2007

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Anuradha Prakash
Chapman University, prakash@chapman.edu

Pei-Chen Chen
Chapman University

Richard L. Pilling
Chapman University

Nicole Johnson
Chapman University

Denise Foley
Chapman University

Recommended Citation

Prakash, Anuradha, et al. "1% calcium chloride treatment in combination with gamma irradiation improves microbial and physicochemical properties of diced tomatoes." *Foodborne pathogens and disease* 4.1 (2007): 89-98. doi: 10.1089/fpd.2006.0069

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FOODBORNE PATHOGENS AND DISEASE
Volume 4, Number 1, 2007

DOI: 10.1089/fpd.2006.0069

1% Calcium Chloride Treatment in Combination with Gamma Irradiation Improves Microbial and Physicochemical Properties of Diced Tomatoes

ANURADHA PRAKASH,[1] PEI-CHEN CHEN,[1] RICHARD L. PILLING,[1] NICOLE JOHNSON,[2] and DENISE FOLEY[2]

ABSTRACT

The purpose of this study was to determine the effect of a combination of a 1% calcium chloride dip with low dose irradiation on microbial populations, and biochemical and physical properties, of fresh diced tomatoes during a two-week storage period. Vine tomatoes at the light-red stage (trial 1) and Celebrity tomatoes at the table ripe stage (trial 2) were diced, dipped in 1% $CaCl_2$, and irradiated at 1 kGy from a Co^{60} source. Tomatoes were also contaminated with cocktail of nalidixic-acid resistant *Salmonella* strains (*S.* Poona, *S.* Hartford, *S.* Gaminara, *S.* Michigan, and *S.* Montevideo) and subjected to gamma irradiation. Calcium treatment alone stimulated ethylene production in the diced tomatoes, whereas irradiation treatment alone suppressed ethylene production. The combination of calcium and irradiation treatments resulted in no change in ethylene production compared to the nontreated control, but respiration rate was suppressed by both irradiation and calcium treatment. The calcium dip was found to limit irradiation-induced loss of firmness. Irradiation, by itself and in combination with calcium treatment, resulted in a >3 log CFU/g decrease in total aerobic counts and psychrotrophs. Additionally, irradiation at 1.5 kGy eliminated >3 log CFU/g of *Salmonella* organisms from tomatoes contaminated with *Salmonella*. Counts continued to decrease to an undetectable level over the 11 day storage period. The results indicate that the combination of calcium treatment and irradiation can reduce the risk of disease due to pathogenic organisms such as *Salmonella* and can eliminate the problem of softening induced by irradiation.

INTRODUCTION

Fresh-cut tomatoes meet consumer demand for convenience and offer a standardized product for the food service industries, supermarkets and warehouse stores. However, the shelf life of fresh-cut tomatoes, as compared to whole tomatoes, is limited by microbial spoilage and enhanced senescence. In addition, outbreaks of salmonellosis have been associated with eating raw domestic tomatoes (Zhuang et al., 1995; Weissinger et al., 2000; Cummings et al., 2001; Guo et al., 2001, 2002). Contamination of tomatoes has been linked to improper production, handling, processing, storage and distribution in the farm-to-table process (Guo et al., 2001). Contact with salmonellae-contaminated soil can also lead to infiltration of the pathogen into the parenchyma and core of the fruit by means of the stem scar and damaged skin surfaces (Burnett and Beuchat, 2001; Guo et al., 2002) which prevents washing from decontaminating the product. *Salmonella* serotypes can grow well on chopped ripe tomatoes at 20–30°C, thus there is a real risk of contracting salmonellosis by consuming improperly handled tomatoes (Zhuang et al., 1995).

Low-dose irradiation is highly effective in reducing microbial load and has been shown to

Departments of [1]Physical Sciences and [2]Biological Sciences, Chapman University, Orange, California.

extend shelf life of various fresh-cut fruits and vegetables (Abdel-Kader et al., 1968; Chervin and Boisseau, 1994; Hagenmaier and Baker, 1998; Prakash et al., 2000, 2002). Specifically, electron beam irradiation at 0.7 and 0.95 kGy of tomato cubes and tomato stem scars inoculated with *Salmonella* Montevideo or *S.* Agona was shown to reduce microbial counts although lactic acid bacteria, yeasts, and molds were more resistant to irradiation than *Salmonella* (Schmidt et al., 2006).

Calcium dips are commonly used for whole or cut tomatoes to minimize softening caused by processing. In various fruits and vegetables, calcium has been shown to have the added benefits of delaying senescence and inhibiting respiration (Poovaiah, 1986), regulating ethylene production (Hong and Lee, 1999), regulating pectinesterase activity (Alonso et al., 1995, 1997; Rexova-Benkova and Markovic, 1976), inhibiting polygalacturonase activity (Lee et al., 2001; Lu et al., 1990; Reddy and Srivastava, 1999), and reducing microflora (Izumi and Watada, 1994, 1995; Luna-Guzman and Barrett, 2000).

Combining calcium dips with irradiation treatment can be beneficial in limiting irradiation-induced softening. Kovács et al. (1988) found that the cell compartments of whole apples and pears were preserved best by dipping in a calcium chloride solution prior to gamma irradiation at 1kGy. Gunes et al. (2001) evaluated the texture of fresh-cut modified atmosphere packaged (MAP) apple slices (2% O_2, 2% CO_2, balance N_2, 95% RH, 0.5°C) with or without 0.5% $CaCl_2$ and irradiation at 2.5 or 5 kGy. They found that firmness was not affected by the MAP and that calcium prevented irradiation-induced softening. Dipping fresh-cut tomatoes in 1% $CaCl_2$ increased firmness by 163% (Magee et al., 2003). Firmness was maintained for 8 days following irradiation at 1 kGy.

Little is known about the effects of combining calcium dip and irradiation treatment on ethylene production and respiration rate of diced tomatoes, as well as its potential as an efficient means to reduce pathogenic contamination. The objective of this study was to investigate the effects of 1% $CaCl_2$ treatment prior to gamma irradiation at 1 kGy on *Salmonella* spp. microbial populations of fresh-cut tomatoes and on their physical properties such as texture, ethylene production, and respiration rate.

MATERIALS AND METHODS

Sample preparation

In trial 1, vine tomatoes at stage five (the light-red stage) were obtained 2 days following harvest from Veg Fresh, a distributor in Fullerton, CA. In trial 2, Celebrity tomatoes at stage six (the table-ripe stage) were obtained from a local farmers' market. Hothouse beefsteak tomatoes were obtained from a local grocer on the day of use for the contamination study. The tomatoes were washed in water, then diced using a 5/16" dicer (Dynacube, Dynamic, Quebec, Canada). The dice were approximately $8 \times 8 \times 7$ mm. Diced tomatoes were divided into four treatment categories: control, calcium dip treatment (1% $CaCl_2$), irradiation (1 kGy), and a combination treatment of calcium dip and irradiation.

Bacterial strains and inoculation

S. Hartford H0778 and *S*. Gaminara F2712 involved in a 1995 orange juice outbreak (Cook et al., 1998) were obtained from Joy Wells, PhD, of the Centers for Disease Control, Washington, DC. *S*. Poona serogroup G, *S*. Michigan serogroup J, and *S*. Montevideo serogroup C1 were isolated from patients in outbreaks associated with cantaloupe (Poona and Michigan) or raw tomatoes (Montevideo). These three strains were generously provided by Larry Beuchat, PhD, of the University of Georgia. Naldixic acid–resistant strains were obtained by subculturing the individual strains in tryptic soy broth (TSB) containing increasing amounts of naldixic acid. On the first day a colony growing on a tryptic soy agar (TSA) plate was chosen and cultured in 10 mL TSB with 10 ug/mL naldixic acid. The following day a loopful of the culture was subcultured in TSB with 20 ug/mL naldixic acid. The process continued until the culture was growing in media with 50 ug/mL naldixic acid. Stability of the induced resistance was verified by subculturing 10 consecutive days into TSB media then once again into TSB with 50 ug/mL nalidixic acid. The resistant culture was checked for proper colony appearance on Hectoen enteric agar (HE) as well as TSA plates with 50 ug/mL naldixic acid. The culture was then frozen with 15% glycerol at −80ºC until needed.

Two days prior to irradiation, overnight cultures of naldixic acid–resistant *Salmonella* were inoculated into 45 mL of TSB with 50 ug/mL of nalidixic acid and incubated for 24 hours. The individual cultures were centrifuged at 3000 *g* for 15 minutes and resuspended in Butterfield's buffer. The cells were enumerated using a hemacytometer to obtain an estimate of cell density. The required amount of each inoculum was added to deionized water to obtain approximately equal concentrations of each strain for a final concentration of 10^8 CFU/mL. Diced tomatoes were contaminated with a cocktail of *S.* Poona, *S.* Hartford, *S.* Gaminara, *S.* Michigan, and *S.* Montevideo. Eight hundred grams of tomatoes for each set were contaminated under a hood by submerging samples in 500 mL of 10^8 CFU/mL diluted inocula and gently mixing for 3 minutes before draining with a salad spinner (Oxo International, New York, NY). The samples were stored at 4°C in resealable bags for one hour. After one hour, half of the samples were gently rinsed with 1 L of 1% $CaCl_2$ for one minute and the other half were rinsed with sterile water. After draining the tomatoes in a sanitized salad spinner, individual 15 g samples were placed in sterile homogenizer bags (Interscience, St. Nom, France), and sealed with clips (Interscience). The samples were stored at 4°C until the next day when they were transported to the irradiation facility.

Calcification

One kilogram of diced tomatoes for trial 1, or 800 g of diced tomatoes for trial 2, was dipped into 1 L of 1% $CaCl_2$ dihydrate (Fisher Scientific, Fairlawn, NJ) solution or deionized water at 25°C for 1 min with gentle stirring. The samples were drained for 1 min, placed in Ziploc (SC Johnson, Racine, WI) bags (17.7 × 20.3 cm) and stored at 4°C until irradiation.

Irradiation

All samples including nonirradiated controls were transported in coolers with ice packs to the irradiation facility. The samples were treated with gamma irradiation at a dose rate of 1 kGy/hr using Co^{60} at IBA, Inc., a contract irradiation facility in Tustin, CA. Midway through the irradiation process the samples were rotated 180° to ensure that a uniform dose was received. The actual applied doses were in the range of 1.0–1.1 kGy for the stage 5 vine tomatoes, 1.1–1.2 kGy for the stage 6 Celebrity tomatoes, and 1.5 kGy precisely for the hothouse beefsteak tomatoes used in the contamination study. Gammachrome dosimeters (Harwell Dosimeters Ltd., Oxfordshire, England) were placed in the front and back of the coolers to estimate the absorption dose. Control and calcium dip only samples remained in the facility but did not receive irradiation treatment. The temperature of the samples did not exceed 6°C during treatment. After treatment, samples were transported back to our institution and stored at 4°C until analyzed.

Microbiological analysis

All treated and control samples were analyzed for total aerobic count, yeast, mold, and psychrotroph counts every 72 hours for two weeks. Dilutions for plating were prepared by mixing 10 g of duplicate samples with 90 mL Butterfield's phosphate buffer and homogenizing for 1 min in a paddle blender (Masticator, IUL, Barcelona, Spain). Serial dilutions were prepared in Butterfield's buffer and dilutions were plated in duplicate on the appropriate media. Plate count agar (PCA) (Difco, Detroit, MI) was used for total aerobic counts and for psychrotrophs incubated at room temperature (25°C) for 3 days and 4°C for 10 days, respectively. For yeast and mold, potato dextrose agar (PDA) (Difco, Detroit, MI) containing 25 μg/mL chloramphenicol (Sigma, St. Louis, MO) was used and plates were incubated at room temperature (25°C) for 5 days. Each data point reported constitutes the average of duplicate samples.

Salmonella enumeration

A 1:10 dilution of all samples with Butterfield's phosphate buffer was obtained by using an automatic diluter (Dilumat3 mk2, AES Laboratoire, Combourge, France). The samples were homogenized for 90 seconds and serial dilutions were performed to reach the desired dilution. All samples were plated in duplicate on TSA containing nalidixic acid (TSAN) and TSAN with two 7–10 mL layers of basal yeast extract (TSAN-TAL) as a recovery method (Wu

and Fung, 2001). Samples were plated using a spiral plater (Whitley Automatic Spiral Plater, dw Scientific, West Yorkshire, United Kingdom); in addition, 0.2 mL of the 1:10 dilution of irradiated samples were also plated using standard spread plate methodology. TSAN plates were incubated for 24 hours at 37°C before enumeration of colonies. TSAN-TAL plates were incubated at 18°C for 18 hours and then at 37°C for another 18 hours.

Physical analyses

In both trials, samples were evaluated at regular intervals for two weeks to determine changes in ethylene production, respiration rate, and texture.

Determination of respiration rate and ethylene production

Three hundred grams of diced tomatoes were placed in gas-tight 1 L amber glass jars (8.1 × 18.4 cm) (I-Chem, Rochester, NY) fitted with rubber stoppers for 1 hour at 4°C after which 50 μL of headspace gas was withdrawn using a 50 μL gas-tight syringe (Fisher Scientific, Fairlawn, NJ) and injected into a Varian gas chromatograph 3800 with a fused silica capillary column (Carboxen 1010, Supelco, Bellefonte, PA) (30 m × 0.53 mm). Carbon dioxide concentration was measured by a thermal conductivity detector (TCD) at 150°C and ethylene was measured using a flame ionization detector at 50°C. The filament temperature in the TCD was 385°C. The carrier gas was helium flowing at 30 mL/min with the same flow for hydrogen. The flow rate of air was 120 mL/min. The initial column temperature was 30°C for 7 minutes and then increased 25°C/min to 100°. After 10 minutes at 100°C, the column temperature was again increased 25°C/min to 200°C and held for 8 minutes. The temperature of the injector port was 225°C. Headspace CO_2 and C_2H_4 concentrations were calculated by comparison of peak areas with a calibration curve prepared from standard gas mixtures. To convert mL CO_2 to mg CO_2, the volume of CO_2 was multiplied by the appropriate density factor based on temperature used and the volume of CO_2 at 4°C was manually calculated based on the difference between 0°C and 10°C. Samples for each treatment were analyzed in triplicate.

Texture analysis

Texture of tomatoes was measured using a Kramer Shear Press with five blades (TA-91) attached to a Stable Micro System Texture Analyzer (Model TA-XT2, Texture Technology Corporation, Scarsdale, NY/Stable Microsystems, Godalming, UK). One hundred grams of tomatoes were placed into the metal container of the Kramer Shear Cell and a 5 flat-plate plunger was forced through the samples. The probe was set at 42 mm from the bottom of the 5 flat-plate plunger. The test speed of the probe was set at 2.0 mm/sec and the post-test speed was 10.0 mm/sec. The measurements were replicated six times for each treatment.

Calcium uptake

Fifty grams of each tomato sample were dried overnight (Isotemp Economy Lab oven, Fisher Scientific, Fairlawn, NJ) at 90°C. Two grams of the dried samples were ground into powder and heated for 6 hours at 600°C in a muffle furnace. The residue was treated with 3 mL concentrated nitric acid, heated at 90°C again until dry and then heated for an additional hour at 600°C. The final ash was dissolved in 10 mL concentrated HCl and then diluted with deionized water to bring to the solution to 50 mL. The solutions were diluted with 4 mg/mL potassium nitrate solution. The solutions were filtered if solids were present and analyzed using an AA spectrometer (Thermo Elemental Solaar AA series, Cambridge, UK) based on an acetylene/nitrous oxide flame, absorption measured at 422.7 nm. Three samples were analyzed for each treatment. A calcium carbonate solution (1 mg/mL) diluted with potassium nitrate solution (4 mg/mL) to 0, 1.0, 3.0, and 5.0 μg/mL was used to develop a standard curve. Calcium uptake of the samples is shown in Table 1.

Statistical analysis

Microsoft Excel 2002 v.6.0 (Microsoft, Seattle, WA) with the data analysis package and SPSS 11.5 for Windows (SPSS Inc., Chicago, IL) software were used to perform statistical analysis. Two-way ANOVA with replication was used to determine the effects of treatments and storage time points in a randomized block design. When F values were significant, least signifi-

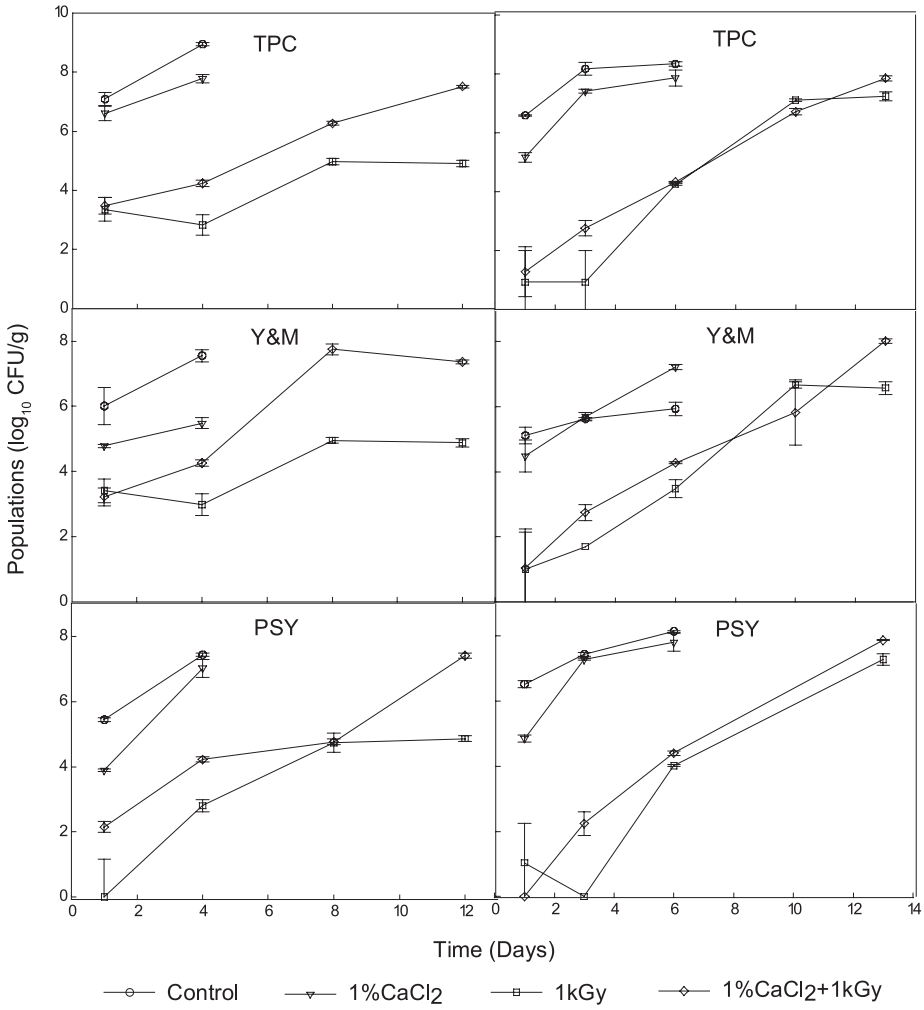

FIG. 1. (**A**) Trial 1 and (**B**) trial 2 changes in mean populations (log CFU/g) of total aerobic microorganisms, yeast, mold, and psychrotrophs in treated diced tomatoes stored at 4°C. Data points represent the average of duplicate samples. Error bars represent standard deviation. TPC, total plate count; Y&M, yeast and mold; PSY, psychrotrophs.

cant differences at $P \leq 0.05$ were calculated using a multiple comparison test. For contamination studies, TSAN-TAL recovery method data were used for analysis due to higher (although not significant) microbial counts.

RESULTS

The evaluations of the control and the calcium treatments were stopped on day 4 due to decay. The samples irradiated at 1 kGy and the combination treated sample (1% $CaCl_2$ + 1 kGy) did not decay until after day 12 in both trials.

Microbial populations

Calcium initially had a small effect ($P \leq 0.05$) in reducing the initial populations of total aerobic microorganisms, psychrotrophs, yeast, and mold (Fig. 1). This effect was transient.

As expected, irradiation at 1 kGy initially decreased microorganism counts (except yeast and mold) in diced tomatoes by >3 log CFU/g. The combination treatment was as effective as irradiation alone, but no more so. The growth rates of microbial populations in the combination treated samples were slightly higher ($P > 0.05$) than in the irradiated samples in both trials. Hence, the combination treatment did not have any additional inhibitory effects on microbial growth compared to irradiation alone.

The microorganism populations in the irradiated sample reached the initial numbers of total aerobic count, psychrotrophs, yeast, and mold in the control samples only after day 8 (vine) and day 10 (Celebrity).

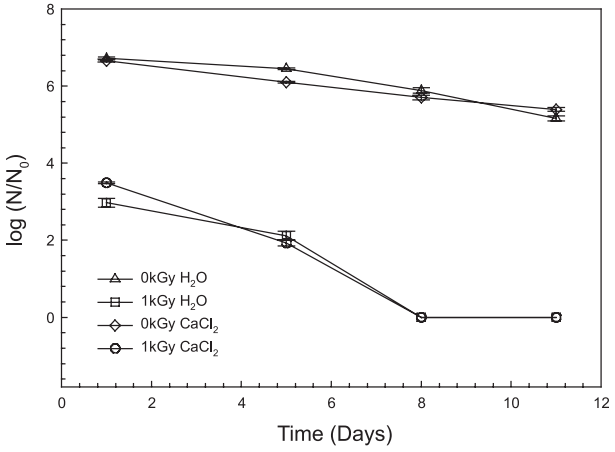

FIG. 2. Log reduction of *Salmonella* in rinsed and irradiated tomatoes plated on TSAN-TAL plates during an 11-day refrigerated storage study. Data points represent the average of duplicate samples. Error bars represent standard error.

Contamination study

TSAN-TAL plates were used to calculate the total log reduction of *Salmonella* over an 11-day period. Similar to our observations of the background flora of the vine and Celebrity tomatoes, there was little difference in *Salmonella*-contaminated irradiated tomatoes rinsed with $CaCl_2$ compared to water-rinsed tomatoes (Fig. 2). Irradiation at 1.5 kGy reduced counts by almost 4 log CFU/g and both irradiated sample populations eventually decreased to an undetectable level over the 11 days. Nonirradiated samples showed little reduction in *Salmonella* populations over the 11-day period.

Ethylene production

Overall, samples experienced a sharp decrease in ethylene production by day 3 or 4 (Fig. 3). The tomatoes appeared to have already passed the ethylene climacteric peak. In Celebrity tomatoes, ethylene was not detected after day 3 (in calcium treated), 4 (in combination treated), and 6 (in irradiated) samples. This may have been due to the end of metabolism in table-ripe tomatoes.

In both Celebrity and vine tomatoes, ethylene production was significantly ($P \leq 0.05$) suppressed by gamma irradiation at 1 kGy. On day 1, irradiation suppressed ethylene production by approximately 31% in diced vine tomatoes at stage 5 and 18% in the Celebrity tomatoes at stage 6.

Respiration rate

The control sample had a brief rise in respiration rate on day 2 for both the vine and Celebrity tomatoes, while the three treatments (calcium, irradiation, and combination) suppressed respiration during storage ($P < 0.05$) (Fig. 4). Since all samples were past the climacteric peak, this increase in respiration rate of the control sample could be a result of wounding induced by dicing (Brecht, 1995).

Respiration rate was significantly ($P \leq 0.05$) suppressed by the calcium (40% and 74%) or irradiation treatment (48% and 61%) in vine and Celebrity tomatoes, respectively. The combination treatment significantly reduced respiration rate only in the stage 5 vine tomatoes. The combination treatment did not have a synergistic or additive effect on respiration rate. Bangerth et al. (1972) reported that respiration rate could be suppressed by calcium because it limits diffusion of the main respiratory substrates (malate

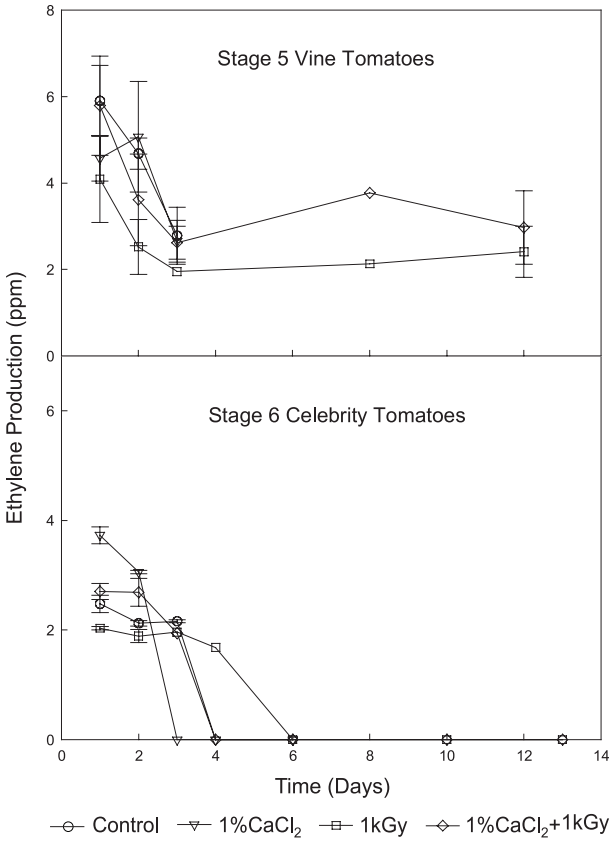

FIG. 3. Effects of calcium and irradiation treatments on ethylene production of diced tomatoes stored at 4°C. Data points represent the average of triplicate samples. Error bars represent standard deviation.

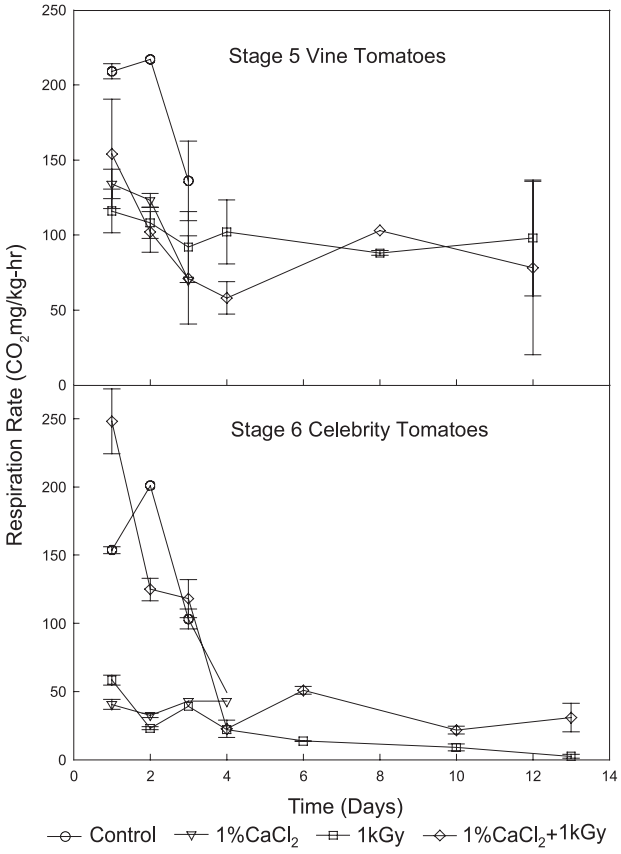

FIG. 4. Effects of calcium and irradiation treatments on the respiration rate of diced tomatoes stored at 4°C. Data points represent the average of triplicate samples. Error bars represent standard deviation.

and sugars) to reach the respiratory enzymes in the cytoplasm and mitochondria.

Texture

Firmness of the control diced tomatoes in trials 1 and 2 did not change significantly ($P > 0.05$) during storage (Fig. 5). Although initial tomato firmness was different in the two trials due to their maturity stages, the effects of irradiation were similar. In both trials, irradiation did not induce additional softening compared to the control.

The calcium dips increased the calcium content of the vine tomatoes by 207% and 505% in the Celebrity tomatoes. The calcium uptake in Celebrity tomatoes was higher than in the vine tomatoes due to the lower ratio of diced tomatoes to calcium solution. Calcium dip treatment significantly improved the firmness of diced tomatoes in both trials. Compared to the control, the firmness of the calcium chloride treated sample was initially increased by 127% for vine tomatoes and 248% for Celebrity tomatoes.

No significant differences in firmness or calcium uptake were found in the combination treated samples compared to the calcium treated samples ($P > 0.05$). This result indicates that calcium limited irradiation-induced softening in the combination treated sample.

DISCUSSION

The effect of irradiation on reduced plate counts, yeast, and mold in fresh-cut products has been well documented. Howard et al. (1995) found that irradiation at 1 kGy initially reduced aerobic mesophilic microflora and total lactic microflora by 2 logs and 0.5 log, respectively, in *pico de gallo*, a cold salad made of tomatoes, yellow onions, and jalapeno peppers,

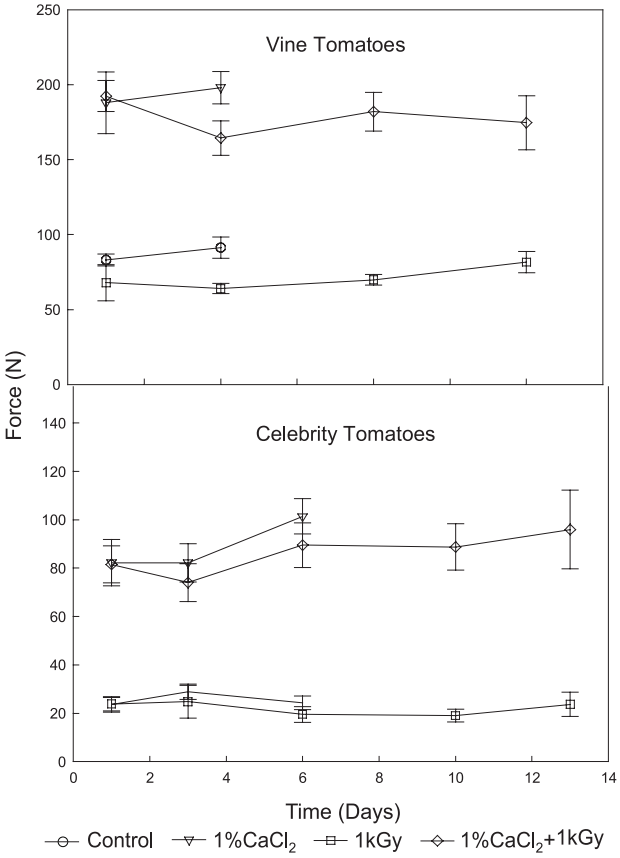

FIG. 5. Effects of calcium and irradiation treatments on the firmness of diced tomatoes stored at 4°C. Data points represent the average of 6 replicates. Error bars represent standard deviation.

Table 1. Effects of Calcium and Irradiation Treatments on the Calcium Content (ppm) of Diced Tomatoes

	Control	*1% $CaCl_2$*	*1 kGy*	*1% $CaCl_2$ + 1 kGy*
Stage 5 vine	51 ± 0.38 (100%)	105 ± 1.56 (207%)	38 ± 0.12 (76%)	114 ± 0.67 (223%)
Stage 6 Celebrity	77 ± 1.99 (100%)	394 ± 9.01 (505%)	69 ± 0.68 (89%)	400 ± 0.94 (513%)

Average values of 3 samples ± standard deviation.

over 6 weeks of refrigerated storage, thus extending shelf life. Previously our group found that irradiation at 0.5 and 1.24 kGy reduced the initial populations (total aerobic counts, yeast, and mold) by 1 log in diced tomatoes, and maintained lower counts through 12 days, compared to control (Prakash et al., 2000). That study also indicated that irradiation at 0.5 kGy significantly ($P \leq 0.05$) reduced total aerobic counts without any unpleasant sensory characteristics.

Calcification has been observed to lower microbial counts in produce. Carrot shreds and cantaloupe cylinders treated with 1% and 2.5% calcium chloride, respectively, had lower yeast and mold total plate counts than water-dipped samples towards the end of shelf life (Izumi and Watada, 1994; Luna-Guzman and Barrett, 2000). Similarly, zucchini squash slices dipped in 0.5% calcium chloride (Izumi and Watada, 1995) reduced total microbial counts by a little less than 1 log during later storage. Conway and Sams (1984) explained that tissue resistance to microbial attack is increased by calcium by stabilizing or strengthening the cell wall.

In a recent study, electron beam irradiation of fresh-cut tomato cubes at 0.95 kGy reduced counts of *S.* Montevideo by 2.2 log CFU/g and of *S.* Agona by 2.4 logs (Schmidt et al., 2006). The counts decreased over a 15-day storage period by a little more than 2 log CFU/g, compared to ~4 log CFU/g in our study. One cause for this disparity might be the different modes of irradiation, electron-beam *versus* gamma. It is also possible that the greater reduction in *Salmonella* counts in our study was due to increased sensitivity of nalidixic acid–adapted *Salmonella* to irradiation as compared to non-nalidixic acid–adapted strains as used by Schmidt et al. (2006). Niemira and Lonczynski (2006) showed that nalidixic acid–resistant strains of *Salmonella* are more sensitive to irradiation than nalidixic acid–sensitive strains in buffer and orange juice. D_{10} values of nalidixic acid–resistant strains were lower by 9% and 17%, respectively, in buffer and orange juice, compared to D_{10} values of nalidixic acid–sensitive parent strains.

Although irradiation-inhibited ethylene production in fruits is not completely understood, the suppressing effect of irradiation on ethylene production may be beneficial due to the resulting inhibition of senescence reactions. Similar to our results, Lee et al. (1968) found that irradiation of mature green tomatoes at 0.2–0.7 kGy decreased ethylene production to half that of the control tomatoes, and within 3–6 days fell to trace levels. Suppression of ethylene production by irradiation has been reported in Early Pak No. 7 tomatoes at the table-ripe stage treated at doses of 6 kGy or more (Abdel-Kader et al., 1968). However, tomatoes irradiated at 0.1–0.6 kGy at the breaker stage had a peak in ethylene production 2 days after irradiation and showed higher ethylene production than the control during the first 10 days after irradiation treatment.

Magee et al. (2003) found that irradiation of diced Roma tomatoes at stage 5 reduced firmness by 66% on day 1 and the tomatoes experienced continued softening with storage. Irradiation-induced loss of firmness could be higher in immature tomato dice but in this study, in which tomatoes were diced at or past the climacteric peak, irradiation did not induce further loss of firmness.

CONCLUSION

In our study, irradiation has a greater influence than calcium dips on physicochemical properties of diced tomatoes. Although the combination treatment (1% $CaCl_2$ + 1 kGy) did not show a synergistic or additive effect on physicochemical properties (ethylene production, respiration rate), it was very effective against a cocktail of *Salmonella*

strains and extended the microbial shelf life of diced tomatoes by 6–8 days while maintaining firmness. Previous work has shown that the combination of irradiation and calcification does not affect the flavor or appearance of diced tomatoes. Thus, the combination technology is appropriate for improving safety of diced tomatoes without adverse effects on quality.

ACKNOWLEDGMENTS

The authors thank the Irvine Health Foundation for its generous funding, Sterigenics for irradiation services, and Malia Jossna Chia for technical support.

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Address reprint requests to:
Anuradha Prakash, PhD
Department of Physical Sciences
Chapman University
One University Drive
Orange, CA 92866

E-mail: prakash@chapman.edu

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