 treatments alone (Fig. 9F).

Ethylene production of slices stored in air was 3-4 fold higher than for those kept in low O_2 or elevated CO_2 (Fig. 10). The 2 kPa O_2 (balance N_2) or air + 10 kPa CO_2 atmospheres generally resulted in lower C_2H_4 production compared to 4 kPa O_2 (balance N_2) or air + 5 kPa CO_2. Storage in 2 kPa O_2 + 5 kPa CO_2 (balance N_2) resulted in the lowest C_2H_4 production rate.

The major plant fermentative metabolism products in fruits are ethanol and acetaldehyde and their accumulation has correlated well with off-flavor development (Ke et al., 1991). The acetaldehyde and ethanol contents

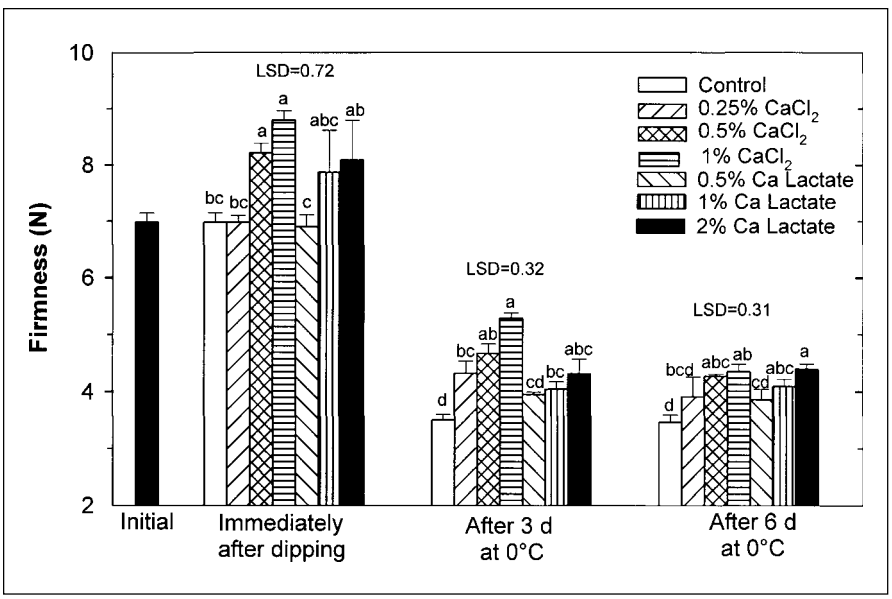

Fig. 8—Effect of CaCl2 and Ca lactate on firmness of fresh-cut kiwifruit slices immediately after dipping and after 3 and 6 days at 0°C.

Table 4—Concentrations of sugars and organic acids in kiwifruit slices stored in air or in controlled atmospheres[a] at 0°C (means±SD of three replicates)

	Storage period (days)	Sugars (g/100mL juice)			Organic Acids (mg/100mL juice)		
		Sucrose	Glucose	Fructose	Citric	Malic	Quinic
Initial	0	1.11±0.06	5.37±0.23	5.61±0.17	964±56	523±21	475±28
Air	6	1.83±0.20	7.43±0.63	8.24±0.63	886±36	366±21	398±49
	12	1.76±0.35	6.24±0.24	7.45±0.26	818±56	372±44	368±61
2 kPa O2+5 kPa CO2	6	1.38±0.07	6.29±0.15	6.89±0.16	880±31	377±13	392±27
	12	1.40±0.20	5.15±0.13	6.10±0.20	1116±146	529±68	470±34
2 kPa O2+10 kPa CO2	6	1.33±0.09	6.35±0.24	7.10±0.32	922±74	386±27	442±66
	12	1.15±0.36	5.85±0.35	5.20±0.30	810±68	338±16	294±43
4 kPa O2+5 kPa CO2	6	1.27±0.01	6.35±0.25	6.70±0.09	1164±84	528±27	393±44
	12	1.23±0.19	5.36±0.37	5.97±0.66	1010±82	501±57	454±26
4 kPa O2+10 kPa CO2	6	1.13±0.16	5.80±0.30	6.27±0.42	1080±120	503±36	378±28
	12	1.31±0.28	5.95±0.43	5.60±0.50	998±84	466±43	418±13
$LSD_{Treatment}$ 0.05 =		0.25	0.21	0.35	122	44	51
LSD_{Time} 0.05 =		0.25	0.21	0.35	122	44	51

[a]Nitrogen was the balance gas in controlled atmospheres.

of fresh-cut kiwifruit slices increased during 12 days storage at 0°C (Fig. 11). Higher acetaldehyde and ethanol concentrations were found in slices stored under low O_2 atmospheres compared to those stored in air (control). Generally, the lower the O_2 level, the higher the acetaldehyde and ethanol concentration although the slices stored in 1 and 2 kPa O_2 did not differ in acetaldehyde. An atmosphere of 0.5 kPa O_2 (balance N_2) resulted in 40% higher fermentative metabolism products compared to 1 kPa O_2 (data not shown). Fresh-cut slices stored in air + 20 kPa CO_2 resulted in higher acetaldehyde and ethanol contents compared to air + 5 or air + 10 kPa CO_2 or air. Slices stored under low O_2 atmospheres accumulated higher acetaldehyde and ethanol concentrations compared to those from elevated CO_2 treatments. Combinations of low O_2 and elevated CO_2 atmospheres did not show any additive effect.The concentration of O_2 in the storage atmosphere was the key factor in accumulation of fermentative products.

The ascorbic acid (AA) content of fresh-cut slices dipped in 1% $CaCl_2$ and stored under 2 kPa O_2+ 5 kPa CO_2 (CA) at 2°C declined from 55 to 38 mg·100g^{-1} FW during 9 days storage but resulted in the highest AA retention among 6 treatments (Table 2). Slices contained 61.8 mg·100g^{-1} FW of vitamin C (AA+DHA) when freshly cut. During 12 days storage slices stored under low O_2 retained higher vitamin C compared to those under the highest CO_2 atmospheres: air + 10 and air + 20 kPa (Table 3). Vitamin C content of the fresh-cut slices under 0.5, 2, and 4 kPa O_2 (balance N_2) decreased by 7, 12 and 18%, respectively, after 12 days storage. Vitamin C content in slices kept in air + 5, 10 and 20 kPa CO_2 decreased by 14, 22 and 34%, respectively, of their initial vitamin C contents. Slices kept in air lost 18% of their vitamin C within the same period.

Ascorbic acid (AA) at 55 mg·100g^{-1} FW accounted for 88% of the vitamin C (AA+DHA) content of freshly cut slices (Table 2). Those kept in lower O_2 were higher in AA, whereas those from higher CO_2 were lower in AA content than air-control slices. Kiwifruit slices kept in air lost 34% AA and reached about 36 mg·100g^{-1} FW AA after 12 d storage. Slices stored under 0.5, 2, or 4 kPa O_2 (balance N_2) lost 10, 20 or 28% of their original AA, respectively, after 12 days storage. Slices held in air + 5, 10 or 20 kPa CO_2 decreased by 26, 33 or 39% of initial AA content.

Over time the AA contents of slices decreased irrespective of storage treatment. A concomitant increase in DHA, from 6.8 to

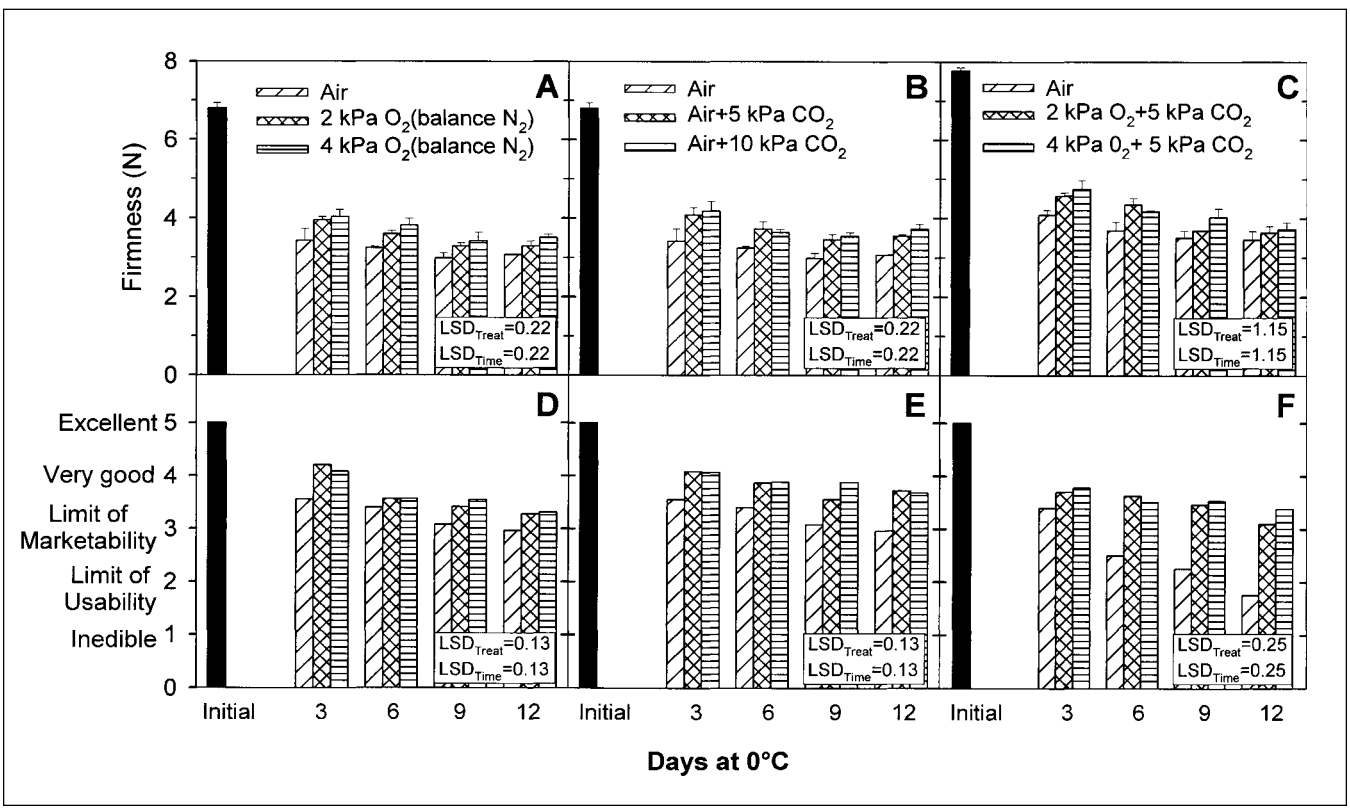

Fig. 9—Effect of low O_2 and/or elevated CO_2 atmosphere storage on the firmness (A, B, C) and visual quality (D, E, F) of kiwifruit slices stored at 0°C for 12 days.

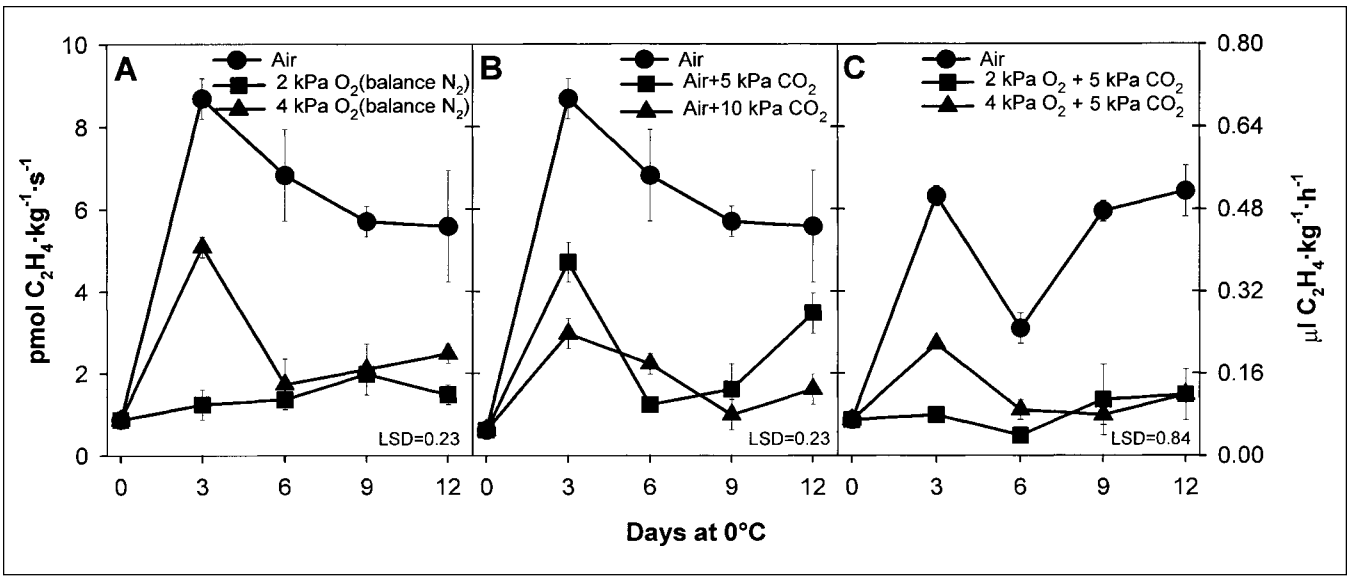

Fig. 10—Effect of low O_2 and/or elevated CO_2 atmosphere storage on the C_2H_4 production rate of fresh-cut kiwifruit slices stored at 0°C for 12 days.

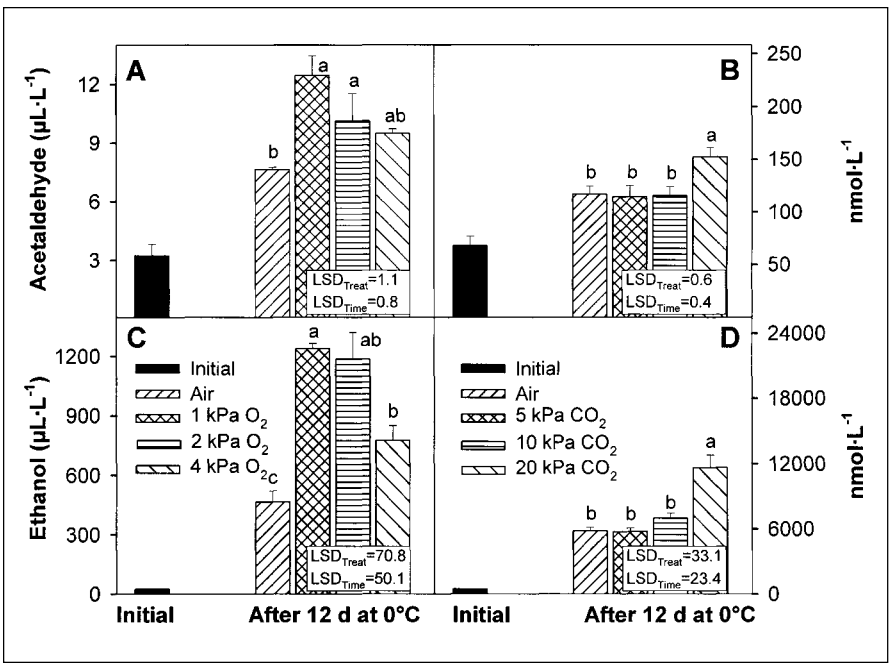

Fig. 11—Effect of low O_2 and elevated CO_2 atmosphere storage on the acetaldehyde (A, B) and ethanol (C, D) concentrations of fresh-cut kiwifruit slices stored at 0°C for 12 days.

14.1 mg·100g^{-1} FW (207% increase) occurred in air-stored kiwifruit slices (Table 2). Those stored in 4 kPa O_2 (balance N_2) and air + 10 kPa CO_2 had a 164% increase in DHA after 12 days (Table 3). However, not all AA degradation was due to conversion of AA to DHA, since a loss of total vitamin C occurred in slices after 12 days. The lowest DHA was in slices stored in 0.5 kPa O_2 (balance N_2) and air + 20 kPa CO_2 which contained the highest and lowest vitamin C, respectively, after 12 days.

Our results confirmed results of Rosen (1987) that 'G3' strawberries stored under 2% O_2 for 7 days at 2.5°C had a higher AA content than fruit stored in air. Reducing the O_2 concentration in elevated CO_2 had little effect on vitamin C content. Similar results have been reported by Bangerth (1977) and Agar et al. (1997) on berries. Generally the CO_2 concentration in the storage atmosphere had a greater influence on degradation of vitamin C in fresh-cut kiwifruit slices. Enhanced losses of vitamin C in response to air + 10 and 20 kPa CO_2 may be due to their stimulating effects on oxidation of AA and/or inhibition of mono- or DHA reduction to AA (Agar et al. 1997). Our results also confirmed results of Nsengimana and Bangerth (1981) on parsley and corn salad and Weichmann (1983) on Brusssels sprouts.

Fructose and glucose constituted nearly 90% of total sugars in fresh-cut kiwifruit slices, followed by sucrose (10%) (Table 4). Generally all 3 increased the first 6 days of storage and declined thereafter. The increase in sugars in air (control) stored slices was greater than for all 4 CA treatments. The total of the 3 sugars increased from 12.1 g·100 mL^{-1} to 17.5 g·100 mL^{-1} and then declined to 15.5 g•100 mL^{-1} after 6 days and 12 days, respectively, in air stored slices. Kiwifruit slices stored in CA contained 13.2 to 14.8 g·100 mL^{-1} total sugars after 6 days storage and 12.2 to 12.9 g·100 mL^{-1} after 12 days storage. The increase in SSC, especially in air stored slices, appear to correlate with the increase in total sugars (data not shown), which was probably due to continued ripening. The CA treatments, particularly 2 kPa O_2 + 10 kPa CO_2 delayed ripening during storage and also resulted in lower sugar content.

Citric, malic and quinic acid were respectively 49%, 26% and 24% of the organic acids determined in fresh-cut slices (Table 4). Total organic acid content of air (control) stored slices decreased by 21% after 12 days storage. Slices stored in CA treatments, with exception of 2 kPa O_2 + 10 kPa CO_2, either retained or had slightly increased organic acid concentrations. Slices stored in 2 kPa O_2 + 5 kPa CO_2 and 4 kPa O_2 + 5 kPa CO_2 treatments had the highest citric, malic and quinic acid contents after 12 days, which may have been due to the low respiration rates.

CONCLUSIONS

STORAGE TEMPERATURE, DEGREE OF TISsue damage and microatmospheric gas composition was important factors for quality retention of fresh-cut kiwifruit slices. The shelf-life of slices held at 0-2°C was longer com-

pared to slices at 5°C or 10°C, which had accelerated softening, mass loss, and AA degradation. Physical damage or wounding caused by slicing and/or peeling resulted in increased CO_2 and C_2H_4 production and caused higher mass loss. Peel contributed to total CO_2 and C_2H_4 production. Removal of C_2H_4 from the storage atmosphere increased retention of firmness and TA, and the rate of softening was increased by exposure to air + 1 Pa C_2H_4. Treatments of $CaCl_2$ (1%) or Ca lactate (2%) were equally effective in firmness retention. No visible cut surface browning was observed in stored slices. Atmospheres of 0.5 and 1 kPa O_2 (balance N_2) did not extend the shelf-life of slices compared to 2 and 4 kPa O_2 (balance N_2). Atmospheres of 2 or 4 kPa O_2 or air + 5 or 10 kPa CO_2 were the most effective in extending shelf-life. Low O_2 helped maintain vitamin C content of fresh-cut slices. A CO_2 concentration of 5 kPa in air helped retain AA but CO_2 concentrations of 10 and 20 kPa in air increased losses of AA. The shelf-life range of fresh-cut kiwifruit slices was 9-12 days if treated with 1% $CaCl_2$ or 2% Ca lactate in combination with chlorine water (100 $\mu l \cdot L^{-1}$) dip and kept at 0-2°C, >90% relative humidity, with C_2H_4 scrubbing, in 2 to 4 kPa O_2 and/or 5 to 10 kPa CO_2.

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Ms received 7/10/98; revised 11/30/98; accepted 12/26/98.

Research supported in part by USDA research agreement no. 95-37500-1910, NRI Competitive Grants Program. We thank Sarah Cathcart, Erica Mandle and Carolyn Menke for their excellent technical assistance.