PHYSICOCHEMICAL, NUTRITIONAL AND MICROBIAL QUALITY OF FRESH-CUT AND FROZEN PAPAYA PREPARED FROM CULTIVARS WITH VARYING RESISTANCE TO INTERNAL YELLOWING DISEASE

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ABSTRACT

Quality, nutritional and microbial analyses were completed for fresh-cut and frozen papaya cubes prepared from cultivars with varying resistance to internal yellowing (IY) disease caused by the bacterium Enterobacter cloacae. *In general, fresh-cut and frozen papaya retained nutritional and microbial quality, but visual and textural quality declined. Fresh-cut fruit pretreated with 1% calcium lactate solution were firmer than control fruit, but translucency limited the shelf life of cubes dipped in either water or calcium lactate. Vitamin C content averaged 61.5 mg/100 g and 52.2 mg/100 g for fresh-cut and frozen fruit, respectively. Vitamin A content was greatest in fresh-cut "Laie Gold" and "Rainbow" fruit, and averaged 35.1 μg retinol activity equivalents per 100 g for all cultivars. Microbial counts were very low or not detectable for most samples. Among the cultivars resistant to IY, "Rainbow" had the highest vitamin A and sugar contents, and did not develop translucency.*

PRACTICAL APPLICATIONS

This study provides new nutritional information for fresh-cut and frozen papaya products that can be included in the U.S. Department of Agriculture

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National Nutrient Database. Also, data on cultivar attributes may assist processors of fresh-cut or frozen papaya products in choosing the best cultivars by considering appearance, texture, flavor, nutritional content and microbial quality. The selection of papaya cultivars with resistance to internal yellowing disease will allow processors to produce nutritious value-added products that conform to food safety guidelines.

INTRODUCTION

Papayas (*Papaya carica* L.) are rich sources of vitamins C and A, and are widely consumed in Hawaii and the Pacific Basin. While ascorbic acid and carotenoid concentrations have been analyzed for ripe fruit of papaya cultivars grown throughout Hawaii (Wall 2006), no information is available for minimally processed papayas. The convenience, uniqueness and nutritional quality of minimally processed papayas could create a marketing opportunity through grocery stores, restaurants and institutional venues. Frozen papayas also have potential as value-added products that could enhance the profitability of the papaya industry. Fresh-cut or frozen papayas could be added to fruit cocktails or a variety of desserts. Frozen papayas could be used in sorbets, fruit smoothies or other health drinks.

There are few reports on the quality of fresh-cut or frozen papayas (O'Connor-Shaw *et al.* 1994; Cano *et al.* 1996b; Paull and Chen 1997; Rivera-Lopez *et al.* 2005). In general, processing of fruit may result in loss of color, texture, flavor and nutrients. Also, bacteria and fungi can flourish on the cut surfaces of minimally processed fruit. For fresh-cut papayas, tissue softening and translucency appear to limit shelf life before other quality attributes decline (O'Connor-Shaw *et al.* 1994; Rivera-Lopez *et al.* 2005). Likewise, frozen papayas soften substantially upon thawing and compositional changes in sugars or vitamins may occur (Cano *et al.* 1996b; Lobo and Cano 1998; Torija *et al.* 1998).

Exogenous calcium treatments may preserve firmness by increasing the amount of calcium available to bind with pectic residues in the cell wall (Magee *et al.* 2003). Calcium lactate has been found to maintain firmness of fresh-cut cantaloupe (Luna-Guzman and Barrett 2000), kiwi (Agar *et al.* 1999), pears (Dong *et al.* 2000) and tomatoes (Magee *et al.* 2003), but had a minimal effect on fresh-cut peaches (Gorny *et al.* 1999). Calcium lactate is preferable to calcium chloride treatment, because it does not impart bitterness to the fruit (Luna-Guzman and Barrett 2000).

In addition to maintaining texture and visual appearance, the assurance of microbiological safety is critical for developing value-added papaya products. Attempts to market fresh-cut or frozen papaya products have been at times unsuccessful because of contamination by coliform bacteria such as *Enterobacter cloacae*, the causal agent of internal yellowing (IY) disease (Nishijima *et al.* 1987). Fruit quality is diminished by fluorescent-yellow discolored flesh and an offensive, rotting odor. Infection is restricted to the flesh surrounding the seed cavity, therefore infected fruit cannot be sorted from good quality fruit based on external appearance (Nishijima *et al.* 1987). *E. cloacae* is one of several coliform bacteria normally found in the intestinal tract of humans and animals (van den Berg *et al.* 2000). Considered an opportunistic pathogen, *E. cloacae* causes infection when a person is debilitated or immunosuppressed (Sanders and Sanders 1997).

A requirement of zero tolerance for food-borne coliforms makes resistance to IY an important criterion in breeding papaya cultivars suitable for fresh-cut and frozen foods. Until recently, “Kapoho” was the major cultivar grown in Hawaii for local and export markets. “Kapoho” is highly susceptible to IY (Nishijima *et al.* 1987, 2007) and papaya ringspot virus (PRSV), which nearly destroyed the “Kapoho” crop when it became established in the Puna district on the island of Hawaii (Gonsalves 1998). PRSV resistance was developed in “SunUp” through genetic engineering (Fitch *et al.* 1992). “SunUp” was hybridized with “Kapoho” to produce “Rainbow,” which is now the most important commercial papaya cultivar in Hawaii (Manshardt 1998). We have identified papaya cultivars with resistance to IY, including “Rainbow” and “SunUp” (Nishijima *et al.* 2007). Preparing value-added products from IY-resistant cultivars appears to be a viable option for diversifying the papaya industry, while ensuring that products adhere to food safety guidelines (Sodexho 2006). However, these cultivars have not been evaluated as fresh-cut or frozen products. Also, the U.S. Department of Agriculture (USDA) National Nutrient Database (USDA, ARS 2006) does not include nutritional information for fresh-cut or frozen papaya. Therefore, our objectives were (1) to determine the effectiveness of calcium lactate treatment for improving the firmness of fresh-cut or frozen papaya cubes and (2) to determine the physicochemical, nutritional and microbial quality of fresh-cut and frozen papaya cubes prepared from cultivars resistant or susceptible to IY.

MATERIALS AND METHODS

Sample Preparation

Mature (5–10% yellow) papaya (*C. papaya* L.) fruit were harvested from commercial farms in Hawaii from April to September, 2006. Cultivars previously identified as resistant (“Sunrise”, “SunUp” and “Rainbow”) or susceptible (“Kapoho”, “Laie Gold”) to *E. cloacae* were included in the study.

"Sunrise" and "SunUp" fruit have orange-red flesh, whereas "Kapoho," "Laie Gold" and "Rainbow" fruit have yellow-orange flesh. Also, "SunUp," "Rainbow" and "Laie Gold" are genetically modified (GMO) for resistance to PRSV.

Fruit were ripened at 22C until approximately 60–65% of the surface was yellow (2/3 ripe). Total soluble solids content was 12–14% at this ripeness stage. Whole fruit were washed in cold, chlorinated (100 ppm) water, rinsed in clean tap water, hand-peeled, deseeded and cut into approximately 3 cm^3 cubes.

Calcium Lactate Treatments

Preliminary trials were conducted to assess the effect of calcium lactate treatment on firmness of fresh-cut and frozen papaya. Fresh-cut papaya cubes (cvs. "Kapoho," "Laie Gold," "Rainbow," "SunUp") were treated for 3 min with either distilled water or a 1% calcium lactate solution. A no-dip control also was included. All fruit and solutions were prechilled at 8C. Cubes from individual fruit were distributed equally to all treatments. Samples were gently blotted, placed into plastic clamshell containers, stored at 4 and 8C for 2 days and then evaluated for firmness, color and translucency. For frozen fruit, "Rainbow" and "SunUp" papaya were treated the same as cubes intended for fresh-cut consumption, however, a 30-s blanch followed by a 3-min dip in 1% calcium lactate solution also was included. Fruit were placed into plastic freezer bags, frozen at −70C for 24 h, transferred to −20C for 1 month and thawed at 4C before quality was evaluated.

Cultivar Evaluations

"Kapoho," "Laie Gold," "Rainbow," "Sunrise" and "SunUp" cultivars were prepared as fresh-cut and frozen cubes, and compared for physicochemical, nutritional and microbial quality. For each cultivar, fresh-cut cubes were placed in plastic clamshell containers and stored at 4C for 2 days before extraction and analyses. Frozen cubes were packaged in plastic freezer bags and placed at −70C for 24 h, transferred to −20C for 3 months and then thawed at 4C for 1 h before analyses.

Quality Analyses

Fruit flesh surface color was measured on each papaya cube at 3 points using a Minolta chromameter (model CR-300, Minolta Corp., Ramsey, NJ) and recorded as lightness (L^*), chroma (C^*) and hue angle ($H°$). Papaya flesh firmness was measured on individual cubes with a Chantillon LTCM-100 force gauge (Ametek, Inc., Largo, FL) mounted on a motorized test stand. The peak force (N) was measured at a penetration depth of 5 mm. Translucency was assessed visually by two evaluators and the number of papaya cubes with a water-soaked appearance was recorded. Papaya cubes exhibiting translucency or tissue breakdown were considered unmarketable.

Sugar Extraction and Analysis

High pressure liquid chromatography (HPLC) was used to separate and quantify glucose, fructose and sucrose in the papaya samples using a method reported by Wall (2004). Briefly, sugars were extracted from each 10-cube, composite sample with hot 80% ethanol. The slurry was boiled, cooled and filtered. The filter cake was washed with 80% ethanol and the sugar extract was brought to a final volume of 100 mL. A 5-mL aliquot was filtered (0.22 μm membranes) into duplicate vials for HPLC. Samples (20 μL) were injected into an Agilent 1100 series liquid chromatograph (Agilent Technologies, Wilmington, DE) with premixed HPLC-grade water (25%) and acetonitrile (ACN) (75%) as the mobile phase and an aminopropylsilane column as the stationary phase (Agilent ZORBAX carbohydrate analysis column, 4.6 mm ID × 150 mm, 5 μm), followed by a refractive index detector. Sugar peaks of the samples were identified according to HPLC retention times in comparison with authentic standards. For recovery tests, samples were spiked with standard solutions before extraction. The recovery was 101% ± 2 for fructose, 100% ± 1 for glucose and 101% ± 3 for sucrose ($n = 3$), and the detection limit for each sugar was 1 μg. Sugar concentrations were expressed as g/100 g edible fresh weight.

Ascorbic Acid Extraction and Analysis

Ascorbic acid was analyzed as described by Wall (2006). Fruit tissue (40 g) was blended with 100 mL of cold metaphosphoric-acetic acid solution, the slurry was centrifuged for 15 min at 10 000 rpm in a cold (4C) centrifuge, and the supernatant was collected. Samples (5 mL) were passed through preconditioned C-18 Sep-Paks and filtered through 0.22 μm membranes into duplicate amber HPLC vials. All samples were kept on ice and HPLC analysis was performed on the same day as extractions. Ascorbic acid was analyzed by HPLC, with 0.2 M NaH_2PO_4, pH 2.14 as the mobile phase, and a PLRP-S column (microbore 2.1 × 250 mm, 5 μm particle size; Polymer Laboratories, Amherst, MA) as the stationary phase, followed by a photodiode array detector set at 254 nm (Lloyd and Warner 1988; Vanderslice and Higgs 1990; Wall 2006). Sample peaks were identified according to HPLC retention times and absorbance spectra in comparison with authentic standards. For recovery tests, samples were spiked with standard solutions before extraction. The recovery was 97% ± 11 ($n = 5$) and the HPLC minimum detection level was 0.05 μg. Vitamin C values were expressed as mg/100 g edible fresh weight.

Carotenoid Extraction and Analysis

Papaya carotenoids (provitamin A pigments and lycopene) were extracted under low light and cold temperatures, as reported by Wall (2006). A 20-g sample was homogenized with 2 g $MgCO_3$, 40 g anhydrous Na_2SO_4 and 75 mL cold tetrahydrofuran (THF). Extracts were filtered and the residue was re-extracted with an additional 100 mL THF to remove all carotenoids. A 10-mL aliquot was concentrated under nitrogen gas and stored at −70C until HPLC analysis. Before analysis, samples were resuspended in 0.4 mL stabilized THF, vortexed and brought to a final volume of 4 mL with equal amounts of HPLC grade ACN and methanol (MeOH). Samples were filtered through 0.22 μm membrane filters into duplicate amber HPLC vials for injection.

Carotenoids were analyzed by HPLC, with ACN (85%) : THF (12.5%) : water (2.5%) as the mobile phase, and an ODS Hypersil C−18 narrow-bore column (5 μm, 100 × 2.1 mm, Agilent) as the stationary phase. A photodiode array detector collected signals in the 380–550 nm range, with maximum detection at 454 nm. Standards of β-carotene, β-cryptoxanthin and lycopene ranging from 0.5 to 6.0 μg/mL were used for calibration. Papayas do not contain α-carotene, a provitamin A carotenoid (Wall 2006). Concentrations of standards were determined using spectrophotometry and molar extinction coefficients in hexane of 2,592 (453 nm), 2,460 (451 nm) and 3,450 (472 nm) for β-carotene, β-cryptoxanthin and lycopene, respectively (Bauernfeind 1981; Hart and Scott 1995). Sample peaks were identified according to HPLC retention times and absorbance spectra in comparison with authentic standards. β-cryptoxanthin esters were quantified using a β-cryptoxanthin standard (Cano *et al.* 1996a; Mutsuga *et al.* 2001; Wall 2006). Nonesterified and esterified forms of β-cryptoxanthin have similar bioavailability (Breithaupt *et al.* 2003) and both forms were included in vitamin A calculations. The extraction recovery was 111% ± 5 for β-carotene, 99% ± 3 for β-cryptoxanthin and 113% ± 2 for lycopene ($n = 3$). The minimum detection level was 0.005 μg for β-carotene and β-cryptoxanthin, and 0.01 μg for lycopene. Vitamin A values for fresh-cut and frozen papayas were expressed as μg retinol activity equivalents (RAE) per 100 g edible fresh weight.

Microbial Analyses

Microbial analyses included enumeration of bacterial populations and identification of problematic Enterobacteriaceae (specifically, *E cloacae* and *Erwinia herbicola*, two bacterial pathogens of papaya fruit in Hawaii) (Nelson and Alvarez 1980; Nishijima *et al.* 1987). For each replication per cultivar of fresh-cut and frozen papaya, 10 randomly selected cubes were weighed and placed in sterile Pulsifier-filter bags (Microbiology International, Frederick, MD) with an equal amount of sterile distilled water (SDW). After macerating the papaya cubes, 1 mL of the fiber-free liquid portion of the puree was used for a dilution series with SDW. Each dilution was pipetted as spots on peptone yeast extract medium agar (Nishijima *et al.* 2004) for total plate counts (bacteria, yeasts, molds). The plates were air-dried under a laminar air flow hood, incubated at 30C for 24 h and counted for colony-forming units (cfu). Also, 10 mL from the filtered portion of the papaya puree was mixed with Butterfield Phosphate Buffer and 1 mL of a 1:20 dilution of the buffered sample was placed on 3M Petrifilm for *E. coli* and coliforms and on 3M Petrifilm for Enterobacteriaceae (3M Microbiology Products, St. Paul, MN). The bacteria populations were determined by counting the Petrifilms after 24–48 h incubation at 30C.

Strains of suspect Enterobacteriaceae were purified by successive single colony isolations, and then oxidative and fermentative reactions were determined by inoculating Difco OF tubes. The facultative anaerobic strains were inoculated on API 20E strips (bioMerieux, Hazelwood, MO) for Enterobacteriaceae and incubated at 30C for 18–24 h. The strains were identified according to results in the biochemical tests and comparisons with the API 20E Analytical Profile Index (bioMerieux). *E cloacae* has distinctive API 20E profiles.

Statistical Analysis

A factorial design was used for calcium lactate trials, with treatments and cultivars as factors. A completely randomized design was used for quality, nutritional and microbial evaluations of cultivars. Four replications were used for all experiments. Sample size included 10 randomly selected papaya cubes for each quality, nutritional or microbial analysis per treatment and replication. Data were subjected to analysis of variance using the general linear models procedure in SAS (SAS Institute 1999). Means and SEs were calculated, and where applicable, means were separated using the Waller-Duncan *k*-ratio *t*-test ($P \leq 0.05$).

RESULTS AND DISCUSSION

Calcium Lactate Effects on Quality

A 1% calcium lactate solution improved fruit firmness of fresh-cut papayas stored at 4C, but not at 8C (Table 1). However, translucency limited the shelf life of papaya cubes dipped in either water or the calcium lactate

TABLE 1.
QUALITY OF FRESH-CUT PAPAYA CUBES FOLLOWING TREATMENT WITH CALCIUM LACTATE SOLUTION AND STORAGE AT 4 OR 8C FOR 2 DAYS†

Treatment	Color‡			Firmness (N)	Soluble solids (%)	Translucent cubes (%)	Marketable cubes (%)
	*L**	*C**	Hue (°)				
Stored at 4C							
None	57.8a	50.4a	71.4a	2.4c	13.6a	17.7a	73.9b
Distilled water	53.4b	49.5a	70.1b	2.8b	13.0b	78.8b	21.2a
1% Calcium lactate	52.3b	47.2b	70.1b	3.0a	13.1b	79.7b	20.3a
Stored at 8C							
None	56.7a	48.9a	72.7a	2.6a	13.8a	23.9a	72.4b
Distilled water	50.4b	44.2b	71.9b	2.9a	13.1b	88.3b	11.7a
1% Calcium lactate	51.3b	45.5b	72.0ab	2.9a	13.1b	79.8b	20.2a

† Values are means of 85–95 observations, combined over four cultivars. Different letters indicate significant differences ($P \leq 0.05$).

‡ Lightness (*L**) is on a scale of 0–100. Chroma (*C**) is on a scale of 0–60, with full saturation at 60. A hue angle of 90° = yellow.

solution. Fruit dipped in calcium lactate appeared darker (*L**) and duller (*C**) in color than nontreated cubes, and had lower soluble solids contents, suggesting some sugars leached from the fruit. Calcium lactate solutions may be more effective at higher concentrations (2%) or temperatures that activate pectin methyl esterase and increase calcium diffusion into the tissues (Luna-Guzman and Barrett 2000; Rico *et al.* 2006). These steps may increase firmness by improving the water-holding capacity of the fruit via enhanced pectic cross-linking (Luna-Guzman and Barrett 2000).

The translucency of fresh-cut papaya was similar at 4 and 8C, demonstrating that translucency was not a symptom of chilling injury, but rather a result of water intrusion into the fruit. Translucency may develop when gas is replaced by liquid in the intercellular space (Lana *et al.* 2006). In other studies, translucency reduced the visual quality of fresh-cut tomatoes, melons, papayas and pears (O'Connor-Shaw *et al.* 1994; Soliva-Fortuny *et al.* 2002; Lana *et al.* 2006). Translucency in tomatoes was not attributed to chilling injury, but increased with fruit maturity (Lana *et al.* 2006).

Calcium lactate-treated frozen papaya cubes were softer in texture and brighter in color than nontreated fruit after thawing (Fig. 1). Blanching combined with calcium lactate treatment improved fruit firmness when compared with water or calcium lactate treatments, but was not different from control fruit. As a result of these experiments, fresh-cut and frozen samples were prepared from nontreated papaya cubes for quality, nutritional and microbial evaluations of cultivars resistant or susceptible to IY. However, methods to improve fruit firmness without inducing translucency are needed and may

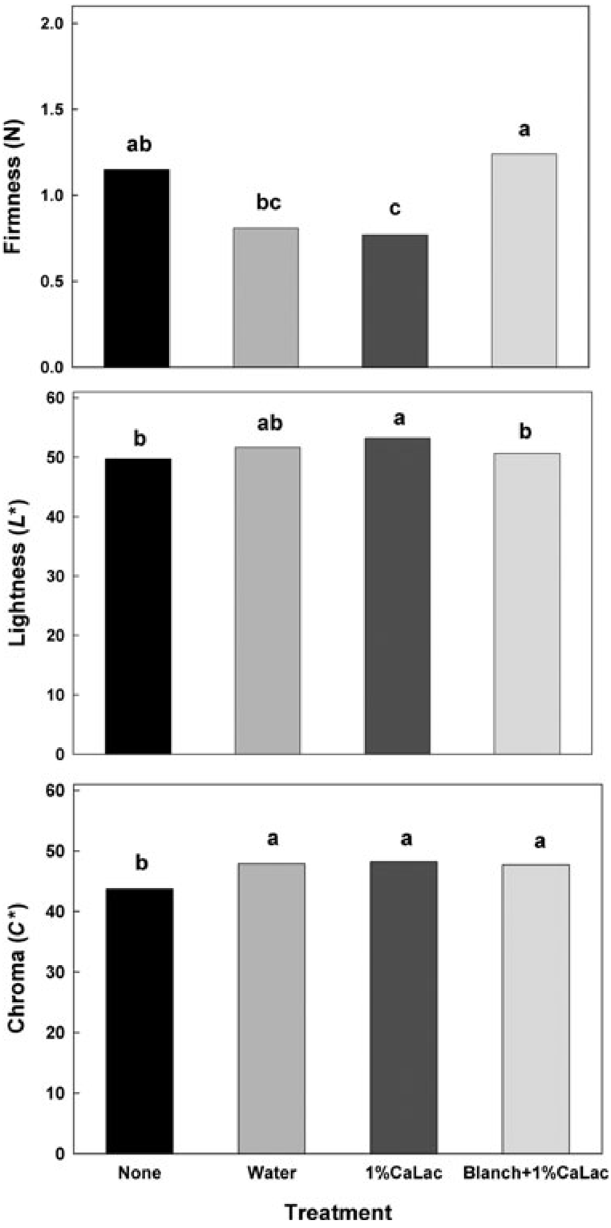

FIG. 1. EFFECTS OF A 3 MINUTE DIP WITH 1% CALCIUM LACTATE OR BLANCHING + 1% CALCIUM LACTATE ON FIRMNESS AND COLOR OF FROZEN PAPAYA CUBES. MEANS FOLLOWED BY DIFFERENT LETTERS ARE SIGNIFICANTLY DIFFERENT ($P < 0.05$)

include enhanced preharvest calcium fertility or postharvest treatment with the ethylene inhibitor 1-methylcyclopropene (1-MCP) (Ergun *et al.* 2006).

Visual and Textural Quality of Papaya Cultivars

Fresh-cut papaya cubes prepared from "Kapoho" (IY susceptible) and "SunUp" (IY resistant) were firmer after 2 days at 4C than cubes from "Laie Gold," "Rainbow" and "Sunrise" cultivars (Table 2). Translucency was limited to a few fresh-cut cubes and did not differ among cultivars. The L^*, C^* and $H°$ values for fresh-cut papaya reflect the typical color of the yellow-orange flesh ("Kapoho," "Laie Gold," "Rainbow") and orange-red flesh ("Sunrise," "SunUp") cultivars. Fresh-cut papaya did not exhibit browning or chilling injury at 4C, but shelf life was limited to 2–3 days by fruit softening, similar to other reports (O'Connor-Shaw *et al.* 1994). For fresh-cut papayas, tissue softening or translucency delimit shelf life and lead to consumer rejection of the product (O'Connor-Shaw *et al.* 1994; Rivera-Lopez *et al.* 2005). Shelf life was extended to 10 days when papaya slices of the cultivar "Maradol" were stored at 5C (Rivera-Lopez *et al.* 2005) and when fresh-cut "Sunrise" fruit were pretreated with 1-MCP (Ergun *et al.* 2006).

TABLE 2.
FIRMNESS, COLOR AND TRANSLUCENCY OF FRESH-CUT AND FROZEN PAPAYA CUBES†

Cultivar	Firmness (N)	Color‡			Translucent cubes (%)
		L^*	C^*	H(°)	
Fresh-cut papaya§					
Kapoho	3.5a	67.9a	57.2b	77.4a	5.0a
Laie Gold	2.8b	61.1c	57.8b	71.4c	10.0a
Rainbow	2.5b	65.2b	60.4a	74.6b	0a
Sunrise	2.9b	55.4d	43.9d	60.2d	15.0a
SunUp	3.6a	53.7e	45.3c	56.3e	0a
Frozen papaya¶					
Kapoho	2.6b	61.4a	57.7a	76.9a	0
Laie Gold	2.7b	58.4c	55.9ab	74.6b	0
Rainbow	4.4a	59.9b	55.6b	75.6b	0
Sunrise	3.9a	52.0d	40.4c	61.5c	0
SunUp	2.7b	50.4e	39.5c	59.7d	0

† Values are means of 40 observations per cultivar. Means within columns followed by different letters are significantly different ($P \leq 0.05$).

‡ Lightness (L^*) is on a scale of 0–100. Chroma (C^*) is on a scale of 0–60, with full saturation at 60. A hue angle of 90° = yellow.

§ Fresh-cut papaya cubes were stored at 4C for 2 days before evaluations.

¶ Frozen papaya cubes were placed at −70C for 24 h and then transferred to −20C for 3-month storage before analysis.

Frozen papaya were slightly darker upon partial thawing than fresh-cut pieces, but in general, the flesh color for each cultivar was similar to fresh-cut samples. Frozen cubes from the IY-resistant cultivars, "Rainbow" and "Sunrise," were firmer than "Kapoho," "Laie Gold" and "SunUp" cubes (Table 2). However, differences in thawing patterns or in the amount of pectins among cultivars could account for variability in the firmness of half-thawed fruit. The freezing process commonly leads to a breakdown in fruit texture because ice crystal formation damages cell integrity (Fennema 1996). Lobo and Cano (1998) reported that frozen "Sunrise" papaya slices retained acceptable texture, color and flavor if thawed at 4C for 2 h, but that sensory attributes (flavor and color) declined after 9-month storage at −24C.

Nutritional Quality of Papaya Cultivars

Vitamin C content did not differ significantly among the 5 papaya cultivars, whether prepared as fresh-cut or frozen products (Table 3). The results agree with the vitamin C content of fully ripened, fresh fruit of these cultivars which ranged from 45.3 to 64.5 mg/100 g (FW) depending on harvest location and season (Wall 2006). Fresh-cut papayas (61.5 mg/100 g) compare favorably with strawberries (58.8 mg/100 g) (USDA, ARS 2006) for vitamin C content. The U.S. Dietary Reference Intake (DRI) for vitamin C is 90 and 75 mg/day for males and females, respectively, ages 19–50 years (Institute of Medicine 2000). On average, Hawaii's cultivars could provide 68–82% of the DRI for adult males and females, respectively, in a 100-g serving of fresh-cut papaya. Fresh-cut "Maradol" papaya cubes and slices contained 65 mg/100 g of ascorbic acid through 6 days of storage at 5C (Rivera-Lopez *et al.* 2005), also indicating that fresh-cut papaya is a good source of vitamin C.

The mean vitamin C content was 15% less for frozen papaya compared with fresh-cut fruit (Table 3). Dehydroascorbic acid (DHAA) was not detected, therefore, this reduction in vitamin C was not from oxidation of ascorbic acid to DHAA, but may have resulted from leaching. Nevertheless, frozen papaya samples had vitamin C levels within the range reported for whole ripe fruit (Wall 2006) and similar to fresh oranges (53.2 mg/100 g) (USDA, ARS 2006). A 100-g serving of frozen papaya would provide about 58% and 70% of the DRI for vitamin C for the average adult male and female, respectively.

Vitamin A content was greater in fresh-cut "Laie Gold" and "Rainbow" fruit than "Kapoho," "Sunrise" and "SunUp" cubes (Table 3). For frozen cubes, the yellow-orange flesh cultivars had more vitamin A than the orange-red flesh cultivars ("Sunrise" and "SunUp"). "SunUp" contained higher levels of lycopene (a red carotenoid) than "Sunrise" for both fresh-cut and frozen samples (Table 3) and $H°$ values also reflected this difference (Table 2).

TABLE 3.
VITAMIN C, VITAMIN A AND CAROTENOID CONTENTS OF FRESH-CUT AND FROZEN PAPAYA CUBES†

Cultivar	Vitamin C (mg/100 g)	Vitamin A‡ (μg RAE/100 g)	β-carotene (μg/100 g)	β-cryptoxanthin (μg/100 g)	Lycopene (μg/100 g)
Fresh-cut papaya§					
Kapoho	57.5 ± 5.1a	29.7 ± 2.5c	137.6 ± 3.6c	437.8 ± 52.3c	ND
Laie Gold	66.0 ± 0.7a	55.2 ± 1.0a	249.3 ± 14.5a	826.7 ± 49.0a	ND
Rainbow	64.4 ± 4.2a	43.9 ± 5.9b	222.3 ± 35.1ab	609.0 ± 85.0b	ND
Sunrise	60.5 ± 4.3a	22.7 ± 3.0c	152.5 ± 25.9bc	239.0 ± 22.4d	897.8 ± 92.0b
SunUp	59.3 ± 3.3a	23.8 ± 2.2c	133.1 ± 20.3c	304.7 ± 19.3cd	1387.7 ± 381.2a
Mean	61.5 ± 1.7	35.1 ± 3.3			
Frozen papaya¶					
Kapoho	50.1 ± 2.6a	30.1 ± 2.3a	102.1 ± 15.1a	518.9 ± 46.6ab	ND
Laie Gold	56.2 ± 2.8a	35.7 ± 6.2a	124.3 ± 63.0a	609.3 ± 42.1a	ND
Rainbow	51.5 ± 1.8a	34.0 ± 4.0a	169.2 ± 16.3a	478.0 ± 63.7b	ND
Sunrise	50.2 ± 1.4a	18.0 ± 0.8b	91.8 ± 5.2a	247.6 ± 15.4c	1180.7 ± 128.1b
SunUp	53.0 ± 4.8a	16.5 ± 2.2b	82.6 ± 9.7a	230.5 ± 34.3c	1501.7 ± 226.4a
Mean	52.2 ± 1.3	26.9 ± 2.3			

† Values are means (± standard error) of four replications per cultivar. Means within columns followed by different letters are significantly different ($P \leq 0.05$). ND = not detected.

‡ Vitamin A carotenoids present in papayas include β-carotene and β-cryptoxanthin.

$$\text{Retinol activity equivalents } (\mu\text{g RAE}) = \frac{\mu\text{g } \beta\text{-carotene}}{12} + \frac{\mu\text{g } \beta\text{-cryptoxanthin}}{24}$$

§ Fresh-cut papaya cubes were stored at 4C for 2 days before evaluations.

¶ Frozen papaya cubes were placed at −70C for 24 h and then transferred to −20C for 3 months.

TABLE 4.
SUGAR CONTENTS OF FRESH-CUT AND FROZEN PAPAYAS CUBES†

Cultivar	Fructose (g/100 g)	Glucose (g/100 g)	Sucrose (g/100 g)	Total sugar (g/100 g)
Fresh-cut papaya‡				
Kapoho	2.53 ± 0.06ab	3.08 ± 0.06ab	4.41 ± 0.56b	10.02 ± 0.47a
Laie Gold	2.20 ± 0.12ab	2.71 ± 0.14b	6.07 ± 0.39a	10.98 ± 0.45a
Rainbow	2.67 ± 0.12a	3.35 ± 0.18a	4.07 ± 0.38b	10.09 ± 0.55a
Sunrise	2.51 ± 0.24ab	3.05 ± 0.25ab	1.90 ± 0.42c	7.46 ± 0.82b
SunUp	2.05 ± 0.12b	2.64 ± 0.16b	2.87 ± 0.27c	7.56 ± 0.44b
Mean				9.22 ± 0.40
Frozen papaya§				
Kapoho	5.19 ± 0.27a	5.77 ± 0.31a	0.16 ± 0.06a	11.12 ± 0.57a
Laie Gold	4.10 ± 0.62ab	4.46 ± 0.66ab	0.02 ± 0.01b	8.58 ± 1.28ab
Rainbow	3.99 ± 0.46ab	4.43 ± 0.53ab	0.17 ± 0.07a	8.59 ± 1.06ab
Sunrise	3.64 ± 0.22b	4.14 ± 0.28ab	0.00 ± 0.00b	7.78 ± 0.50b
SunUp	3.53 ± 0.39b	3.97 ± 0.45b	0.01 ± 0.01b	7.51 ± 0.85b
Mean				8.72 ± 0.46

† Values are means (±standard error) of four replications per cultivar. Means within columns followed by different letters are significantly different ($P \leq 0.05$).
‡ Fresh-cut papaya cubes were stored at 4C for 2 days before evaluations.
§ Frozen papaya cubes were placed at −70C for 24 h and then transferred to −20C for 3-month storage before analysis.

Although the variability in papaya vitamin A and lycopene concentrations is affected by cultivar, maturity and environment, the results generally agree with other reports for fresh or frozen papaya (Cano *et al.* 1996b; Muller 1997; Holden *et al.* 1999; Wall 2006). The U.S. DRI for vitamin A is 900 and 700 µg RAE/day for adult males and females, respectively (Institute of Medicine 2001). On average, fresh-cut papaya (100 g) could provide 4–5% of the DRI for vitamin A, with higher percentages for "Laie Gold" and "Rainbow." Consumption of frozen papaya (100 g) could meet about 3–4% of the DRI for vitamin A, slightly less than for fresh-cut fruit. Cano *et al.* (1996b) also found that carotenoid content decreased in frozen papaya slices ("Sunrise"), although the color was similar to fresh fruit.

Total sugar concentrations were highest in fresh-cut cubes of the yellow-orange fleshed cultivars (Table 4). "Laie Gold" had the most sucrose, whereas "Sunrise" and "SunUp" had the least sucrose among cultivars (Table 4). Sugar concentrations reflect relative differences in sweetness among cultivars and may impact consumer preference. Hawaii's papaya cultivars (Solo type) are valued for their sweetness in comparison to Southeast Asia cultivars, typified by a musky papaya aroma (Nakasone and Paull 1998).

Total sugar concentrations for frozen papaya were similar to fresh-cut fruit, but sucrose was hydrolyzed by invertase to fructose and glucose

(Table 4). Blanching prior to freezing could inactivate invertase, but unlike vegetables, fruit are usually not blanched prior to freezing because of their delicate texture and natural acidity (Rickman *et al.* 2007). Torija *et al.* (1998) also reported a conversion of sucrose to reducing sugars in frozen "Sunrise" papayas. This shift in sugar profiles may not impact consumer preference because total sugars remained high in frozen cubes.

Microbial Quality of Papaya Cultivars

Microbial counts were very low or not detectable for most papaya samples (Table 5). However, *E. cloacae* (1 cfu/g) was detected in one replicate of fresh-cut "Rainbow" papaya and coliforms attributed to *Enterobacter* sp. (<1 cfu/g) were detected in one sample of frozen "SunUp" cubes. Enterobacteriaceae bacteria found in frozen "Laie Gold" cubes were attributed to *Pantoea* sp. (synonyms of *P. agglomerans*: *Enterobacter agglomerans*, *E. herbicola*, *Erwinia milletiae*) (Holt *et al.* 1994).

The detection of *Enterobacter* sp., *E. cloacae* and *Pantoea* sp. (possibly *E. herbicola*) is reflective of the natural occurrence of these bacteria in papaya fruit. *E. cloacae* and *E. herbicola* are pathogens of papaya (Nelson and Alvarez 1980; Nishijima *et al.* 1987) that affect fruit flesh and can reduce the quality of

TABLE 5.
MICROBIAL COUNTS OF FRESH-CUT AND FROZEN PAPAYA CUBES

Cultivar	Microbial Counts (cfu/g)†				
	Total bacteria	Total coliforms	*E. coli*	Enterob.	Yeasts/molds
Fresh-cut papaya‡					
Kapoho	8	0	0	0	0
Laie Gold	<1	0	0	0	0
Rainbow	18	<1	0	0	0
Sunrise	2	0	0	0	0
SunUp	1	0	0	0	0
Frozen papaya§					
Kapoho	0	0	0	0	0
Laie Gold	5	0	0	TNTC	0
Rainbow	8	0	0		0
Sunrise	<1	0	0	0	0
SunUp	2	<1	0	<1	0

† Values are means of four replications.
‡ Fresh-cut papaya cubes were stored at 4C for 2 days before evaluations.
§ Frozen papaya cubes were placed at –70C for 24 h and then transferred to –20C for 3-month storage before analysis.
TNTC, too numerous to count at 1:200 dilution for one replication, 0 colonies for all other replications.

processed papaya products. The coliform counts of *E. cloacae* and *Enterobacter* sp. in the fresh-cut and frozen papaya cubes were within food safety guidelines for frozen products (<100 cfu/g for coliforms) (Sodexho 2006). However, there is potential for higher bacterial counts based on a report of naturally occurring populations of *E. cloacae* at 4.17×10^5 cfu/g in "Kapoho" fruit displaying IY symptoms (Nishijima *et al.* 2007).

Although bacterial counts in this study were low for papaya cubes processed from either resistant or susceptible cultivars, the natural occurrence of IY can be as high as 43% in "Kapoho" fruit surveyed from packinghouses (Nishijima *et al.* 1987). Also, in inoculation tests, "Rainbow", "Sunrise" and "SunUp" exhibited resistance when challenged with *E. cloacae*, whereas "Kapoho" and "Laie Gold" were susceptible (Nishijima *et al.* 2007). Therefore, the use of IY-resistant cultivars could reduce the risk of detecting *E. cloacae* when processing commercial quantities of value-added papaya products.

CONCLUSIONS

Processors of fresh-cut or frozen papaya products should choose the best cultivars for processing by considering appearance, texture and flavor, but also nutritional content. Microbial quality is essential for meeting food safety guidelines and the use of IY-resistant cultivars could eliminate or reduce coliform bacteria from minimally processed papaya. The "Kapoho" and "Laie Gold" cultivars are not good candidates for value-added products because of susceptibility to IY, although "Laie Gold" was high in vitamin and sugar contents. Among the IY-resistant cultivars, "Rainbow" had the highest vitamin A and sugar contents, and did not develop translucency. "Rainbow" is widely grown in Hawaii and would be acceptable for fresh-cut or frozen preparations.

In general, fresh-cut and frozen papaya retained nutritional and microbial quality, but visual and textural quality declined. Preliminary trials showed that calcium lactate treatments were marginally effective at enhancing firmness, but the solutions caused translucency, a major quality defect. Methods to improve fruit firmness without inducing translucency are needed and may include enhanced preharvest calcium fertility or postharvest treatment with 1-MCP. Also, postharvest disinfection treatments with heat or ozone may be effective at reducing bacterial populations in batches contaminated with *E. cloacae.* However, breeding a range of cultivars with resistance to IY that are also firm and nutritious could meet a variety of market opportunities, while conforming to food safety guidelines.

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