Effect of Processing Under Ultraviolet Light on the Shelf Life of Fresh-Cut Cantaloupe Melon

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ABSTRACT: The effect of processing cantaloupe melon under ultraviolet-C (UV-C) radiation on storage properties of the cut fruit at 10 °C was compared with post-cut UV-C fruit treatment and the untreated control. Cutting fruit under UV-C light induced a hypersensitive defense response that resulted in increased accumulation of ascorbate peroxidase relative to the other 2 treatments. Fruit processed under UV-C radiation had the lowest esterase activity throughout the storage period. Lipase activity was higher in post-cut treated fruit than fruit processed under UV-C light and the control fruit. Lipase activity, however, decreased rapidly in fruit processed under UV-C and was undetectable after 7 d of storage. Human sensory aroma evaluation indicates reduced rancidity, and instrumental texture measurements suggested improved firmness retention in fruit cut under UV-C radiation. The treatment also reduced respiration during cut fruit storage. UV-C was effective in reducing yeast, mold, and *Pseudomonas* spp populations in both treatments. Fresh-cut pieces from whole melon cut under UV light had lower populations of aerobic mesophilic and lactic acid bacteria relative to the control and post-cut treated pieces. Results indicate that while post-cut application of UV improved shelf life of cut cantaloupe melon, cutting fruit under UV-C radiation further improves product quality.

Keywords: UV-light, minimal processing, postharvest, fruit, *Cucumis melo* L

Introduction

Ultraviolet (UV) technology is widely used as an alternative to chemical sterilization and reduction of vegetative organisms in food products. Ultraviolet light also induces biological stress in plants and defense mechanisms of plant tissues with the consequent production of phytoalexin compounds (Mercier 1997). Phytoalexin accumulation could be accompanied by other inducible defenses such as cell wall modifications, defense enzymes, and hypersensitive cell death. Our research has demonstrated that post-cutting exposure of cantaloupe melon to ultraviolet light enhances the production of β-cyclocitral, *cis*- and *trans*- β-ionone, terpinyl acetate, geranylacetone, and dihydroactinidiolide in the fruit tissue (Lamikanra and others 2002; Lamikanra and Richard 2002). Terpenoids play important roles as phytoalexins in the disease resistance of a variety of plant families (Elgersma and Liem 1989; Fulton and others 1994; Baichini and others 1999). β-ionone, a fragment of β-carotene for example, is well known for its high antifungal and antibacterial properties in plants (Anzaldi and others 1999). Ultraviolet treatment of cut pineapples also increased the amount of the sesquiterpene α-copaene (Lamikanra and Richard 2004).

Mechanical damage to plant tissue causes an increase in abscisic acid (ABA), which in turn activates the biosynthesis of jasmonic acid (JA). The resulting higher endogenous JA levels subsequently activate the expression of wound-inducible genes (Dammann and others 1997). Defensive gene expressions are induced by signal transduction through the octadecanoid pathway. Tomato plants and potato plants have been used extensively as model systems to monitor release and perception of wound signals (Dammann and others 1997; Lee and Howe 2003). Induction of the proteinase inhibitors involving ABA (Pena-Cortes and others 1991) and JA occurs (Farmer and Ryan 1992), and these proteinase inhibitors accumulate. Systemic responses to localized wounding, however, involve long-distance signals that evidently move rapidly and freely through the living tissue (Malone and others 1994; Malone and Alarcon 1995). Thus, a localized stimulus can cause local and long-range effects. The rapid long-range or systematic effects could involve a massive amplification of response, as local changes occurring within 1 cell or a small group of cells produce systemic changes throughout the entire product (Bowles 1991; Leon and others 2001).

Ultraviolet radiation applications in minimally processed food products traditionally occur after cutting, primarily for the purpose of sterilization. In light of the rapid and systemic response to wound stimulus, the impact of post cut UV applications only occurs after wound signal responses have already been induced and their consequent effects on product shelf life are well underway. The ability of UV radiation to alter wound signals under this condition may be limited, and the benefit of UV treatment would essentially be antimicrobial protection and synthesis of phytoalexins. Ultraviolet light maximally induces the expression of several plant defensive genes that are normally activated through the octadecanoid pathway during wounding (Conconi and others 1996). Ultraviolet-C (UV-C) radiation considerably increases proteinase inhibitor synthesis (Stratmann and others 2000) and induces 48-kDa myelin basic protein kinase activity. Such activity increases in response to some defense-related proteins, oligosaccharide elicitors, and a rapid hydraulic signal generated by wounding (Stratmann and Ryan 1997). Thus, application of UV radiation during the wounding or cutting process could better modify or intensify wound defense responses that will improve product shelf life relative to post-cut UV applications. In this study, we compare the effect of cutting cantaloupe melon under UV-C light on product quality and sensory traits with post-cut UV-treated and non–UV-treated cut fruit.

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Materials and Methods

Materials

Ultraviolet-C light source, a CS-SWT-24 fixture equipped with a sleeved single ended Steril-Aire Emitter™ at 254 nm was provided by C&S Equipment Co. (Caldwell, Idaho, U.S.A.). Cantaloupe melon (*Cucumis melo* L. var. reticulates) was supplied by Del Monte Fresh Produce Co. (Coral Gables, Fla., U.S.A.) and was received at 4 °C. Low-profile juice catcher containers used for were from Winkler Forming Inc. (Carrollton, Tex., U.S.A.), and fruit cups were obtained from Rock-Tenn Co. (Norcross, Ga., U.S.A.). Chemicals and reagents were purchased from Sigma-Aldrich Co. (St. Louis, Mo., U.S.A.).

Fruit preparation

Before processing, whole fruit was dipped in water at 4 °C containing sodium hypochlorite (100 ppm free chlorine) at pH 6.5 and scrubbed with a brush. All unprocessed fruit were stored away from the UV light source. Fruit was processed by cutting longitudinally (approximately 18 cm) into 2 halves, removing seeds, and cutting off approximately 4 cm each from both ends of each half. The remaining fruit was then cut into 8 equal parts. The skin was removed and cubes of approximately 2 to 3 cm × 2.5 cm were prepared in pie-like wedges cut from the 2.5-cm-wide slices. Good manufacturing practices and best possible sanitary conditions were strictly adhered to during processing and during all subsequent handling stages. Fruit processed under UV-C light was placed under the light source. The lamp was hung 35 cm above the processing surface. Output of the lamp corrected for distance was approximately 1.18×10^3 microwatt-seconds/cm^2. For safety against exposure to UV radiation during processing, lab coats, protective gloves, and a Oberon OB-S FF-071AF UV face shield was worn. Exposure time for each fruit from the initial cut until the fruit was placed in storage containers was approximately 4 min. Post-cut treated fruit were processed under fluorescent light after which they were immediately placed under the UV-C light source. To provide comparable exposure time to those processed under UV-C radiation, they were kept under the light source for a total of 4 min. Each fruit piece was flipped over after 2 min to expose the entire surface to UV light. Approximately 300 g of cubes from each melon were placed into 24-ounce (about 1 L) low-profile plastic Juice Catcher containers and stored at 10 °C, and the entire fruit was used as 1 of 3 replicates on a sampling date. Cut fruit from 4 cantaloupe melons for each treatment were combined for sensory analysis. Samples comprised 6 melon cubes stored in 5-cm fruit cups labeled with the panelist's name and a 3-digit random number.

Enzyme extraction

Enzyme extraction for each treatment was from 3 randomly selected fruit. Cut fruit (100 g) was homogenized with cold acetone (300 mL; –20 °C) in a Waring blender (Waring Pro, East Windsor, N.J.) for 30 s. The blended mixture was further homogenized using a Tekmar™ Tissumizer (Cincinnati, Ohio, U.S.A.) for 30 s. The homogenate was then vacuum-filtered through Whatman nr 4 filter paper to remove the residue. The residue was successively homogenized in cold acetone and filtered until a colorless filtrate, and a white mass was obtained. The mass was dried to a powder under a stream of air at room temperature. The acetone powder (1 g) was homogenized in a mixture of phosphate buffer (0.05 *M*; pH 8.0, 15 mL) and Triton X-100 (2%). The homogenate was centrifuged at 12000 × g at 0 °C for 20 min. The resulting supernatant was used for enzymatic activity assays.

Peroxidase assay procedure

Peroxidase (POD) activity was assayed in a buffer consisting of 0.02 *M* Na_2HPO_4 and 0.08 *M* NaH_2PO_4, 20 m*M* guaiacol 4 m*M* H_2O_2, enzyme extract (10 μL), pH 6 in a total volume of 3 mL (Civello and others 1995). The reaction mixture was transferred into a cuvette and transferred into the sample compartment of the spectrophotometer that was set at 50 °C. Absorbance readings at 470 nm between 30 s and 90 s of the reaction time were used to determine the initial rates of reactions.

Esterase assay procedure

Esterase activity was monitored spectrophometrically by measuring the production of p-nitrophenol from p-nitrophenyl acetate substrate (Lamikanra and Watson 2003). The reaction mixture (3 mL) contained deionized water (2.4 mL) p-nitrophenyl acetate (300 μL) and the enzyme extract (300 μL). p-Nitrophenyl acetate (10 m*M*) was dissolved in dimethyl sulfoxide (DMSO). The reaction was started by addition of the enzyme extract. The solution was then incubated in a water bath at 50 °C for 5 min and centrifuged at 3000 × g for 3 min. Absorbance was determined at 420 nm.

Lipase assay procedure

Lipase activity was assayed using p-nitrophenyl laurate (P-NPL) as substrate (Pinsirodom and Parkin 2001). Reaction mixtures (4.0 mL) contained Tris buffer (1.5 mL; 0.05 *M*; pH 8.2), *P*-NPL (1.5 mL 420 μ*M*) and the enzyme extract (1 mL). The substrate was prepared by mixing *P*-NPL (0.0135 g) with sodium dodecyl sulphate (SDS) (0.017 g) and 1% Triton X-100 in a 100 mL solution and heating to 65 °C for 25 min in a water bath. The resulting mixture was thoroughly agitated by vortexing and allowed to reach ambient temperature before use. The reaction was started by addition of the enzyme extract and the cuvette containing the reaction mixture was immediately transferred into the spectrophotometer after agitation by vortexing. Increase in absorbance at 410 nm was monitored for up to 3 min using an identical mixture that did not contain the enzyme extract as reference. Enzymatic activity was based on initial velocity of the reaction measured between 10 s and 70 s of the reaction time.

Determination of respiration

Cut fruit from each treated melon (50 g) was placed into separate Mason jars (0.5 L) fitted with air-tight lids equipped with rubber septums and stored at 10 °C. Analysis for CO_2 and O_2 gas in the headspace was carried out by withdrawing a sample gas (8 cm^3) with a needle syringe attached to Mocon Pack Check 650 analyzer (MOCON\Modern Controls, Inc., Minneapolis, Minn., U.S.A.) through the rubber septum of the respective jar. Differences in respiration rate between samples during storage were assessed from the gas composition.

Descriptive sensory analysis

Nine panelists, having from 1 y to 10 y of experience in descriptive sensory analysis of cantaloupe melon participated in the sensory evaluation. They evaluated aroma attributes sweet aromatic, chemical/musty, fruity melon, and rancid/painty (Bett 2002). During evaluations, panelists vented the lids to allow the headspace to enter the nose. Intensities of the various aromas emitted from the samples were assessed. Intensity was rated on a 0- to 15-point anchored scale with 0 being not detectable and 15 being more intense than most foods (Meilgaard and others 1999). Sensory analysis was conducted under red lights to discourage preconceptions associated with food coloration. A warm-up sample of freshly cut cantaloupe melon was presented 1st during each panel session to reduce the 1st sample position bias. Thereafter, the experimental samples were presented monadically in random order at 10-min intervals

within a session. All panelists received the samples in the same order. Data were analyzed using SAS PROC MIXED, Analyst options (SAS, Release 8.2, 1999-2001, Cary, N.C., U.S.A.). Mean comparisons were done with Tukey's Honestly Significantly Difference (HSD) test (Steel and Torrie 1980).

Texture analysis

Texture evaluations were performed on a texture analyzer (Model TA-TX2, Texture Technologies Corp., Scarsdale, N.Y., U.S.A.) equipped with a 25-kg load cell and 35-mm-dia cylindrical aluminum probe. The probe compressed samples in a 2-cycle test. Equipment settings were as follows: preset speed, 2 mm/s; test speed, 1 mm/s; distance as 30% strain; time 1 s; trigger force, 20 g. Hardness values were used assess firmness and were recorded for 5 fruit samples for each treatment.

Microbiological analyses

One hundred milliliters of 0.1% peptone water was added to Stomacher® bags containing fresh-cut pieces (approximately 70 g/bag) and the bag contents pummeled for 30 s in a Stomacher® model 400 (Dynatech Laboratories, Alexandria, Va., U.S.A.) at medium speed. For initial fresh-cut samples, 0.1 mL was plated in duplicate on a range of media. Plate Count Agar (PCA, BBL/Difco, Sparks, Md., U.S.A.) with incubation at 30 °C for 3 d was used for enumeration of mesophilic aerobes. *Pseudomonas* spp. was enumerated by plating 0.1 mL on *Pseudomonas* isolation agar (Difco) with incubation at 27 °C for 3 d. Lactic acid bacteria were enumerated with de Man, Rogosa, and Sharpe agar (MRS, Oxoid, Ogdensburg, N.Y., U.S.A.) with 0.08% sorbic acid as a supplement with incubation at 30 °C for 3 d (Reuter 1985). For fresh-cut pieces stored for more than 3 d, decimal serial dilutions prepared in 0.1% peptone water were plated on the agar media listed previously.

Results and Discussion

Processing of cantaloupe melon under UV light considerably increased POD activity in the freshly cut fruit relative to fruit treated with UV radiation after cutting, and the control (Figure 1). The effect of post-cut application on POD activity, when compared with that of the untreated control in freshly cut fruit, was a slight increase. During storage, POD activities in both sets of fruit were comparable, whereas fruit processed under UV light was higher. Peroxidase enzyme in cantaloupe melon was previously shown to be ascorbate in nature (Lamikanra and Watson 2001). Ascorbate PODs are important defense enzymes that protect plant cells from oxidative stress damage, and activity could be indicative of oxidative stress in plant tissues (Kampfenkel and others 1995; Gueta-Dahan and others 1997). It has been suggested (Lamikanra and Watson 2001) that loss of POD during storage of fresh-cut cantaloupe may be related to the enzyme's instability relative to other peroxidase enzymes and/or residual oxidative stress during storage. It is also known that POD activity in cut cantaloupe melon during storage may be affected by pre-harvest conditions (Bett-Garber and others 2005). Ultraviolet light, however, also induces a rapid accumulation of photooxidation products, to which plants react by stimulating their defense mechanisms against oxidation (Ait-Barka 2001). These may include POD-related enzymes and generated activated oxygen species by way of increased nicotinamide adenine dinucleotide phosphate, reduced form (NADPH)-oxidase activity (Rao and others 1996). Wounding of the fruit under UV-C light evidently induced a hypersensitive defense response that resulted in increased accumulation of POD.

Post-cut treatment of cantaloupe melon with UV radiation appears to lower esterase (ES) activity in fresh-cut fruit (Lamikanra and Watson 2004). In this study, processing under UV-C light lowered ES activity in the cut fruit relative to post-cut treated fruit and the untreated control, and maintained lower activity levels during storage (Figure 2). Barka and others (2000) reported that UV-C targets the cell wall–degrading enzymes (polygalacturonase, pectin methyl esterase, cellulase, xylanase, beta-D-galactosidase, and protease) and that by this action delays cell wall degradation and the tissue senescence process. Esterase in cantaloupe melon is predominantly carboxylesterase (B-esterase) and its activity appears to be regulated by metalloproteases presumably metalloexoprotease (Lamikanra 2003; Lamikanra and Watson 2003). Esterase-mediated loss of esters could be involved in the stress adaptation to tissue wounding (Garcia 1993; Gamba-Invernizzi and others 1993; Hildenbrand and Ninnemann 1994). The loss of esters and the concurrent production phytoalexin compounds, however, also appear to be important early reaction steps related to loss of freshness during storage of some cut fruits (Lamikanra and Richard 2002; 2004; Lamikanra 2003). The reduction of esterase activity in fruit processed under UV light could lead to retention of the fruity character of cut fruit during storage.

Lipase activity in fruit processed under UV-C light was lower than post-cut treated fruit, but comparable to the untreated control immediately after cutting (Figure 3). However, lipase activity progressively decreased in fruit processed under UV-C light, and after 7 d of storage time at 10 °C, lipase activity was not detected. A dis-

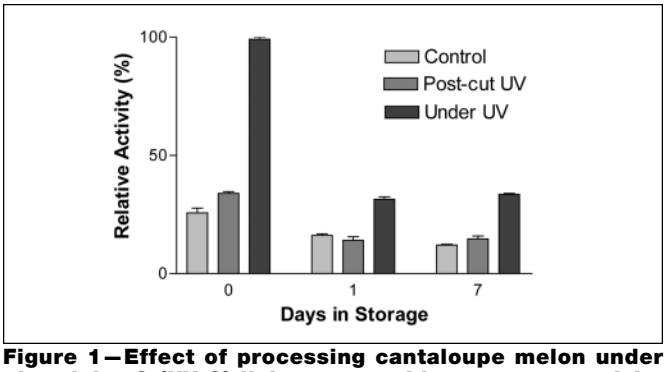

Figure 1—Effect of processing cantaloupe melon under ultraviolet-C (UV-C) light on peroxidase enzyme activity during storage of fresh-cut cantaloupe melon at 10 °C. Peroxidase was assayed using guaiacol as substrate at pH 6.0.

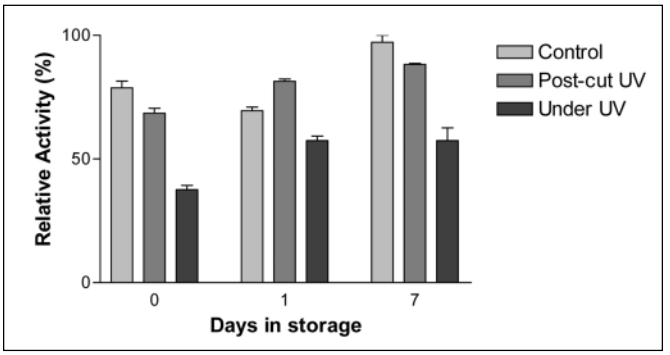

Figure 2—Effect of processing cantaloupe melon under ultraviolet-C (UV-C) light on esterase activity during storage of fresh-cut cantaloupe melon at 10 °C. Esterase activity was monitored spectrophometrically by measuring the production of *P*-nitrophenol from *P*-nitrophenyl acetate substrate.

Table 1—Effects of ultraviolet (UV) treatment on aroma attributes of fresh-cut melons during storage

Storage day	UV treatment	A-Sweet Aromatic	A-Chemical/ Musty	A-Fruity/ Melon	A-Rancid/ Painty
3	Traditional	1.7	1.3	2.7	0.5b
	Post-UV	1.6	1.4	2.6	0.8a
	UV cut	1.4	1.4	2.2	0.5b
6	Traditional	1.8	1.8	2.8	0.9b
	Post UV	2.4	1.9	3.8	1.3a
	UV cut	1.7	1.0	3.2	0.4c
LSD		0.59	0.82	0.75	0.54
Analysis of variance (ANOVA) results					
Effect			**Probability**		
Treatment		0.16	0.19	0.20	0.02
Days of storage		0.50	0.73	0.39	0.45
Treatment × days		0.25	0.20	0.03	0.20

tinguishing property between carboxyl esterases and lipase is that while the former acts upon soluble substrates, lipases act only at the water-lipid interface. The alkaline nature of lipase in cantaloupe melon has been demonstrated (Lamikanra and Watson 2004). Alkaline lipase activity is often stimulated and controlled by JA (Ranjan and Lewak 1994; Ranjan 1998). Lipase enzymes may contribute to food flavor through lipolytic actions on triglycerides and subsequent breakdown of products such as hydrolysis of esters and enzymatic oxidation of fatty acids by lipoxygenase enzymes (Galliard and others 1976).

Preliminary descriptive sensory evaluation of fruit aroma suggests that cutting under UV light prevents the development of off-flavors such as musty and rancidity, but may not enhance retention of desirable flavors such as sweet aromatic and fruity melon aroma relative to post-cut UV-treated fruit (Table 1). The panel did not determine significant differences in desirable flavors between post-cut UV-treated and fruit cut under UV light, but scored the latter significantly lower in rancid aroma than post-cut UV-treated and untreated control. The loss of lipase activity in stored fruit processed under UV light could to be related to the lower rancid aroma attribute of fresh-cut melons during storage. Lipase catalyzed hydrolytic attack on endogenous lipids is the initial event on disruption of some fruit tissue, and in the formation of lipid degradation products among which are volatile carbonyl compounds responsible for the characteristic flavor (Galliard and others 1976). The process is a sequential breakdown of fatty acids that involves acyl hydrolyses followed by enzymatic cleavage processes. A number of lipases are also exhibit carboxylesterase activity (Bjurlin and others 2002).

Headspace gas composition indicate reduced respiration rate in fruit processed under UV light (Figure 4). The reduced relative respiration rates were maintained during storage of the cut fruit. The lowering effect of UV-C radiation on respiration rates in a number of fruits such as fresh strawberry (Baka and others 1999) and tomato (Maharaj and others 1999) could be attributed to increased production of antisenescence agents exerting opposite physiological effect to ethylene. Gonzalez-Aguilar and others (2004) did not observe differences in respiration rates between UV-C–treated peaches and untreated fruit. Higher levels of polyamines, however, occurred as a consequence of UV-C treatment that was attributed to increased resistance of treated fruit to deterioration and chilling injury. Firmness retention during storage was also suggested to have occurred in UV-C–treated peaches as a result of polyamine accumulation. The texture of UV-C–treated strawberries and tomatoes were reported to be better as a result of UV-C treatment (Baka and others 1999; Maharaj and others 1999). Maharaj and others (1999) concluded that polyamines suppressed cell wall softening and activity of polyglacturonase in tomatoes and that they function by way of a mechanism similar to that of calcium, involving formation of cation cross-links with pectic acid and other polysaccharides. Fresh-cut cantaloupe melon processed under UV-C was observed in this study to retain firmness better than either untreated or the post-cut treated fruit (Figure 5), apparently by way of a similar mechanism.

Ukuku and Fett (2002) reported that aerobic mesophilic bacteria followed by lactic acid bacteria and *Pseudomonas* spp. were the predominant classes of spoilage organisms on cantaloupe and honeydew fresh-cut melons. In unwrapped and wrapped sliced watermelon, *Pseudomonas* spp., *Escherichia coli*, *Enterobacter* spp. and micrococci comprised the predominant microflora (Abbey and others 1988). In this study, aerobic mesophilic bacteria, lactic acid bacteria, and *Pseudomonas* spp. were targeted to determine the efficacy of UV-C treatments on microbial quality of fresh-cut cantaloupes. The effect of cutting under UV-C and post-cut treatments of fresh-cut cantaloupe melon on the native microflora during refrigerated storage at 10 °C is shown in Figure 6. Populations of aerobic mesophilic bacteria, lactic acid, and *Pseudomonas* spp. of fresh-cut cantaloupes prepared from untreated whole melon were similar to those reported in the literature (Ukuku and Fett 2002). Popula-

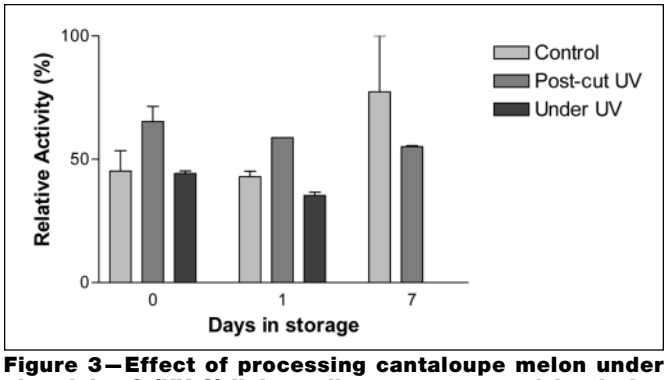

Figure 3—Effect of processing cantaloupe melon under ultraviolet-C (UV-C) light on lipase enzyme activity during storage of fresh-cut cantaloupe melon at 10 °C. Lipase activity in enzyme extract was assayed using *P*-nitrophenyl laurate as a substrate.

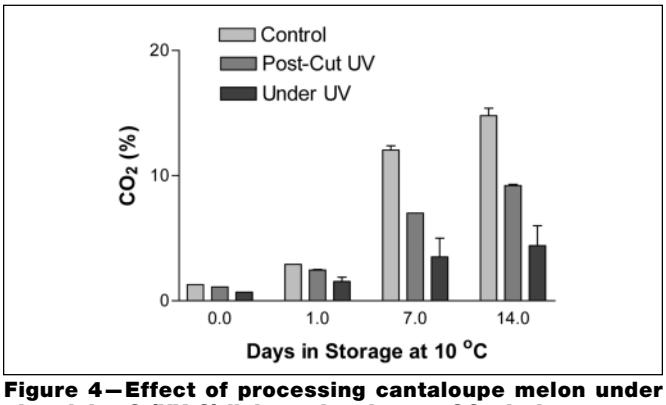

Figure 4—Effect of processing cantaloupe melon under ultraviolet-C (UV-C) light on headspace CO_2 during storage of fresh-cut cantaloupe at 10 °C. Headspace gas sample (50 cm³) of cut cantaloupe melon (50 g) stored in pint-size glass Mason jars was extracted with a syringe, and CO_2 content was measured using a Dual Head Space Analyzer (Mocon/Modern Control Inc., Minneapolis, Minn.

tions of aerobic mesophilic bacteria and lactic acid bacteria were lowest in fruit processed under UV-C light. However, populations of yeasts and molds determined in fresh-cut pieces from whole melon processed under UV light and the fresh-cut pieces directly treated after cutting were below detection (<1 colony-forming unit [CFU]). Populations of aerobic mesophilic bacteria and lactic acid bacteria including *Pseudomonas* spp. increased in all samples as storage time increased, regardless of the treatment. Boyette and others (1993) reported that the microbial decay of minimally processed lettuce is largely due to the growth of microorganisms originating from preharvest environments. In this study, processing of the fruit under UV light was more effective in reducing spoilage microbial populations of fresh-cut pieces during storage than treatments of fresh-cut pieces after preparation. Both treatments were effective in reducing the populations of *Pseudomonas* spp. throughout storage.

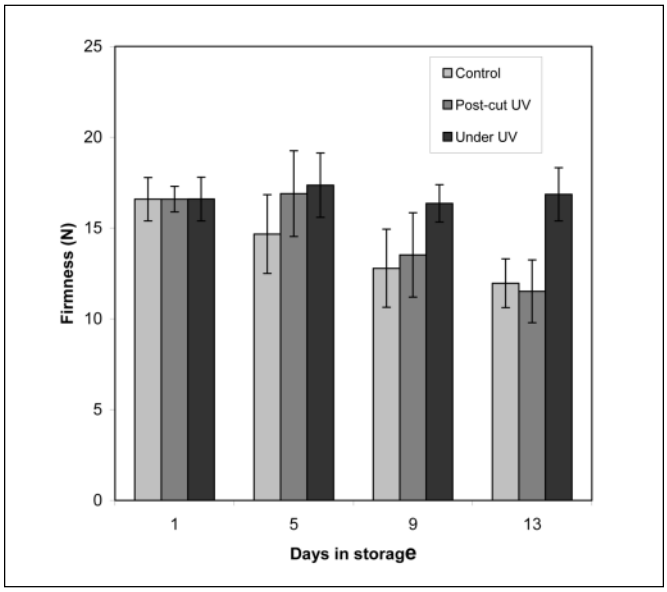

Figure 5—Effect of processing cantaloupe melon under ultraviolet-C (UV-C) light on firmness measurements during storage of fresh-cut cantaloupe melon at 10 °C

Conclusions

Wound responses are altered by UV-C radiation. In cut fruit, there are differences in responses between fruit processed under UV radiation and those treated after the fruit has been fresh-cut processed. A hypersensitive defense response is induced by the former treatment that increases POD production relative to the post-cut treated and the untreated fruit. The stress response of processing under UV light also reduces esterase activity and respiration rate during fruit storage. Loss of lipase activity occurred more rapidly during storage of fruit processed under UV light. The reduced lipase activity with storage time and other antisenescence defense responses induced appear to reduce rancidity and improve firmness retention in the stored fruit. UV radiation, when applied during processing, also reduces spoilage microorganisms such as mesophilic and lactic acid bacteria. Our results indicate the potential for improving sensory quality and shelf life of fresh-cut cantaloupe melon by processing the fruit under UV-C light.

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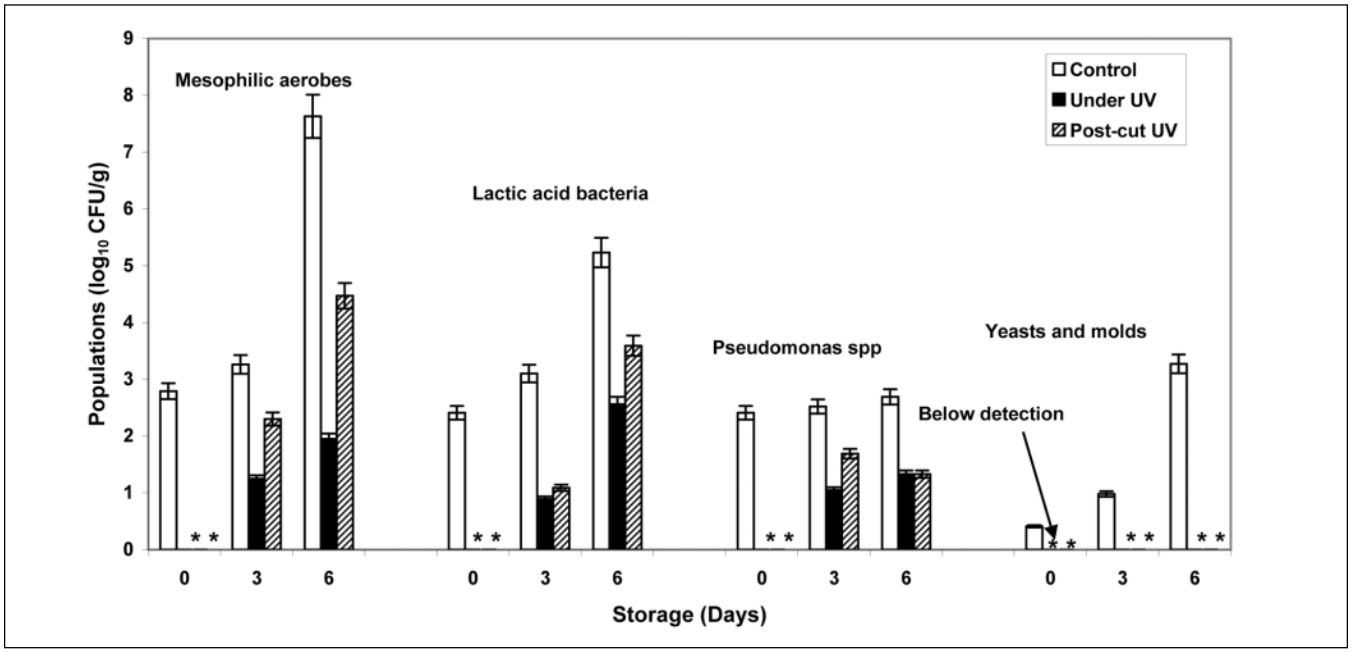

Figure 6—Effect of processing under ultraviolet-C (UV-C) light on spoilage microflora of fresh-cut cantaloupe melon during storage at 10 °C

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