

# Compilation of Research Citations on the Microbiological Safety and Risk Reduction Interventions for Fresh and Fresh-cut Melons

Prepared 21 April 2008  
by Carol D'lima and Trevor Suslow  
University of California, Davis  
Department of Plant Sciences  
[tvsuslow@ucdavis.edu](mailto:tvsuslow@ucdavis.edu)  
<http://ucgaps.ucdavis.edu>  
<http://postharvest.ucdavis.edu>

The following is an up-to-date compilation of peer-reviewed research directed at microbial food safety risks, modes of contamination transfer, and disinfection or other risk reduction interventions for cantaloupe, honeydew, and watermelon. It was originally intended to support an updated, industry –oriented “white paper” on **practical** food safety guidance for melon growers, shippers, handlers, processors, retailers, and consumers that may be gleaned from published research. However, we felt there is a value in making this generally available as a citation list at this time. In preparing this resource we became aware of another similar effort provided below:

Microbiological Safety of Fresh and Fresh-Cut Melons:  
A Bibliography Compiled by Robert L. Buchanan, Ph.D.  
Food and Drug Administration  
Center for Food Safety and Applied Nutrition  
College Park, Maryland, USA  
March, 2008 [http://www.jifsan.umd.edu/Tomato/Melon\\_Bibliography.pdf](http://www.jifsan.umd.edu/Tomato/Melon_Bibliography.pdf)

We believe the list that follows is comprehensive and have included the research Abstracts, when available, to facilitate access to an understanding of what data may already exist as a guide for those engaging in prioritization of future research on these and closely related commodities. As we have attempted to make this citation and research outcome resource available in timely manner there may be some omissions or minor errors. We will be continuing to “clean-up” and modify this list and improve its usefulness, in the near future, by primary topical groupings. We will also compile an appendix list of current research abstracts from 2008 professional meetings, which are generally a view into what has most recently been funded. We hope this overview will be useful in an assessment of what issues remain as data and knowledge gaps and what issues remain as implementation gaps for improved development of Commodity-Specific Guidance documents and performance in microbial food safety management for melons.

## **Research Publication Resource**

1. *Multistate outbreaks of Salmonella serotype Poona infections associated with eating cantaloupe from Mexico--United States and Canada, 2000-2002.* MMWR Morb Mortal Wkly Rep, 2002. **51**(46): p. 1044-7.

Three multistate outbreaks of Salmonella serotype Poona infections associated with eating cantaloupe imported from Mexico occurred in the spring of consecutive years during 2000-2002. In each outbreak, the isolates had indistinguishable pulsed-field gel electrophoresis (PFGE) patterns; the PFGE patterns observed in the 2000 and 2002 outbreaks were indistinguishable, but the pattern from 2001 was unique among them. Outbreaks were identified first by the California Department of Health Services (2000 and 2001) and the Washington State Department of Health (2002) and involved residents of 12 states and Canada. This report describes the investigations, which led ultimately to an import alert on cantaloupes from Mexico. To limit the potential for cantaloupe contamination, the Food and Drug Administration (FDA) continues to work with the Mexican government on a food-safety program for the production, packing, and shipping of fresh cantaloupes.

2. Aguayo, E., et al., *Microbial and sensory quality changes in fresh processed melon under high carbon dioxide controlled atmosphere.*, in *Proceedings of the international conference on quality in chains, an integrated view on fruit and vegetable quality*, L.M.M. Tijskens, Editor. 2003, Acta Horticulturae: Wageningen, Netherlands. p. 795-798.

Melon cv. Amarillo was fresh-processed on trapeze-shaped sections and stored under controlled atmosphere (CA) at 5°C up to 14 days. By means of a gas mixing system, a continuous humidified flow (0.03 litre/minute and 95% RH) inside a 0.750-litre glass jars (350 g per jar) was injected. Treatments comprised: gas compositions of 4 kPa O<sub>2</sub> + 15 kPa CO<sub>2</sub>, 21 kPa O<sub>2</sub> + 15 kPa CO<sub>2</sub> and 21 kPa O<sub>2</sub> + 0 kPa CO<sub>2</sub> (as the control). Sensorial quality attributes, firmness and microbial counts were monitored. At the end of storage, quality evaluations in the control fell under the limit of marketability. However, fresh-cut melons stored for 14 days under CA kept all sensorial parameters within the marketability range without significant differences among the treatments. Compared to the control, both CA treatments, particularly 4 kPa O<sub>2</sub> + 15 kPa CO<sub>2</sub>, were effective for avoiding softness. At any time, off-aroma was detected. At the end of storage, mould and yeast counts were lower than 2 CFU/g in CA treatments and 3 CFU/g in the control. Mesophilic and psychrotrophic bacterial counts appeared in 2.7 and 3.8 CFU/g, respectively, in CA, and in 4.7 and 6.6 CFU/g, respectively, in the control.

3. Aharoni, Y., A. Copel, and E. Fallik, *The use of hydrogen peroxide to control postharvest decay on 'Galia' melons*. Ann Appl Biol, 1994. **125**: p. 189-193.  
Melon cv. Amarillo was fresh-processed on trapeze-shaped sections and stored under controlled atmosphere (CA) at 5°C up to 14 days. By means of a gas mixing system, a continuous humidified flow (0.03 litre/minute and 95% RH) inside a 0.750-litre glass jars (350 g per jar) was injected. Treatments comprised: gas compositions of 4 kPa O<sub>2</sub> + 15 kPa CO<sub>2</sub>, 21 kPa O<sub>2</sub> + 15 kPa CO<sub>2</sub> and 21 kPa O<sub>2</sub> + 0 kPa CO<sub>2</sub> (as the control). Sensorial quality attributes, firmness and microbial counts were monitored. At the end of storage, quality evaluations in the control fell under the limit of marketability. However, fresh-cut melons stored for 14 days under CA kept all sensorial parameters within the marketability range without significant differences among the treatments. Compared to the control, both CA treatments, particularly 4 kPa O<sub>2</sub> + 15 kPa CO<sub>2</sub>, were effective for avoiding softness. At any time, off-aroma was detected. At the end of storage, mould and yeast counts were lower than 2 CFU/g in CA treatments and 3 CFU/g in the control. Mesophilic and psychrotrophic bacterial counts appeared in 2.7 and 3.8 CFU/g, respectively, in CA, and in 4.7 and 6.6 CFU/g, respectively, in the control.
  
4. Akins, E.D., M.A. Harrison, and W. Hurst, *Washing practices on the microflora on Georgia-grown cantaloupes*. J Food Prot, 2008. **71**(1): p. 46-51.

In recent years, several foodborne illness outbreaks have been associated with the consumption of cantaloupe. Cantaloupes can be contaminated with pathogens anywhere from the field to the packing line. In the United States, cantaloupes are handled and packed differently in each state. Georgia-grown cantaloupes are brought to sheds, washed, and packed, whereas California-grown cantaloupes are field packed. In this study, the microbiological status of cantaloupes produced by four Georgia growers that use various washing and packing practices was assessed to determine the influence of these different practices. The facilities were visited four times during the harvest season. Aerobic bacteria, *Escherichia coli*, and coliforms on these Georgia-grown cantaloupes were enumerated in transport trailers, after washing, and after packing. Samples also were analyzed for the presence of *Salmonella* and *E. coli* O157:H7. In sheds 1 and 4, a chlorinated dump tank was used to wash melons. In sheds 2 and 3, heated water with chlorine was used in the dump tanks. Although there was a significant reduction ( $P < 0.05$ ) in the populations of the aerobic bacteria and *E. coli* between the transport trailer and the dump tank for sheds 1 and 4, the reduction was less than 0.5 log CFU/cm<sup>2</sup>. The temperatures of the water in the dump tanks at sheds 2 and 3 were not high enough to effectively reduce the microbial populations evaluated. Populations on the melons increased slightly ( $< 0.5$  log CFU/cm<sup>2</sup>) after the melons were removed from the dump tank, suggesting possible contamination after washing.

5. Alvarado-Casillas, S., et al., *Comparison of rinsing and sanitizing procedures for reducing bacterial pathogens on fresh cantaloupes and bell peppers*. J Food Prot, 2007. **70**(3): p. 655-60.

Increased consumption of fruits and vegetables is linked to health benefits but also to an increase in the number of outbreaks of foodborne illness. To determine the effectiveness of different sanitizing treatments for reducing bacterial pathogens on fresh produce, fresh cantaloupes and bell peppers were harvested and inoculated with suspensions of Salmonella Typhimurium and Escherichia coli O157:H7. The inoculated fruits were treated with water wash alone or were washed and then waxed or rinsed with 200 mg/liter hypochlorite, 10% Ca(OH)<sub>2</sub>, or 2% lactic acid solutions applied by dipping for 15 s or spraying for 15 s. Preliminary experiments with chlorine treatments indicated that spraying with a 200, 600, or 1,000 mg/liter hypochlorite solution reduced populations of both pathogens by 2.1 to 2.6 and 1.5 to 2.1 log CFU for Salmonella Typhimurium and E. coli O157:H7, respectively. In general, no differences were observed between chlorine solutions without pH adjustment (pH 9.2) and those with pH adjusted to 6.0. When different wash regimes were applied to inoculated cantaloupes or bell peppers, water wash alone produced significantly lower counts of both pathogens on bell peppers in comparison to untreated controls. However, this reduction was not observed on cantaloupes, indicating a possible surface effect. Application of 2% L-lactic acid by spray was the treatment that resulted in the lowest bacterial counts on both cantaloupes and bell peppers. This treatment did not produce any deleterious change in the sensorial characteristics of the products tested. None of the pathogens studied was able to grow during refrigerated storage (5 degrees C for cantaloupes and 10 degrees C for bell peppers), although numbers close to the detection limit of the counting method were found in randomly tested individual samples at days 14 and 28 of storage, indicating that these pathogens can survive for long periods on the produce surface. These results indicate that selected produce commodities could be sanitized at the packing facility. However, these interventions should not be applied as a replacement for but only as a complement to good hygiene practices

6. Annous, B.A., A. Burke, and J.E. Sites, *Surface pasteurization of whole fresh cantaloupes inoculated with Salmonella poona or Escherichia coli*. J Food Prot, 2004. **67**(9): p. 1876-85.

Numerous outbreaks of salmonellosis by Salmonella Poona have been associated with the consumption of cantaloupe. Commercial washing processes for cantaloupe are limited in their ability to inactivate or remove this human pathogen. Our objective was to develop a commercial-scale surface pasteurization process to enhance the microbiological safety of cantaloupe. Populations of indigenous bacteria recovered from cantaloupes that were surface pasteurized at 96, 86, or 76 degrees C for 2 to 3 min were significantly ( $P < 0.05$ ) lower than those of the controls. Whole cantaloupes, surface inoculated with Salmonella Poona RM 2350 or Escherichia coli ATCC 25922 to a final cell

concentration of ca. 5 log CFU/cm<sup>2</sup> were stored at 4 degrees C or room temperature (RT = 19+/-1 degrees C) for up to 72 h before processing. Treatments at 76 degrees C for 2 to 3 min at 24 h post-inoculation resulted in a reduction in excess of 5 log CFU/cm<sup>2</sup> of Salmonella Poona and E. coli populations. Cantaloupes that were surface pasteurized and stored at 4 degrees C for 21 days retained their firmness qualities and had no visible mold growth compared with the controls, which became soft and moldy. These results indicate that surface pasteurization will enhance the microbiological safety of cantaloupes and will extend the shelf life of this commodity as well. Storage of untreated inoculated cantaloupes at RT for 24 to 72 h post-inoculation caused a significant (P < 0.05) increase in Salmonella Poona and E. coli populations compared with storage at 4 degrees C. This indicates that cantaloupes should be refrigerated as soon as possible following harvest to suppress the growth of any possible contaminant on the rind.

7. Annous, B.A., et al., *Biofilm formation by Salmonella spp. On cantaloupe melons*. 2005. p. 276-287.

The ability of two strains of Salmonella to form biofilms on whole cantaloupe melons was investigated. Ten microliters of bacterial suspensions was spot-inoculated onto cantaloupe melon rinds in pre-marked areas, and the cantaloupe melons were held at either 10 or 20C. Biofilm formation was monitored using scanning electron microscopy on excised portions of the cantaloupe melon rind at 2, 24, 48, 72 and 144h post-inoculation. Micrographs indicated that biofilm formation occurred rapidly following introduction of cells (2h at 20C) onto the cantaloupe melon rind. A fibrillar material was visible after just 2h at 20C, and cells were embedded in extracellular polymeric material after 24h at either temperature. These results indicate that a human pathogen is capable of forming a biofilm on plant tissue and that biofilm formation may be responsible for the increased recalcitrance of bacteria to aqueous sanitizers.

8. Anon, *Multistate outbreak of Salmonella poona infections - United States and Canada*. Morbidity and Mortality Weekly Report, 1991. **40(32)**: p. 549-552.

During June and July 1991, more than 400 laboratory-confirmed infections with Salmonella poona occurred in 23 states (Figure 1) and in Canada. This report describes several investigations that indicated this was a large nationwide outbreak related to consumption of cantaloupes. UNITED STATES Illinois and Michigan

During June and July, laboratories in Illinois and Michigan identified 49 cases of S. poona infection for which onset of illness had occurred during the first 3 weeks of June. Symptoms included nausea, vomiting, diarrhea, abdominal cramps, and fever; the duration of symptoms was 3-12 days. A case-control investigation

compared culture-confirmed cases with age- and residence-matched controls using the same questionnaire in both states; nine (28%) of 32 ill persons and three (7%) of 45 controls specifically recalled consuming cantaloupe in fruit salad (odds ratio (OR)=5.9; 95% confidence interval (CI)=1.3-36.1); 14 (44%) of 32 ill persons and 18 (38%) of 48 controls recalled eating cantaloupe during the 3 days before onset of symptoms (OR=2.6; 95% CI=0.9-7.7). Seventeen *S. poona* outbreak isolates from seven states were characterized by the Michigan Department of Public Health Laboratory. Chromosomal digest by low-frequency cutting restriction endonuclease and pulse field gel electrophoresis revealed an identical pattern, suggesting a probable common origin.

Industry sources reported that the temporal and geographic distributions of cases were compatible with distribution of cantaloupe to the affected states from the Rio Grande region of Texas from mid-May to mid-June. Minnesota During June and July, 20 *S. poona* isolates were identified by the Minnesota Department of Health, Division of Public Health Laboratories, an increase from 1989 and 1990 when four *S. poona* isolates per year were reported. Onset of symptoms occurred from June 5 through July 7; eight cases occurred during the week of June 10-16.

In a case-control study of the first 13 cases and 26 age- and telephone-exchange-matched controls, eight (62%) ill persons and no controls reported consuming cantaloupe from a salad bar or in a fruit salad (OR=undefined; p less than 0.01). Illness was not associated with consumption of fresh sliced cantaloupe (OR=2.6; 95% CI=0.5-15.2).

Grocery stores, restaurants, and distributors reported that the implicated cantaloupes were from Texas. Industry sources identified the probable source of these cantaloupes as an area including Hidalgo and Starr counties in the lower Rio Grande Valley of Texas. Distribution of onset of illness coincided with the shipping of cantaloupes from this area from May 10 through June 15. New Jersey

During June, 17 *S. poona* isolates were identified in New Jersey. Onset of illness ranged from May 20 to June 26. Two isolates were identified from among the 75 attendees at a June 9 party. Food histories were obtained from 38 attendees; 17 (45%) were ill with diarrhea. Analysis of these histories associated illness with eating a fruit salad served at the party (OR=6.2; 95% CI=1.2-41.9; p=0.03). The fruit salad contained cantaloupe, honeydew melon, watermelon, strawberries, grapes, and pine apples. The suppliers of the party caterer reported that they received cantaloupes from Arizona, California, and Texas. CANADA

As of July 24, 72 laboratory-confirmed cases of *S. poona* had been reported to the Laboratory Centre for Disease Control, Health and Welfare Canada--66 (92%) from Ontario and the remainder from Newfoundland, Quebec, and Saskatchewan. Since 1969, three to 18 human isolates of this serotype have

been reported annually in Canada. Most cases occurred in the second and third weeks of June. A case-control study to examine vehicles of infection is in progress.

9. Ayhan, Z., G.W. Chism, and E.R. Richter, *The shelf-life of minimally processed fresh cut melons*. J Food Quality, 1998. **21**: p. 29-40.

Honeydew and cantaloupe melons were surface sterilized by scrubbing with a hypochlorite solution at low level (200 ppm total available chlorine) and high level (2000 ppm total available chlorine), peeled and cut into "chunks". Fruit pieces were dipped in a dilute hypochlorite solution (pH 6) of 50 ppm total available chlorine prior to packaging under an atmosphere of 95% N<sub>2</sub> and 5% O<sub>2</sub> and storage at 2.2C. Unwashed and water-washed samples were also prepared as controls. Microbial counts and sensory analyses were monitored during a 20 day storage period. Microbial counts of unwashed and water-washed samples were found to be significantly ( $p \leq 0.05$ ) different from the fruits which were chlorine washed initially, and during the storage time. However, increasing the free available chlorine concentration tenfold did not result in any further significant increase in the shelf-life. Rapid decline was observed in all measured microbial and sensory quality factors of unwashed samples during storage. Proper sanitation and production practices along with raw material selection can ensure a shelf-life of 15 days for cantaloupe and honeydew pieces.

10. Barak, J.D., B. Chue, and D.C. Mills, *Recovery of surface bacteria from and surface sanitization of cantaloupes*. Journal of Food Protection, 2003. **66**(10): p. 1805-1810.

Practical, effective methods that could be implemented in a catering establishment (restaurant or delicatessen) for the surface sanitization of cantaloupes were microbiologically evaluated. Cantaloupes (*Cucumis melo* var. *reticulatus*) were immersed in an inoculum containing *Salmonella enterica* serovar Poona or *Pantoea agglomerans* at  $10^4$  to  $10^5$  CFU/ml. An efficient method for the recovery of bacteria from the cantaloupe surface was developed and validated. The method consisted of washing the entire melon with Butterfield's buffer containing 1% Tween 80 in a plastic bag placed inside a plastic pail affixed to an orbital shaker. Levels of *S. enterica* Poona recovered by washing the entire melon were significantly higher than those recovered by the more common laboratory method of blending the rind. *P. agglomerans* can be used as a nonpathogenic proxy for *S. enterica* Poona. A three-compartment surface sanitization method consisting of washing with an antimicrobial soap solution, scrubbing with a brush in tap water, and immersion in 150 ppm of sodium hypochlorite reduced the initial level of recoverable viable bacteria by 99.8%. When examined separately, scrubbing with a vegetable brush in tap water, washing with soap, and dipping in chlorine reduced the bacterial load by 70, 80, and 90%, respectively.

11. Bastos, M.d.S.R., et al., *The effect of the association of sanitizers and surfactant in the microbiota of the Cantaloupe (Cucumis melo L.) melon surface*. Food Control, 2005. **16**(4): p. 369-373.

This work aimed to evaluate the efficiency of 200, 500 and 1000 mg l<sup>-1</sup> of free available chlorine (FAC) and 60 mg l<sup>-1</sup> of peracetic acid (APA) associated or not with Tween 80 in reducing the mesophilic aerobes, coliforms group and fecal coliforms on cantaloupe melon surface. Also, the action of the organic chloramine in removing the Salmonella enteritidis when attached on the melon surface. All treatments reduced significantly (p<0.05) the microbiota analyzed when compared with a water washing, used as control. The treatment with 1000 mg l<sup>-1</sup> of organic chloramine with surfactant reduced the mesophilic aerobes (p<0.05) by 4-log cycles, more than the control. Also this chlorine solution was the most efficient in removing S. enteritidis after attachment of the microorganisms to the fruit surface, between 1 and 24 h.

12. Behrsing, J., et al., *Survival of Listeria innocua, Salmonella salford and Escherichia coli on the surface of fruit with inedible skins*. Postharvest Biology and Technology, 2003. **29**(3): p. 249-256.

The survival and growth of Salmonella salford, Escherichia coli and Listeria innocua on the surface of fruit with inedible skins was investigated. Passionfruit, banana, cantaloupe (rock melon) and honeydew melon were inoculated by immersion in solutions containing two inoculum levels and then stored under normal storage and distribution temperature regimes. A low (ca. 10<sup>3</sup> cfu ml<sup>-1</sup>) and high (10<sup>5</sup>-10<sup>6</sup> cfu ml<sup>-1</sup>) inoculum concentration was used for each organism. Bananas were stored for 13 days at 18 °C, passionfruit for 6 days at 10 °C, cantaloupes for 7 days at 8 °C and honeydew melons for 1 day at 12 °C then 5 days at 8 °C. Generally, the fruit did not support growth under the conditions employed, although test organisms could usually be recovered either directly or after an enrichment step. The exception was the growth of L. innocua on the skin of cantaloupe. Significant growth was observed for both the low and high inoculum levels during storage at 8 °C. Cantaloupes inoculated with 2.4×10<sup>6</sup> cfu ml<sup>-1</sup> had an initial level of 3.4×10<sup>3</sup> cfu cm<sup>-2</sup> and this increased to 2.9×10<sup>5</sup> cfu cm<sup>-2</sup> during 7 days storage. For the low inoculum (1.3×10<sup>3</sup> cfu ml<sup>-1</sup>), levels that could only be detected by enrichment initially increased to 1.4×10<sup>2</sup> cfu cm<sup>-2</sup>.

13. Beuchat, L.R., *Pathogenic microorganisms associated with fresh produce*. J Food Prot, 1996. **59**: p. 204-216.
14. Beuchat, L.R. *Surface Decontamination of Fruits and Vegetables Eaten Raw: A Review of Food Safety Issues*. 1998 [cited; 42]. Available from: who/fsf/fos/98.2.
15. Beuchat, L.R., *Use of sanitizers in raw fruit and vegetable processing*, in *Minimal Processing in Food Preservation*, S.M. Alzamora, M.S. Tapia, and A. Lopez-Malo, Editors. 2000, Aspen Publ: Gaithersburg, MD. p. 63-78.

16. Beuchat, L.R., *Ecological factors influencing survival and growth of human pathogens on raw fruits and vegetables*. Microbes Infect, 2002.

Outbreaks of human infections associated with consumption of raw fruits and vegetables have occurred with increased frequency during the past decade. Factors contributing to this increase may include changes in agronomic and processing practices, an increase in per capita consumption of raw or minimally processed fruits and vegetables, increased international trade and distribution, and an increase in the number of immuno-compromised consumers. A general lack of efficacy of sanitizers in removing or killing pathogens on raw fruits and vegetables has been attributed, in part, to their inaccessibility to locations within structures and tissues that may harbor pathogens. Understanding the ecology of pathogens and naturally occurring microorganisms is essential before interventions for elimination or control of growth can be devised.

17. Beuchat, L.R., et al., *Standardization of a method to determine the efficacy of sanitizers in inactivating human pathogenic microorganisms on raw fruits and vegetables*. J Food Prot, 2001. **64**: p. 1079-1084.

The efficacy of sanitizers in killing human pathogenic microorganisms on a wide range of whole and fresh-cut fruits and vegetables has been studied extensively. Numerous challenge studies to determine the effects of storage conditions on survival and growth of pathogens on raw produce have also been reported. Results of these studies are often difficult to assess due to the lack of sufficient reporting of methodologies, or comparatively because of variations in procedures for preparing and applying inocula to produce, conditions for treatment and storage, and procedures for enumerating pathogens. There is a need for a standard method to accurately determine the presence and populations of pathogenic microorganisms on produce. The adoption of standard, well-characterized reference strains would benefit a comparative assessment of a basic method between laboratories. A single protocol will not be suitable for all fruits and vegetables. Modifications of a basic method will be necessary to achieve maximum recovery of pathogens on various types of produce subjected to different sanitizer or storage treatments. This paper discusses parameters that must be considered in the course of developing a basic standard method against which these modifications could be made.

18. Beuchat, L.R., et al., *Standardization of a Method to Determine the Efficacy of Sanitizers in Inactivating Human Pathogenic Microorganisms on Raw Fruits and Vegetables*1. 2003. p. 174-178.

19. Beuchat, L.R., et al., *Development of a proposed standard method for assessing the efficacy of fresh produce sanitizers*. J Food Prot, 2001. **64**: p. 1103-1109.

A series of studies was done for the purpose of developing a proposed standard method to evaluate point-of-use home sanitizers for fresh produce. Preliminary experiments were done to determine the survival of Escherichia coli O157:H7, Salmonella, and Listeria monocytogenes after inoculation onto the surface of ripe

tomatoes and drying for up to 24 h at 22 +/- 2 degrees C. Within 2 h, the initial population (6.88 log<sub>10</sub> CFU/tomato) of *E. coli* O157:H7 was reduced by approximately 3 log<sub>10</sub>, while reductions in similar initial populations of *Salmonella* and *L. monocytogenes* were approximately 1 and 0.6 log<sub>10</sub> CFU/tomato, respectively, after 40 min and 3 h. A pilot study evaluated treatment with 200 ppm free chlorine and a prototype Fit produce wash (Fit) for their efficacy in killing a five-serotype mixture of *Salmonella* or *L. monocytogenes* spot inoculated on tomatoes using the proposed inoculation and recovery procedures. Inoculated tomatoes were sprayed with chlorinated water, Fit, or sterile distilled water (control) and hand rubbed for 30 s. Each tomato was then placed in a plastic bag and rinsed with 200 ml of sterile water by vigorously agitating for 30 s to simulate a procedure consumers might use for sanitizing and rinsing produce in a home setting. Each tomato was transferred to a second bag, and 20 ml of sterile 0.1% peptone was added; tomatoes were rubbed by hand for 40 s. Populations of *Salmonella* or *L. monocytogenes* in the rinse water and the 0.1% peptone wash solution were determined. Treatment with 200 ppm chlorine and Fit resulted in > or = 3.07 and > 6.83 log<sub>10</sub> reductions, respectively, in *Salmonella*. Treatment with 200 ppm chlorine and Fit reduced the number of *L. monocytogenes* by > or = 3.33 and > or = 4.96 log<sub>10</sub> CFU/tomato, respectively. The proposed standard method for testing the efficacy of point-of-use produce sanitizers needs to be evaluated for reproducibility of results through a larger scale series of experiments.

20. Beuchat, L.R. and A.J. Scouten, *Factors affecting survival, growth, and retrieval of Salmonella Poona on intact and wounded cantaloupe rind and in stem scar tissue*. Food Microbiology, 2004. **21**(6): p. 683-694.

Studies were done to determine the survival and recovery of *Salmonella enterica* serotype Poona from cantaloupe rind as affected by environmental conditions between the time of contamination and analysis. Detection and enumeration of the pathogen as influenced by analytical methods were also investigated. Combinations of pre-enrichment broth (lactose broth or universal preenrichment broth), enrichment broth (Rappaport-Vassiliadis broth or tetrathionate broth), and selective agar medium (bismuth sulfite agar or xylose lysine desoxycholate agar) for detecting *S. Poona* on inoculated cantaloupes stored at 4°C for 7 days or 21°C for 3 days were equivalent in performance. The use of nalidixic acid resistance as a marker in *S. Poona* and nalidixic acid in media used to enhance detection or enumeration of the pathogen by inhibiting background micro-flora in sanitizer efficacy studies, for example, would not adversely affect its survival on or recovery from cantaloupes. Overall, the composition of the carrier (water or 5% horse serum, a high organic matrix) used to prepare inocula did not influence the number of *S. Poona* recovered from the intact rind surface, wounds in the surface, or the stem scar tissue. Regardless of inoculation site or composition of the carrier, populations on spot inoculated melons stored at 4°C remained constant between 2 and 24 h after inoculation. The pathogen grew within 24 h in wounds of spot- and dip-inoculated cantaloupes stored at 21°C and 37°C. The

addition of up to 1.0% Tween 80 to 0.1% peptone used to remove *S. Poona* from the rind surface did not adversely affect viability and may have enhanced detachment. Consideration of these observations is recommended when developing a method to test the efficacy of sanitizers in killing salmonellae on the rind surface of inoculated cantaloupes and to detect or enumerate salmonellae that may be natural contaminants.

21. Blostein, J., *An outbreak of Salmonella javiana associated with consumption of watermelon*. J Environ Health, 1993. **56(1)**: p. 29-31.

Foodborne salmonellosis outbreaks associated with fruits or other produce are rare. Less than two percent of more than 340 salmonellosis outbreak reports to the Centers for Disease Control and Prevention (CDC) from 1983 to 1987 implicated fruits or vegetables as a vehicle of transmission (1). Watermelons in particular are an unusual vehicle; in a recent review, the U.S. Food and Drug Administration (FDA) found only three published reports of salmonellosis outbreaks associated with watermelons in the past 40 years (2). The following report describes a recent outbreak in which watermelon was implicated epidemiologically and microbiologically.

22. Bowen, A., et al., *Infections associated with cantaloupe consumption: a public health concern*. Epidemiol Infect, 2006. **134(4)**: p. 675-85.

Fresh produce is an important part of a healthy diet and is consumed in greater quantity in the United States than ever before. Consumption of cantaloupe has recently been associated with several large outbreaks of infections in North America, highlighting the need for a better understanding of practices and processes that may contribute to contamination. We reviewed all cantaloupe-associated outbreaks that were reported to the Centers for Disease Control and Prevention (CDC) and published in the literature. Twenty-three outbreaks occurred between 1984 and 2002; 1434 people became ill, 42 were hospitalized, and two died in these outbreaks. Aetiological agents in the outbreaks included five serotypes of *Salmonella enterica*, *Campylobacter jejuni*, *Escherichia coli* O157:H7, and norovirus. We reviewed processes contributing to cantaloupe contamination, conditions affecting survival and growth of bacterial pathogens on melons, and potential methods for sanitization. For maximum safety, industry, federal, and international partners must collaborate to ensure that appropriate interventions are in place to minimize the risk of contamination and prevent the growth of pathogens during cantaloupe production, processing, storage, and preparation.

23. Brackett, R.E., *Incidence, contributing factors, and control of bacterial pathogens in produce*. Postharvest Biology and Technology, 1999. **15(3)**: p. 305-311.

The importance of bacterial pathogens in the transmission of foodborne illness has become apparent in recent years. Several large, well-publicized outbreaks of

foodborne illness have been linked to cantaloupe, tomatoes, lettuce, alfalfa sprouts, and both apple and orange juices. In addition, numerous other smaller scale outbreaks linked to these and other commodities have also been reported. Although contributing factors have not been determined in all cases, several notable causes have been proposed. In particular, cross contamination with fecal matter of both domestic as well as wild animals have been suggested. In addition, contact with contaminated water has also been identified as a source of contamination. However, the use of untreated manure or sewage, lack of field sanitation, poorly or unsanitized transportation vehicles, and contamination by handlers are also suggested as potential contributing factors. Control of foodborne pathogens in produce must begin before produce is even planted by avoiding fields which have been subjected to flooding, on which animals have been recently grazed, or have otherwise been contaminated with manure. After planting, only clean potable water should be used for irrigation and harvesting equipment should be thoroughly cleaned and sanitized. Both field workers and packinghouse and processing plant personnel should be instructed in proper personal hygiene and provided with adequate sanitary and handwashing facilities. Vehicles transporting finished products should be sanitized, properly loaded to provide adequate air circulation, and maintained at proper temperatures. Likewise, retail display cases must be kept clean and at proper refrigeration temperatures. Finally, consumers should be informed as to proper handling of produce, particularly in the case of new generation products such as modified atmosphere packaged produce.

24. Bradford, M.A., T.J. Humphrey, and H.M. Lappin-Scott, *The cross-contamination and survival of Salmonella enteritidis PT4 on sterile and non-sterile foodstuffs*. Letters in Applied Microbiology, 1997. **24(4)**: p. 261-264.

The ability of two strains of *Salmonella enteritidis* PT4 to cross-contaminate from inoculated egg droplets on surfaces onto melon or beef (sterile or non-sterile) was investigated. When the foods were placed on these surfaces where egg droplets were still wet, cross-contamination occurred within 1 s onto every piece of food. It took at least 1 min for all the food pieces to be contaminated when egg droplets had been allowed to dry. Both strains were capable of rapid growth on melon and beef (sterile or non-sterile) at 20°C, but growth rates on beef appeared to be slowed by pre-exposure to either 4 or -18°C.

25. Bradley, M.L., et al., *The localization and persistence of bacterial and viral contaminants on the surface of inoculated cantaloupe and their response to disinfection treatments [abstract]*, in *IAFP 88th Annual Meeting [Program and abstract book]; 2001 Aug 5-8; Minneapolis, MN*. 2001. p. p 54.
26. Burnett, A.B. and L.R. Beuchat, *Comparison of sample preparation methods for recovering Salmonella from raw fruits, vegetables, and herbs*. J Food Prot, 2001. **64**: p. 1459-1465.

Methods for preparing raw fruits, vegetables, and herbs for enrichment or direct plating to determine the presence and populations of pathogenic bacteria vary greatly. A study was done to compare three sample processing methods (washing in 0.1% peptone, stomaching and homogenizing) for their influence on recovery of Salmonella inoculated onto 26 types of raw produce. The mean numbers of Salmonella recovered from 10 fruits, 11 vegetables, and 5 herbs using all three processing methods were 7.17, 7.40, and 7.27 log<sub>10</sub> CFU/sample respectively. Considering all 26 types of produce and all processing methods, the number of Salmonella recovered ranged from 7.24 to 7.29 log<sub>10</sub> CFU/sample, with no significant differences attributable to a particular sample processing method. Mean percent recoveries of Salmonella from washed, stomached, and homogenized produce were 39.4, 44.7, and 42.4%, respectively. Mean percent recoveries from fruits, vegetables, and herbs, regardless of sample preparation method, were 41.7, 50.1, and 25.9%, respectively. The number of Salmonella recovered from stomached and homogenized produce, but not washed produce, with pH ≤ 4.53 was significantly less than the number recovered from produce with pH from 5.53 to 5.99, suggesting that the acidic environment in stomachates and homogenates was lethal to a portion of Salmonella. Reduced percent recoveries from herbs (pH 5.94 to 6.34) is attributed, in part, to antimicrobials released from plant cells during sample preparation. Overall, the type of processing method did not substantially affect the number of Salmonella recovered from the 26 types of raw produce representing a wide range of structural and morphological characteristics, composition, and pH. The influence of sample size, diluent composition, and processing time on efficiency of recovery of Salmonella and other pathogens needs to be evaluated before a method(s) for processing samples of raw produce can be recommended.

27. Burnett, S.L. and L.R. Beuchat, *Human pathogens associated with raw produce and unpasteurized juices, and some reasons related to difficulties in decontamination*. J Food Microbiol Biotechnol, 2001. **25**: p. 281-287.

The ability of public health agencies to identify, through enhanced epidemiologic and surveillance techniques, raw fruits, vegetables, and unpasteurized juices as probable sources of infectious microorganisms, has undoubtedly resulted in increased numbers of documented outbreaks. Changes in agronomic, harvesting, distribution, processing, and consumption patterns and practices have also likely contributed to this increase. The risk of illness associated with raw produce and unpasteurized produce products can be reduced by controlling or preventing contamination, or by removing or killing pathogenic microorganisms by washing or treating them with sanitizers. However, the hydrophobic cutin, diverse surface morphologies, and abrasions in the epidermis of fruits and vegetables limit the efficacy of these treatments.

28. Busta, F.F., Suslow, T.V., Parish, M.E., Beuchat, L.R., Farber, J.N., Garrett, E.H., and L.J. Harris. *The Use of Indicators and Surrogate Microorganisms for the Evaluation of Pathogens in Fresh and Fresh-Cut Produce*. 2003. p. 179-185.

Indicators and surrogate microorganisms may be used for evaluating safety of fresh or fresh-cut fruit and vegetable products by assessing or validating the effectiveness of microbial control measures. Although frequently used on an informal basis within a specific company, use of indicators is highly dependent upon microbiological criteria that are in place for the specific produce item or category. All the considerations that must be addressed in establishing microbiological criteria must also be in place if indicators are to be utilized in process verification. Sampling design, stringency, and statistical significance are critical to the evaluation of indicators or surrogates in the assurance of food safety. General ideal qualities of indicators and surrogates are valuable starting points when developing a safety program. The importance of selecting the significant target pathogen for the specific product, its source, handling practices, and distribution practices cannot be overemphasized. The same is true for selection of the indicator or surrogate to represent those pathogens. The extensive lists of considerations and procedures should be helpful when using indicators and surrogates with fresh and fresh-cut produce. The use and limitations of indicators and surrogates to determine or validate treatment effectiveness have been delineated. Challenges are identified for selection of an indicator or surrogate for the specific situation and conditions of an individual produce item, including growing, harvesting, processing, handling, storage, and packaging.

29. Caldwell, K.N., et al., *Ingestion of Salmonella enterica serotype Poona by a free-living nematode, Caenorhabditis elegans, and protection against inactivation by produce sanitizers*. Applied and Environmental Microbiology, 2003. **69**(7): p. 4103-4110.

Free-living nematodes are known to ingest food-borne pathogens and may serve as vectors to contaminate preharvest fruits and vegetables. *Caenorhabditis elegans* was selected as a model to study the effectiveness of sanitizers in killing *Salmonella enterica* serotype Poona ingested by free-living nematodes. Aqueous suspensions of adult worms that had fed on *S. enterica* serotype Poona were treated with produce sanitizers. Treatment with 20 µg of free chlorine/ml significantly ( $\alpha=0.05$ ) reduced the population of *S. enterica* serotype Poona compared to results for treating worms with water (control). However, there was no significant difference in the number of *S. enterica* serotype Poona cells surviving treatments with 20 to 500 µg of chlorine/ml, suggesting that reductions caused by treatment with 20 µg of chlorine/ml resulted from inactivation of *S. enterica* serotype Poona on the surface of *C. elegans* but not cells protected by the worm cuticle after ingestion. Treatment with Sanova (850 or 1200 µg/ml), an acidified sodium chlorite sanitizer, caused reductions of 5.74 and 6.34 log<sub>10</sub> CFU/worm, respectively, compared to reductions from treating worms with water. Treatment with 20 or 40 µg of Tsunami 200/ml, a peroxyacetic acid-based sanitizer, resulted in reductions of 4.83 and 5.34 log<sub>10</sub> CFU/worm, respectively, compared to numbers detected on or in worms treated with water. Among the

organic acids evaluated at a concentration of 2%, acetic acid was the least effective in killing *S. enterica* serotype Poona and lactic acid was the most effective. Treatment with up to 500 µg of chlorine/ml, 1% hydrogen peroxide, 2550 µg of Sanova/ml, 40 µg of Tsunami 200/ml, or 2% acetic, citric, or lactic acid had no effect on the viability or reproductive behavior of *C. elegans*. Treatments were also applied to cantaloupe rind and lettuce inoculated with *S. enterica* serotype Poona or *C. elegans* that had ingested *S. enterica* serotype Poona. Protection of ingested *S. enterica* serotype Poona against sanitizers applied to cantaloupe was not evident; however, ingestion afforded protection of the pathogen on lettuce. These results indicate that *S. enterica* serotype Poona ingested by *C. elegans* may be protected against treatment with chlorine and other sanitizers, although the basis for this protection remains unclear.

30. Caldwell, K.N., et al., *Attraction of a free-living nematode, Caenorhabditis elegans, to foodborne pathogenic bacteria and its potential as a vector of Salmonella Poona for preharvest contamination of cantaloupe*. Journal of Food Protection, 2003. **66**(11): p. 1964-1971.

*C. elegans* was studied to determine the potential role of free-living microbivorous nematodes as vectors for preharvest contamination of fruits and vegetables with foodborne pathogens. The propensity of *C. elegans* to be attracted to seven strains of *Escherichia coli* O157:H7 (932, 994, C7927, E0018, F4546, H1730, SEA13B88), eight serotypes of *Salmonella* (Baildon, Enteritidis, Michigan, Montevideo, Muenchen, Poona, Stanley, Typhimurium), six strains of *Listeria monocytogenes* (F8027, F8255, F8369, F8385, G1091, HO222), and cantaloupe juice was investigated. Twenty to 30 adult worms were placed on the surface of K agar midway between a 24-h bacterial colony and 10 µl of uninoculated tryptic soy broth (TSB) or cantaloupe juice positioned 1.5 cm apart. The numbers of nematodes that migrated to the colony, to the TSB, and to the cantaloupe juice within 5, 10, 15, and 20 minutes at 21°C were determined, and then the plates were incubated at 37°C for up to 7 days to determine the ability of *C. elegans* to survive and reproduce in bacterial colonies. The nematode was attracted to colonies of all test pathogens and survived and reproduced within colonies for up to 7 days. *C. elegans* was not attracted to cantaloupe juice. The potential of *C. elegans* to serve as a vector for the transport of *Salmonella* Poona to cantaloupe rinds was investigated. Adult worms that had been immersed in a suspension of *Salmonella* Poona were deposited 1 or 3 cm below the surface of soil on which a piece of cantaloupe rind was placed. The rind was analysed for the presence of *Salmonella* Poona after 1, 3, 7, and 10 days at 21°C. The presence of *Salmonella* Poona was evident more quickly on rinds positioned on soil beneath which *C. elegans* inoculated with *Salmonella* Poona was initially deposited than on rinds positioned on soil beneath which *Salmonella* Poona alone was deposited. The time required to detect *Salmonella* Poona on rinds was longer when the rind was placed 3 cm above the inoculum than when the rind was placed 1 cm above the inoculum. Free-living nematodes may play a role in the preharvest dispersal of incidental human pathogens in soil to the surfaces of

raw fruits and vegetables in contact with soil during development and maturation, as evidenced by the behaviour of *C. elegans* as a test model.

31. Castillo, A. and E.F. Escartin, *Survival of Campylobacter jejuni on sliced watermelon and papaya [a research note]*. J Food Prot, 1994. **57(2)**: p. 166-8.
32. Castillo, A., et al., *Salmonella contamination during production of cantaloupe: a binational study*. Journal of Food Protection, 2004. **67(4)**: p. 713-720.

Six cantaloupe farms and packing plants in South Texas (950 cantaloupe, 140 water, and 45 environmental samples), including the Rio Grande Valley area, and three farms in Colima State, Mexico (300 cantaloupe, 45 water, and 15 environmental samples), were sampled to evaluate cantaloupe contamination with *Salmonella* and *Escherichia coli* during production and processing. Samples collected from external surfaces of cantaloupes, water, and the environments of packing sheds on cantaloupe farms were examined for the presence of *Salmonella* and *E. coli*. Of a total of 1,735 samples collected, 31 (1.8%) tested positive for *Salmonella*. Fifteen *Salmonella* serotypes were isolated from samples collected in Texas, and nine from samples collected in Colima. Two serotypes (Poona and Oranienburg) that have been associated with three large *Salmonella* outbreaks in the United States and Canada linked to the consumption of contaminated cantaloupe were found in water samples collected at four farms (three from the United States). Susceptibility of *Salmonella* isolates to 10 antimicrobials was evaluated by disk diffusion. Eighty-eight percent of the isolates from the United States and Mexico were pan-susceptible to the antimicrobials tested; eight isolates from the United States demonstrated an intermediate susceptibility to streptomycin and only two isolates were resistant to the same antimicrobial. From Mexico, four isolates showed an intermediate susceptibility to streptomycin and one isolate was resistant to nalidixic acid and streptomycin. Repetitive sequence-based PCR analysis of *Salmonella* isolates helped to trace potential sources of *Salmonella* contamination in source water and in subsequent water samples obtained after the filtration systems of U.S. and Mexican cantaloupe farms. No differences could be seen between the levels of *Salmonella* contamination in melons from both countries.

33. CDC, *Salmonella oranienburg gastroenteritis associated with consumption of pre-cut watermelons-Illinois*. MMWR, 1979. **28**: p. 522-3.
34. CDC, *Epidemiologic notes and reports multistate outbreak of Salmonella poona infections - United States and Canada, 1991*. Mmwr, 1991. **40(32)**: p. 549-552.
35. CDC, *Surveillance for foodborne-disease outbreaks - United States, 1988-1992*. Mmwr, 1996. **45**: p. NoSS-5.
36. Cherry, J.P., *Improving the safety of fresh produce with antimicrobials*. Food Tech, 1999. **53(11)**: p. 54-59.
37. Del Rosario, B.A. and L.R. Beuchat, *Survival and growth of enterohemorrhagic Escherichia coli O157:H7 in cantaloupe and watermelon*. J Food Prot, 1995. **58**: p. 105-107.

The ability of *Escherichia coli* O157:H7 to survive and grow on cubes of cantaloupe and watermelon and on the external rind surface of these fruits was investigated. Populations of the pathogen increased on cubes stored at 25°C but remained constant at 5°C over a 34-h storage period. Growth was observed on the rind of melons stored under high relative humidity at 25°C for 14 to 22 days. The pathogen rapidly died on the rind surface of melons stored at 5°C

38. Draughon, A., et al., *Lethality of 5 mev e-beam to Staphylococcus, Salmonella and Listeria in sliced cantaloupe and tomato*, in *IAFP 88th Annual Meeting [Program and abstract book]*; 2001 Aug 5-8; Minneapolis, MN. 2001. p. p 101.
39. Escartin, E.F., A.C. Ayala, and J.S. Lozano, *Survival and growth of Salmonella and Shigella on sliced fresh fruit*. *J Food Prot*, 1989. **52**: p. 471-472.

The ability of five strains of enteropathogenic bacteria (*Shigella sonnei*, *S. flexneri*, *S. dysenteriae*, *Salmonella derby*, and *S. typhi*) to survive and grow on sliced jicama, papaya, and watermelon was investigated. Fruit portions were obtained aseptically and inoculated on the surface with washed suspensions of each microorganism. The test organisms survived, and in most cases increased in numbers when inoculated fruits were stored at room temperature (25-27 degrees C) for up to 6 h. Suspensions of papaya and watermelon in sterile distilled water supported growth of *S. sonnei* and *S. typhi*, respectively. Application of lemon juice to the surface of jicama and papaya reduced the count of *S. typhi* somewhat, but growth resumed after several hours. Practical recommendations are presented to control risks of contamination and subsequent growth of enteric pathogens on fruits and fruit salads during preparation and sale

40. Espinoza-Medina, I.E., et al., *PCR identification of Salmonella: potential contamination sources from production and postharvest handling of cantaloupes*. *J Food Prot*, 2006. **69**(6): p. 1422-5.

*Salmonella* is one of the most frequently reported etiological agents in outbreaks of foodborne diseases associated with the consumption of cantaloupes. Sensitive and reliable methods for detecting and identifying foodborne microorganisms are needed. The PCR can be used to amplify specific DNA fragments and thus to detect and identify pathogenic bacteria. In this study, a PCR method was used to evaluate the incidence of *Salmonella* at cantaloupe production, harvest, and packaging steps, and the results were compared with those of the standard method for detection of *Salmonella* in foods (Mexican NOM-114-SSA1-1994). *Salmonella* was detected by both standard and PCR methods in 23.5% of the irrigation water samples but only by the PCR method in 9.1% of the groundwater samples, 4.8% of the chlorinated water samples, 16.7% of samples from the hands of packing workers, 20.6% of samples from the packed cantaloupes, and 25.7% of samples from the in-field cantaloupes. With the standard method, *Salmonella* was found in 8.3% of the crop soil samples. Statistical analysis

indicated a significant difference in sensitivity ( $P < 0.05$ ) between the two methods; the PCR method was 4.3 times more sensitive than the standard method. *Salmonella* was found at seven of the eight points evaluated during the production and postharvest handling of cantaloupe melons.

41. Fan, X., et al., *Effect of Hot Water Surface Pasteurization of Whole Fruit on Shelf Life and Quality of Fresh-Cut Cantaloupe*. 2008. p. M91-M98.

Cantaloupes are associated with recent outbreaks of foodborne illnesses and recalls. Therefore, new approaches are needed for sanitization of whole and cut fruit. In the present study, whole cantaloupes were submerged into water in the following 3 conditions: 10 °C water for 20min (control), 20ppmchlorine at 10 °C for 20min, and 76 °C water for 3 min. Populations of microflora were measured on the rinds of the whole cantaloupes. Quality and microbial populations of fresh-cut cantaloupes prepared from whole fruit were analyzed after 1, 6, 8, 10, 13, 16, and 20 d of storage at 4 °C. The hot water significantly reduced both total plate count (TPC) and yeast and mold count on rind of whole fruits while chlorine or cold water wash did not result in a significant reduction of microbial population. Fresh-cut pieces prepared from hot water-treated cantaloupes had lower TPC than the other 2 treatments in the later storage periods (days 13 to 20) in 2 of 3 trials. The hot water treatment of whole fruits was inconsistent in reducing yeast and mold count of fresh-cut pieces. Soluble solids content, ascorbic acid content, fluid loss, and aroma and appearance scores were not consistently affected by either hot water or chlorine treatment. Our results suggested that hot water pasteurization of whole cantaloupes frequently resulted in lower TPCs of fresh-cut fruit during storage and did not negatively affect quality of fresh-cut cantaloupes.

42. Fan, X., et al., *Combination of hot-water surface pasteurization of whole fruit and low-dose gamma irradiation of fresh-cut cantaloupe*. *J Food Prot*, 2006. **69**(4): p. 912-9.

Improvements in methods for disinfecting fresh-cut cantaloupe could reduce spoilage losses and reduce the risk of foodborne illness from human pathogen contamination. The objective of this study was to investigate the feasibility of using hot-water treatment in combination with low-dose irradiation to reduce native microbial populations while maintaining the quality of fresh-cut cantaloupe. Whole cantaloupes were washed in tap water at 20 or 76 degrees C for 3 min. Fresh-cut cantaloupe cubes, prepared from the washed fruit, were then packaged in clamshell containers, and half the samples were exposed to 0.5 kGy of gamma radiation. Native microflora populations and sensory qualities were evaluated during the subsequent 7 days of storage at 4 degrees C. The hot-water surface pasteurization reduced the microflora population by 3.3 log on the surface of whole fruits, resulting in a lower microbial load on the fresh-cut cubes compared with cubes cut from fruit treated with cold water. Irradiation of cubes prepared from untreated fruit to an absorbed dose of 0.5 kGy achieved a low microbial load similar to that of cubes prepared from hot-water-treated fruit. The

combination of the two treatments was able to further reduce the microflora population. During storage, the headspace atmosphere of the packages was not significantly influenced by any of the treatments. Color, titratable acidity, pH, ascorbic acid, firmness, and drip loss were not consistently affected by treatment with irradiation, hot water, or the combination of the two. Cubes prepared from hot-water-treated whole fruit had slightly lower soluble solids content. The combination of hot-water pasteurization of whole cantaloupe and low-dose irradiation of packaged fresh-cut melon can reduce the population of native microflora while maintaining the quality of this product.

43. Farber, J.N., et al., *Microbiological Safety of Controlled and Modified Atmosphere Packaging of Fresh and Fresh-Cut Produce*. 2003. p. 142-160.
44. FDA. *Guide to minimize microbial food safety hazards for fresh fruits and vegetables*. 1998 [cited; Available from: <http://www.foodsafety.gov/~dms/prodguid.html>.
45. FDA. *FDA Survey of Imported Fresh Produce: FY 2000 Field Assignment*. 2001 [cited Jan 30, 2001]; Available from: <http://www.cfsan.fda.gov>.
46. FDA. *Survey of Domestic Fresh Produce: Interim Results (July 31, 2001)*. 2001 [cited; Available from: <http://www.cfsan.fda.gov>.
47. FDA-CFSAN and O.o.P.a.D.F.a. Beverages. *FDA survey of imported fresh produce: FY 2000 Field Assignment, January 30, 2001*. [cited; Available from: <http://vw.cfsan.fda.gov/~dms/prodsur6.html>.
48. Fredlund, H., et al., *Watermelon as a vehicle of transmission of Shigellosis*. *Scand J Infect Dis*, 1987. **19**: p. 219-21.

An epidemic of *Shigella sonnei* infection is described in which the only common source of infection was the ingestion of water-melon. Bacteriological studies demonstrated that *S. sonnei* bacteria injected into water-melons could multiply to infective doses. Therefore water-melons should not be excluded as a possible source of *S. sonnei* infection.

49. Gagliardi, J.V., et al., *On-farm and postharvest processing sources of bacterial contamination to melon rinds*. *Journal of Food Protection*, 2003. **66**(1): p. 82-87.

Multistate and international foodborne illness outbreaks, particularly involving melon (*Cucumis melo*) and often involving rare *Salmonella* spp., have increased dramatically over the past 13 years. This study assessed the sources and extent of melon rind contamination in production fields and at processing and packing facilities. In the spring of 1999, melon (cv. Cruiser) sampled from two sites in the Rio Grande River Valley (in Texas, USA) showed that postharvest-processed melon rinds often had greater plate counts of bacterial contaminants than field-fresh melons. Cantaloupe in the field had 2.5 to 3.5 log CFU/g rind total coliforms by aerobic plate counts, whereas washed melons had 4.0 to 5.0 log CFU/g. In the fall of 1999, coliforms on honeydew melons (cv. Honey Brew) ranged from 2.6 to 3.7 log CFU/g after processing, and total and faecal coliforms and enterococci never fell below 2.5 log CFU/g. A hydrocooler at another site

contaminated cantaloupe rinds with up to 3.4 log CFU/g total and faecal enterococci; a secondary rinse with chlorinated water incompletely removed these bacteria. Sources of coliforms and enterococci were at high levels in melon production soils, especially in furrows that were flood irrigated, in standing water at one field, and in irrigation water at both sites. At one processing facility, wash water pumped from the Rio Grande River may not have been sufficiently disinfected prior to use. Because soil, irrigation water, and process water were potential sources of bacterial contamination, monitoring and management on-farm and at processing and packing facilities should focus on water quality as an important control point for growers and packers to reduce bacterial contamination on melon rinds.

50. Garrett, E.H., et al., *Microbiological Safety of Fresh and Fresh-Cut Produce: Description of the Situation and Economic Impact*. 2003. p. 13-37.
51. Gayler, G.E., et al., *An outbreak of Salmonellosis traced to watermelon*. Public Health Reports, 1955. **70(3)**: p. 311-3.
52. Golden, D.A., E.J. Rhodehamel, and D.A. Kautter, *Growth of Salmonella spp in cantaloupe, watermelon, and honeydew melons*. J Food Prot, 1993. **56**: p. 194-196.

The ability of *Salmonella* spp. to grow on the interior tissues of cantaloupe, watermelon, and honeydew melons was investigated. Pieces of rind-free melons (pH 5.90-6.67) and tryptic soy broth (TSB, pH 5.90) were inoculated with a mixed culture (approximately 100 CFU/g or ml) containing equal proportions of five species of *Salmonella* (*S. anatum*, *S. chester*, *S. havana*, *S. poona*, and *S. senftenberg*). Inoculated melon pieces and TSB were incubated for 24 h at 5 or 23 degreesC. Viable populations of salmonellae were determined by surface plating test portions on Hektoen enteric agar. Results indicated that *Salmonella* growth was rapid and prolific on the melons and in TSB at 23 degrees C incubation. Final populations on watermelons were approximately 1.0 log<sub>10</sub> greater than populations on cantaloupe and honeydew and in TSB. Although viable *Salmonella* populations on melons and in TSB did not increase during the 24-h incubation at 5 degrees C, little or no decrease in viable populations was observed.

53. Hammack, T.S., et al., *Relative effectiveness of the Bacteriological Analytical Manual method for the recovery of Salmonella from whole cantaloupes and cantaloupe rinses with selected preenrichment media and rapid methods*. Journal of Food Protection, 2004. **67(5)**: p. 870-877.

Soak and rinse methods were compared for the recovery of *Salmonella* from whole cantaloupes. Cantaloupes were surface inoculated with *Salmonella* cell suspensions and stored for 4 days at 2 to 6degreesC. Cantaloupes were placed in sterile plastic bags with a nonselective preenrichment broth at a 1:1.5 cantaloupe weight-to-broth volume ratio. The cantaloupe broths were shaken for 5 minutes at 100 rpm after which 25-ml aliquots (rinse) were removed from the

bags. The 25-ml rinses were preenriched in 225-ml portions of the same uninoculated broth type at 35degreesC for 24 h (rinse method). The remaining cantaloupe broths were incubated at 35degreesC for 24 h (soak method). The pre-enrichment broths used were buffered peptone water (BPW), modified BPW, lactose (LAC) broth, and universal pre-enrichment (UP) broth. The Bacteriological Analytical Manual Salmonella culture method was compared with the following rapid methods: the TECRA Unique Salmonella method, the VIDAS ICS/SLM method and the VIDAS SLM method. The soak method detected significantly more Salmonella-positive cantaloupes ( $P < 0.05$ ) than the rinse method: 367 Salmonella-positive cantaloupes of 540 test cantaloupes by the soak method and 24 Salmonella-positive cantaloupes of 540 test cantaloupes by the rinse method were detected. Overall, BPW, LAC, and UP broths were equal with respect to the recovery of Salmonella from cantaloupes. Both the VIDAS ICS/SLM and TECRA Unique Salmonella methods detected significantly fewer Salmonella-positive cantaloupes than the culture method: the VIDAS ICS/SLM method detected 23 of 50 Salmonella-positive cantaloupes (60 tested) and the TECRA Unique Salmonella method detected 16 of 29 Salmonella-positive cantaloupes (60 tested). The VIDAS SLM and culture methods were equivalent: both methods detected 37 of 37 Salmonella-positive cantaloupes (60 tested).

54. Harris, L.J., et al., *Outbreaks Associated with Fresh Produce: Incidence, Growth, and Survival of Pathogens in Fresh and Fresh-Cut Produce*. 2003. p. 78-141.

An important consideration when addressing safety issues is the incidence of pathogens and outbreaks associated with particular food products. This chapter addresses outbreaks that have been associated with the consumption of fresh and fresh-cut produce. In addition, studies that investigate the incidence of pathogens and factors contributing to the survival and growth of pathogens are reviewed. Although they may not be exhaustive, the tables at the end of the chapter include highlights of incidence studies from industry and published literature sources (Tables I1-I7), outbreaks (Tables O1-O10), and growth/survival studies related to fresh produce (Tables G/S1 to G/S8).

55. Johnston, L.M., et al., A field study of the microbiological quality of fresh produce of domestic and Mexican origin *Int J Food Microbiol*, 2006. **112**(2): p. 83-95.

Produce is responsible for an increasingly larger proportion of foodborne disease outbreaks. In particular, the globalization of the food supply may introduce new food safety risks and allow widespread distribution of contaminated food, particularly produce. The objectives of this study were to: (i) compare the overall quality of domestic and Mexican produce throughout the packing process; (ii) examine changes in microbiological quality of both domestic and Mexican produce at each stage of production and processing; and (iii) evaluate the prevalence of select pathogens on fresh produce, including leafy green, herbs, melons, and vegetables. Furthermore, we also sought to characterize the antibiotic resistance profiles of *Enterococcus faecium* and *Enterococcus faecalis*

strains isolated from fresh produce. A total of 466 produce and matching environmental swab samples was collected from various locations in packing sheds in the southern US from November 2002 through December 2003. These samples were assayed by enumerative tests for total aerobic bacteria (APC), total coliforms, total Enterococcus, and *E. coli*. Produce samples were also analyzed for the presence of *Salmonella*, *Listeria monocytogenes*, *Shigella*, and *E. coli* O157:H7. A total of 112 *E. faecium* and *E. faecalis* isolates were further screened for antibiotic resistance using a panel of seventeen antibiotics. Overall, the microbiological quality of fresh produce ranged from 4.0 to 7.9 log(10) CFU/g (APC); less than 1.0 log(10) to 4.5 log(10) CFU/g (coliforms); less than 1.0 log(10) to 4.0 log(10) CFU/g (*E. coli*); and less than 1.0 log(10) to 5.4 log(10) CFU/g (Enterococcus). No *Salmonella*, *Shigella*, or *E. coli* O157:H7 were detected from the 466 25-g produce samples tested. However, three domestic cabbage samples were found to be positive for *L. monocytogenes*. Of the Enterococcus isolates, *E. faecium* had a higher degree of resistance to antibiotics in general, while Enterococcus spp. isolated from Mexican produce had a higher degree of antibiotic resistance when compared to strains isolated from produce samples of domestic origin. Despite increased attention to the role of imported produce in foodborne disease, this study does not support the assumption that domestic produce is of higher microbial quality than Mexican produce.

56. Kärenlampi, R. and M.L. Hänninen, *Survival of Campylobacter jejuni on various fresh produce*. International Journal of Food Microbiology, 2004. **97**(2): p. 187-195.

The survival of seven human and two chicken *Campylobacter jejuni* strains, with known Penner heat-stable (HS) serotypes and pulsed-field gel electrophoresis (PFGE) genotypes, was investigated on fresh-cut iceberg lettuce. In addition, the survival of four selected *C. jejuni* strains was assessed on cantaloupe pieces, cucumber slices, grated carrot and strawberries. Fresh produce was inoculated with 10<sup>5</sup> to 10<sup>7</sup> colony-forming units (CFU) of *C. jejuni* per gram, and the bacterium was enumerated using standard procedures after sample storage at 7 and 21 °C for 24, 48 and 72 h. The absolute values of the slopes (death rates) of the survival curves (log<sub>10</sub> CFU/g versus time) were calculated and compared. At 7 °C, the mean death rates (day<sup>-1</sup>) were 0.44 on cantaloupe, 0.41 on cucumber slices, 0.43 on grated carrot, 0.59 on iceberg lettuce and 1.02 on strawberries. The corresponding death rates (day<sup>-1</sup>) at 21 °C were 1.52, 1.55, 2.61, 1.39 and 8.74. The death rate of *C. jejuni* on strawberries (pH 3.4) was significantly ( $P < 0.05$ ) higher than on other produce. Moreover, the death rate at 21 °C as compared with 7 °C was significantly higher ( $P < 0.05$ ). Minor differences were observed in the survival of different *C. jejuni* strains. Our results suggest that after contamination of fresh produce, including strawberries, *C. jejuni* may survive sufficiently long to pose a risk to the consumer.

57. Kim, H., J.-H. Ryu, and L.R. Beuchat, *Survival of Enterobacter sakazakii on fresh produce as affected by temperature, and effectiveness of sanitizers for its elimination*. International Journal of Food Microbiology, 2006. **111**(2): p. 134-143.

A study was done to determine the survival characteristics of *Enterobacter sakazakii* on the surface of apples, cantaloupes, strawberries, lettuce, and tomatoes stored at 4, 12, and 25 °C for 8-28 days. Populations significantly decreased ( $p \leq 0.05$ ) on all test produce at all storage temperatures. The efficacy of chlorine, chlorine dioxide, and a peroxyacetic acid-based sanitizer (Tsunami 200®) treatments (1 and 5 min) in killing the bacterium on apples, tomatoes, and lettuce was determined. Chlorine and chlorine dioxide, at  $\geq 50$  [mu]g/ml, were equivalent in killing *E. sakazakii* on apples. Populations of *E. sakazakii* on apples treated with 10 [mu]g/ml chlorine dioxide for 1 or 5 min were significantly reduced ( $p \leq 0.05$ ) by 3.38 and 3.77 log CFU/apple, respectively, compared to the number remaining on apples after washing with water. Treatment with Tsunami 200 at 40 [mu]g/ml for 1 min caused reductions of  $\geq 4.00$  log CFU/apple. Reductions of  $\geq 3.70$  log CFU/tomato were achieved by treatment with 10 [mu]g/ml chlorine or chlorine dioxide or 40 [mu]g/ml Tsunami 200 for 5 min. Reductions in populations of *E. sakazakii* on lettuce treated with chlorine at 10, 50, and 100 [mu]g/ml for 1 min ranged from 1.61 to 2.50 log CFU/sample (26  $\pm$  4 g), compared to populations remaining on lettuce washed with water. Chlorine was less effective in killing *E. sakazakii* on lettuce than on apples or tomatoes. Treatment of lettuce with Tsunami 200 (40 and 80 [mu]g/ml) for 5 min caused a reduction of  $\geq 5.31$  log CFU/sample. Results provide insights to predicting survival characteristics of *E. sakazakii* on produce and the efficacy of sanitizers in killing the bacterium.

58. Larson, A.E. and E.A. Johnson, *Evaluation of botulinal toxin production in packaged fresh-cut cantaloupe and honeydew melons*. J Food Prot, 1999. **62**(8): p. 948-52.

The ability of *Clostridium botulinum* to produce toxin on cubed, packaged melons was investigated relative to microbial spoilage at various incubation temperatures and in different packaging systems. Freshly cut cubes (approximately 2.5 cm<sup>3</sup>) of cantaloupe and honeydew melons were surface inoculated with a 10 strain mixture of proteolytic and nonproteolytic spores of *C. botulinum* (10 to 15 cubes per package; approximately 100 total spores per package). To initially evaluate toxin production and spoilage in a passively modified atmosphere, melon cubes were loosely packaged in air in polyethylene pouches, sealed, and incubated at 7 or 15°C for up to 21 days. At various sampling intervals, samples were tested for headspace oxygen and carbon dioxide levels, pH, presence of botulinal toxin, aerobic and anaerobic plate counts, and counts of yeasts and molds. During incubation, headspace oxygen levels decreased, headspace carbon dioxide levels increased, aerobic and anaerobic plate counts increased, and the pH remained constant or decreased slightly. Botulinal toxin was not detected in any cantaloupe samples or in honeydew samples incubated at 7°C. Botulinal toxin

was detected in some honeydew samples at 15°C after 9 days of incubation, but the toxic honeydews were severely spoiled and considered organoleptically unacceptable. A similar second experiment was performed in which half of the melon cubes were treated with UV light to inactivate vegetative organisms before packaging, and these were incubated at 7, 15, or 27°C. In this second experiment, toxin production occurred in the UV-treated samples at 15°C with gross spoilage and at 27°C with only marginal spoilage. These data indicate that inhibition of spoilage organisms with UV light could result in botulinal toxin formation in packaged melons before overt spoilage.

59. Leverentz, B., et al., *Examination of bacteriophage as a biocontrol method for salmonella on fresh-cut fruit: a model study*. J Food Prot, 2001. **64**(8): p. 1116-21.

The preparation and distribution of fresh-cut produce is a rapidly developing industry that provides the consumer with convenient and nutritious food. However, fresh-cut fruits and vegetables may represent an increased food safety concern because of the absence or damage of peel and rind, which normally help reduce colonization of uncut produce with pathogenic bacteria. In this study, we found that *Salmonella* Enteritidis populations can (i) survive on fresh-cut melons and apples stored at 5 degrees C, (ii) increase up to 2 log units on fresh-cut fruits stored at 10 degrees C, and (iii) increase up to 5 log units at 20 degrees C during a storage period of 168 h. In addition, we examined the effect of lytic, *Salmonella*-specific phages on reducing *Salmonella* numbers in experimentally contaminated fresh-cut melons and apples stored at various temperatures. We found that the phage mixture reduced *Salmonella* populations by approximately 3.5 logs on honeydew melon slices stored at 5 and 10 degrees C and by approximately 2.5 logs on slices stored at 20 degrees C, which is greater than the maximal amount achieved using chemical sanitizers. However, the phages did not significantly reduce *Salmonella* populations on the apple slices at any of the three temperatures. The titer of the phage preparation remained relatively stable on melon slices, whereas on apple slices the titer decreased to non-detectable levels in 48 h at all temperatures tested. Inactivation of phages, possibly by the acidic pH of apple slices (pH 4.2 versus pH 5.8 for melon slices), may have contributed to their inability to reduce *Salmonella* contamination in the apple slices. Higher phage concentrations and/or the use of low-pH-tolerant phage mutants may be required to increase the efficacy of the phage treatment in reducing *Salmonella* contamination of fresh-cut produce with a low pH.

60. Leverentz, B., et al., *Biocontrol of Listeria monocytogenes on fresh-cut produce by treatment with lytic bacteriophages and a bacteriocin*. Applied and Environmental Microbiology, 2003. **69**(8): p. 4519-4526.

The fresh-cut produce industry has been the fastest-growing portion of the food retail market during the past 10 years, providing consumers with convenient and nutritious food. However, fresh-cut fruits and vegetables raise food safety concerns, because exposed tissue may be colonized more easily by pathogenic bacteria than intact produce. This is due to the higher availability of nutrients on

cut surfaces and the greater potential for contamination because of the increased amount of handling. We found that applied *Listeria monocytogenes* populations survived and increased only slightly on fresh-cut Red Delicious apples stored at 10°C but increased significantly on fresh-cut honeydew melons stored at 10°C over 7 days. In addition, we examined the effect of lytic, *L. monocytogenes*-specific phages via two phage application methods, spraying and pipetting, on *L. monocytogenes* populations in artificially contaminated fresh-cut melons and apples. The phage mixture reduced *L. monocytogenes* populations by 2.0 to 4.6 log units over the control on honeydew melons. On apples, the reduction was below 0.4 log units. In combination with nisin (a bacteriocin), the phage mixture reduced *L. monocytogenes* populations by up to 5.7 log units on honeydew melon slices and by up to 2.3 log units on apple slices compared to the control. Nisin alone reduced *L. monocytogenes* populations by up to 3.2 log units on honeydew melon slices and by up to 2.0 log units on apple slices compared to the control. The phage titre was stable on melon slices, but declined rapidly on apple slices. The spray application of the phage and phage plus nisin reduced the bacterial numbers at least as much as the pipette application. The effectiveness of the phage treatment also depended on the initial concentration of *L. monocytogenes*.

Survival of *Listeria monocytogenes* (strain LCDC 81-861 serotype 4b) populations applied to fresh-cut Red Delicious apples and fresh-cut honeydew melons stored at 10°C over 7 days was investigated. *L. monocytogenes* survived and increased only slightly on fresh-cut apples but increased significantly on fresh-cut honeydew melons. In addition, effects of lytic *L. monocytogenes*-specific phages (applied via spraying or pipetting) on *L. monocytogenes* populations in artificially contaminated fresh-cut melons and apples were examined. The phage mixture reduced *L. monocytogenes* populations by 2.0- 4.6 log units over the control on honeydew melons. On apples, the reduction was <0.4 log units. When applied in combination with nisin, the phage mixture reduced *L. monocytogenes* populations by <less than or equal to>5.7 log units on honeydew melon slices and by <less than or equal to>2.3 log units on apple slices compared to the control. Nisin alone reduced *L. monocytogenes* populations by <less than or equal to>3.2 log units on honeydew melon slices and by <less than or equal to>2.0 log units on apple slices compared to the control. The phage titre was stable on melon slices, but declined rapidly on apple slices. Spray application of the phage and phage + nisin reduced bacterial numbers by as much as the pipette application. Effectiveness of the phage treatment also depended on initial concn. of *L. monocytogenes*.

61. Leverentz, B., et al., *Optimizing concentration and timing of a phage spray application to reduce Listeria monocytogenes on honeydew melon tissue*. J Food Prot, 2004. **67**(8): p. 1682-6.

A phage cocktail was applied to honeydew melon pieces 1, 0.5, and 0 h before contamination with *Listeria monocytogenes* strain LCDC 81-861 and 0.5, 1, 2, and 4 h after contamination. The phage application was most effective when applied 1, 0.5, or 0 h before contamination with *L. monocytogenes*, reducing pathogen populations by up to 6.8 log units after 7 days of storage. This indicates that under commercial conditions, if contamination occurs at the time of cutting, phage would have to be applied as soon as possible after cutting the produce. However, all phage applications from 1 h before to 4 h after contamination and all phage concentrations ranging from 10(4) to 10(8) PFU/ml reduced bacterial populations on honeydew melon pieces. Higher phage concentrations were more effective in reducing pathogen populations. A phage concentration of approximately 10(8) PFU/ml was necessary to reduce the pathogen populations to non-detectable levels immediately after treatment, and pathogen growth was suppressed by phage concentrations of 10(6) through 10(8) throughout the storage period of 7 days at 10 degrees C. In an attempt to enhance the effectiveness of the phage cocktail on low pH fruit, such as apples, the phage was applied in combination with MnCl<sub>2</sub>. This combination, however, did not enhance the effectiveness of the phage on apple tissue. The results from this study indicate that the effectiveness of the phage application on honeydew melon pieces can be optimized by using a phage concentration of at least 10(8) PFU/ml applied up to 1 h after processing of the honeydew melons.

62. Li-Cohen, A.E. and C.M. Bruhn, *Safety of consumer handling of fresh produce from the time of purchase to the plate: a comprehensive consumer survey*. J Food Prot, 2002. **65**(8): p. 1287-96.

A national mail survey focusing on consumer handling of fresh fruits and vegetables was conducted among 2,000 randomly selected households in the United States. The objective was to quantify consumer practices relating to the purchase, transport, storage, and preparation of fresh produce, with emphasis on practices that affect safety. Following an additional mailing procedure, a response rate of 33% was obtained. Six percent of the consumers responded that they seldom or never wash fresh produce, and more than 35% indicated that they do not wash their melons before preparation. Twenty-three percent of the respondents indicated placing their meat, poultry, and fish on a refrigerator shelf above other foods, and 9% do not place their produce at any specific location in the refrigerator. Almost half of the respondents indicated not always washing their hands before handling fresh produce. Ninety-seven percent of respondents reported that they always wash their food preparation surfaces after contact with meat products, yet 5% and 24% dry wipe or wash with water only, respectively. The results from this study suggest that women, lower-income households, people 65 years and older, and non-college graduates practice safer food handling methods than men, higher-income households, people younger than 65 years, and college or postcollege graduates. The survey findings suggest that consumer education materials should emphasize safe handling practices from purchase through consumption. Educational outreach should target specific

subpopulations, men, college graduates, higher-income households, and people younger than 65 years because of their higher frequency of unsafe handling and washing practices.

63. Madden, J.M., *Microbial pathogens in fresh produce - the regulatory perspective {Contains 1990/91 FDA survey results from cantaloupe}*. J Food Protection, 1992. **55**: p. 821-823.
64. Materon, L.A., *Survival of Escherichia coli O157:H7 applied to cantaloupes and the effectiveness of chlorinated water and lactic acid as disinfectants*. World Journal of Microbiology & Biotechnology, 2003. **19**(8): p. 867-873.

An initial survey of 4 packing houses indicated that bacterial and fungal populations on the surface of cantaloupes were significantly reduced by sanitizing procedures particularly on faecal coliforms. In this study, several combinations of disinfectants were tested in an attempt to obtain a more effective antimicrobial activity on aerobic bacteria, fungi and total coliforms. Efficacy of aqueous chlorine (200 mg/l) and lactic acid (1.5%) on inactivation of inoculated *Escherichia coli* O157:H7 on cantaloupe surfaces was investigated at 25 and 35°C and immersion times of 1 and 10 min. Max. log reductions were achieved with both sanitizing agents when the initial bacterial population of *E. coli* was 7.42 log cfu/cm<sup>2</sup>. A highly significant 7.2 log reduction ( $P < 0.01$ ) was obtained with a solution of lactic acid with and without Tergitol<sup>TM</sup> (0.3%) surfactant when cantaloupes were immersed for 10 min regardless of the temp. of the solution. Although the sanitizers caused substantial mortality, some bacterial cells remained attached at relatively low numbers on the fruit surface. It is suggested that there is need for the development of sanitizers more efficacious than Cl for total elimination of *E. coli* O157:H7 from the surface of cantaloupes.

65. Mohle-Boetani, J.C., et al., *An outbreak of Salmonella serogroup Saphra due to cantaloupes from Mexico*. J Infect Dis, 1999. **180**: p. 1361-1364.

An outbreak of *Salmonella* serogroup Saphra (*S. saphra*) infections was studied by laboratory-based surveillance, case-control and trace-back studies, and a survey of cantaloupe preparation practices. Twenty-four patients with *S. saphra* infections had illness onsets between 23 February and 15 May 1997; 75% were ≤6 years old; 23% were hospitalized. Case patients were more likely than controls to have consumed cantaloupe (88% vs. 45%; matched odds ratio [MOR], 15.5; 95% confidence interval [CI], 1.7–139) and pre-cut cantaloupe (59% vs. 19%; MOR, 14.5; 95% CI, 1.6–128). The trace-back study identified 1 growing region in Mexico as the source of cantaloupes for 95% of the patients who ate cantaloupes. Only 17% of case patients washed cantaloupes before cutting them. This outbreak is another example of gastrointestinal disease in the United States associated with imported contaminated produce. Consumers and retailers should wash cantaloupes before cutting them; there should be international efforts to ensure food safety.

66. Mosqueda-Melgar, J., R.M. Raybaudi-Massilia, and O. Martin-Belloso, *Influence of treatment time and pulse frequency on Salmonella Enteritidis, Escherichia coli and Listeria monocytogenes populations inoculated in melon and watermelon juices treated by pulsed electric fields*. Int J Food Microbiol, 2007. **117**(2): p. 192-200.

Consumption of unpasteurized melon and watermelon juices has caused several disease outbreaks by pathogenic microorganisms worldwide. Pulsed electric field (PEF) has been recognized as a technology that may inactivate those bacteria present in fluid food products at low temperatures. Hence, PEF treatment at 35 kV/cm, 4  $\mu$ s pulse duration in bipolar mode and square shape were applied on Salmonella Enteritidis, E. coli and L. monocytogenes populations inoculated in melon and watermelon juices without exceeding 40 degrees C outlet temperatures. Different levels of treatment time and pulse frequency were applied to evaluate their effects on these microorganisms. Treatment time was more influential than pulse frequency ( $P \leq 0.05$ ) on the PEF microbial reduction levels for both melon and watermelon juices. Populations of S. Enteritidis, E. coli and L. monocytogenes were experimentally reduced and validated in a single process up to  $3.71 \pm 0.17$ ,  $3.7 \pm 0.3$  and  $3.56 \pm 0.26$  log(10) units, respectively, in melon juice when 1440  $\mu$ s and 217 Hz were used; whereas reductions up to  $3.56 \pm 0.12$ ,  $3.6 \pm 0.4$  and  $3.41 \pm 0.13$  log(10) units of those microorganisms, respectively, were reached in watermelon juice treated for 1727  $\mu$ s at 188 Hz. Although PEF treatment reduced the populations of the three microorganisms, L. monocytogenes was more resistant to PEF than S. Enteritidis and E. coli in both juices when treated at the same processing conditions.

67. National Advisory Committee on Microbiological Criteria for Foods, *Microbiological safety evaluations and recommendations on fresh produce*. Food Control, 1999. **10**: p. 117-143.
68. Parish, M.E., Beuchat, L.R., Suslow, T.V., Harris, L.J., Garrett, E.H., Farber, J.N., and Busta, F.S. *Methods to Reduce/Eliminate Pathogens from Fresh and Fresh-Cut Produce*. 2003. p. 161-173.

In response to the current public health concerns with the microbiological safety of fresh and fresh-cut produce, researchers have investigated the efficiency of numerous physical, chemical, and biological methods for reducing the microbiological load of produce. This chapter focuses on this growing area of research with a particular emphasis on human pathogenic microorganisms; however, research related to mitigation treatment effects on nonpathogenic organisms is also included. There have been several reviews that address this topic and they are pointed out throughout the chapter; therefore, the focus here is on the latest and most significant research findings. A matrix (Table V-1) summarizing the characteristics of intervention methods is also included at the end of the chapter.

69. Park, C.M. and L.R. Beuchat, *Evaluation of sanitizers for killing Escherichia coli O157:H7, Salmonella, and naturally occurring microorganisms on cantaloupes, honeydew melons, and asparagus*. Dairy, Food and Environmental Sanitation, 1999. **19**: p. 842-847.
70. Parnell, T.L., L.J. Harris, and T.V. Suslow, *Reducing Salmonella on cantaloupes and honeydew melons using wash practices applicable to postharvest handling, foodservice, and consumer preparation*. Int J Food Microbiol, 2005. **99**(1): p. 59-70.

Washing conditions that included a soak or brush scrub were evaluated for removal of Salmonella from the surface of smooth (honeydew) or complex (cantaloupe) melon rinds. Melon rinds were spot-inoculated onto a 2.5 cm<sup>2</sup> area of rind (squares) with approximately 6.0 log(10) CFU/square of an avirulent nalidixic acid-resistant strain of Salmonella typhimurium. Melons were washed by immersion in 1500 ml of water or 200 ppm total chlorine and allowed to soak or were scrubbed over the entire melon surface with a sterile vegetable brush for 60 s. Inoculated sites, uninoculated sites ("next to" sites) that were adjacent to inoculated sites, and sites on the side of the melon opposite (remote sites) the inoculated site were excised and pummeled in a stomacher for 2 min prior to plating onto tryptic soy or bismuth sulfite agar supplemented with 50 microg/ml nalidixic acid. S. typhimurium was reduced on the rind of cantaloupe by 1.8 log CFU/melon after soaking for 60 s in 200 ppm total chlorine, which was significantly better than the 0.7 log CFU/melon achieved with soaking in water. For both water and 200 ppm total chlorine, scrubbing with a vegetable brush was shown to be significantly (0.9 log CFU/cantaloupe) more effective than soaking alone. When honeydew melons were soaked or scrubbed in water, reductions of 2.8 log CFU/melon or >4.6 log CFU/melon (four of five samples), respectively, were observed. However, when water treatments were used, the presence of Salmonella-positive "next to" and remote sites indicated that bacteria were spread from inoculated site on the rind to uninoculated sites either through the rinse water (40-70 CFU/ml of Salmonella) or scrub brush (400-500 CFU/brush). Transfer to other sites occurred more often with cantaloupe than honeydew melons. This transfer was eliminated when 200 ppm total chlorine was used. When 200 ppm total chlorine was used, Salmonella could not be detected in the water or on the scrub brush. For optimal microbial removal in food service and home settings, melons should be scrubbed with a clean brush under running water. However, to ensure the benefits of brushing, instructions for cleaning and sanitizing brushes must also be emphasized. For food service settings where concentration and pH can be adequately measured, the use of chlorinated water may provide additional benefit.

71. Penteado, A.L. and M.F.F. Leitão, *Growth of Salmonella Enteritidis in melon, watermelon and papaya pulp stored at different times and temperatures*. Food Control, 2004. **15**(5): p. 369-373.

The ability of *Salmonella* Enteritidis to grow on melon (*Cucumis melo*), watermelon (*Citrullus vulgaris*) and papaya (*Carica papaya*) pulp stored at different times and temperatures was investigated. Fruit pulp portions with an average pH of 5.87, 5.50 and 4.87 for melon, watermelon and papaya, respectively, were obtained aseptically, homogenized, weighed and inoculated with suspensions (approximately 102 CFU/g) of *Salmonella* Enteritidis. Viable populations of *Salmonella* were determined by the pour plate technique using of test portions on TSA agar. The test organism increased in numbers at all tested temperatures. The generation times for melon at 10, 20 and 30 °C were respectively 7.31, 1.69 and 0.69 h, for watermelon were 7.47, 1.60 and 0.51 h and for papaya 16.61, 1.74 and 0.66 h. The results showed that *Salmonella* Enteritidis can grow on low acid fruit pulp, and that refrigeration at 10 °C, although reducing the generation rate, does not inhibit its growth.

72. Penteadó, A.L. and M.F.F. Leitão, *Growth of Listeria monocytogenes in melon, watermelon and papaya pulps*. International Journal of Food Microbiology, 2004. **92**(1): p. 89-94.

Growth of *Listeria monocytogenes* in low-acid fruits (melon, watermelon and papaya) at different times of incubation and at temperatures of 10, 20 and 30 °C was studied. Fruit pulp portions with an average pH of 5.87, 5.50 and 4.87 for melon, watermelon and papaya, respectively, were obtained aseptically, homogenized, weighed and inoculated with suspensions (approximately 102 CFU/g) of *L. monocytogenes*. Generation times of 7.12, 13.03 and 15.05 h at 10 °C, 1.74, 2.17 and 6.42 h at 20 °C and 0.84, 1.00 and 1.16 h at 30 °C were obtained, respectively, for melon, watermelon and papaya. The results showed that *L. monocytogenes* grew in low-acid fruits at all tested temperatures, although growth was diminished, but not inhibited at 10 °C.

73. Richards, G.M. and L.R. Beuchat, *Attachment of Salmonella Poona to cantaloupe rind and stem scar tissues as affected by temperature of fruit and inoculum*. J Food Prot, 2004. **67**(7): p. 1359-64.

A negative temperature differential between fruits or vegetables and the water in which they are immersed theoretically enhances infiltration of water and any microorganisms it might contain into tissues. The effect of temperature differentials between cantaloupes and wash water, each at 4 and 30 degrees C, on changes in cantaloupe weight and populations of *Salmonella enterica* Poona recovered from rinds and stem scar tissues of Eastern and Western (shipper) types of cantaloupes was assessed. The percent weight increase in Western cantaloupes was significantly greater ( $P < \text{or} = 0.05$ ) than that in Eastern cantaloupes for all cantaloupe and inoculum temperature combinations. *Salmonella* Poona attachment to or infiltration of Eastern but not Western cantaloupe rind is enhanced when the fruit is at 4 degrees C, compared with 30 degrees C, regardless of the temperature of the immersion suspension. The number of *Salmonella* Poona cells recovered from rind tissue of Western

cantaloupes at 30 degrees C immersed in inoculum at 30 degrees C was significantly less ( $P < \text{ or } = 0.05$ ) than that recovered from rind tissues of cantaloupes at 4 or 30 degrees C that were immersed in inoculum at 4 degrees C. *Salmonella* Poona in immersion water can adhere to or infiltrate surface tissues of cantaloupes. The populations of *Salmonella* Poona recovered from stem scar tissues of Eastern and Western types of cantaloupes were not significantly ( $P > 0.05$ ) affected by cantaloupe and inoculum temperature combinations. Populations of cells adhering to or infiltrating various cantaloupe tissues is not dictated entirely by temperature differentials between fruits and immersion suspensions: rather, it also apparently is influenced by structures unique to surface tissues.

74. Richards, G.M. and L.R. Beuchat, *Infection of cantaloupe rind with Cladosporium cladosporioides and Penicillium expansum, and associated migration of Salmonella poona into edible tissues*. Int J Food Microbiol, 2005. **103**(1): p. 1-10.

A study was undertaken to determine if the growth of two phytopathogens, *Cladosporium cladosporioides* and *Penicillium expansum*, in wounds on cantaloupe rinds facilitates migration of *Salmonella poona* into subsurface mesocarp tissues. Wounded sites in cantaloupe rind were inoculated with *S. poona* only, *S. poona* and mold simultaneously, or mold followed by *S. poona* 3 days later. A cylindrical plug (ca. 3 cm diameter and 4 cm deep) of inoculated tissue extending from the rind surface into edible tissues was removed and cut transversely into four segments (0-1, 1-2, 2-3, and 3-4 cm) representing distances from the rind surface. Regardless of the type of inoculum or the time of storage subsequent to inoculation, the pH of the tissues was significantly higher ( $P < \text{ or } = 0.05$ ) as the distance from the rind surface increased. Test microorganisms and naturally occurring microorganisms on the rind surface which were introduced into internal tissues during wounding, as well as physiological changes in cantaloupe tissue, contributed to these changes. *C. cladosporioides* and *P. expansum* were recovered from the inoculated rind and underlying tissues throughout storage at 20 degrees C for 10 days. *S. poona* persisted and grew in wounds on rinds on inoculated cantaloupe incubated at 20 degrees C. Recovery of *S. poona* from tissues 3-4 cm below the inoculated wound supports the hypothesis that it can migrate from the site of inoculation into adjacent mesocarp tissues. Survival and migration of *S. poona* into the internal tissues of cantaloupes were enhanced by co-inoculation with *C. cladosporioides* and, to a lesser extent, *P. expansum*. Consumption of cantaloupes from which diseased tissue has been removed is not advisable because *S. poona* and perhaps other enteric pathogens may still be present in remaining tissues.

75. Richards, G.M. and L.R. Beuchat, *Metabiotic associations of molds and Salmonella Poona on intact and wounded cantaloupe rind*. Int J Food Microbiol, 2005. **97**(3): p. 327-39.

Salmonella Poona, a serotype rarely implicated in human infections, has recently caused several cantaloupe-associated outbreaks of salmonellosis. Metabiotic associations of molds and foodborne pathogens on produce have been reported. We tested proteolytic activity and measured changes in the pH of cantaloupe rind caused by growth of *Alternaria alternata*, *Cladosporium cladosporioides*, *Epicoccum nigrum*, *Geotrichum candidum*, and *Penicillium expansum*. Survival and growth characteristics of *Salmonella Poona* co-infected with each mold on the surface rind and in wounded rind tissue as affected by temperature were determined. *C. cladosporioides*, *G. candidum*, and *P. expansum*, but not *A. alternata* and *E. nigrum*, showed proteolytic activity on agar media containing gelatin and/or casein, with concurrent increases in pH, thus favoring survival and growth of salmonellae. Intact and mechanically wounded tissue of cantaloupe rinds were inoculated with a five-strain mixture of *S. Poona* and/or test mold. Five inoculation schemes were used: mold only, *S. Poona* only, mold and *S. Poona* simultaneously, mold then *S. Poona* 3 days later, and *S. Poona* then mold 3 days later. The pH of cantaloupe rinds inoculated with molds and stored at 20 degrees C for 14 days was significantly higher ( $P < \text{or} = 0.05$ ) than on day 0. Only the pH of rinds inoculated with *C. cladosporioides* or *G. candidum* was significantly higher ( $P < \text{or} = 0.05$ ) on day 21 than on day 0, when cantaloupes were stored at 4 degrees C. An initial population of *S. Poona* increased from 3.3 log(10) cfu/sample (ca. 7 cm<sup>2</sup>) of cantaloupe rind to populations as high as 9.5 log(10) cfu/sample during storage at 20 degrees C for up to 14 days, regardless of co-inoculation with molds. Populations of *S. Poona* decreased or remained constant at 4 degrees C for up to 21 days. Results demonstrate that persistence and growth of *S. Poona* on intact, wounded, and decaying cantaloupe rind are not markedly affected by the presence of molds.

76. Rodgers, S.L., et al., *A comparison of different chemical sanitizers for inactivating Escherichia coli O157:H7 and Listeria monocytogenes in solution and on apples, lettuce, strawberries, and cantaloupe*. *Journal of Food Protection*, 2004. **67**(4): p. 721-731.

Ozone (3 ppm), chlorine dioxide (3 and 5 ppm), chlorinated trisodium phosphate (100- and 200-ppm chlorine), and peroxyacetic acid (80 ppm) were assessed for reduction of *Escherichia coli* O157:H7 and *Listeria monocytogenes* in an aqueous model system and on inoculated produce. Initially, sanitizer solutions were inoculated to contain approximately 10<sup>6</sup> CFU/ml of either pathogen, after which aliquots were removed at 15-s intervals over a period of 5 min and appropriately plated to determine log reduction times. Produce was dip inoculated to contain approx. 10<sup>6</sup> *E. coli* O157:H7 or *L. monocytogenes* CFU/g, held overnight, submerged in each sanitizer solution for up to 5 min, and then examined for survivors. In the model system study, both pathogens decreased > 5 log following 2 to 5 min of exposure, with ozone being most effective (15 s), followed by chlorine dioxide (19 to 21 s), chlorinated trisodium phosphate (25 to 27 s), and peroxyacetic acid (70 to 75 s). On produce, ozone and chlorine dioxide (5 ppm) were most effective, reducing populations approx. 5.6 log, with

chlorine dioxide (3 ppm) and chlorinated trisodium phosphate (200 ppm chlorine) resulting in maximum reductions of approx.4.9 log. Peroxyacetic acid was the least effective sanitizer (approx.4.4-log reductions). After treatment, produce samples were stored at 4degreesC for 9 days and quantitatively examined for *E. coli* O157:H7, *L. monocytogenes*, mesophilic aerobic bacteria, yeasts, and moulds. Populations of both pathogens remained relatively unchanged, whereas numbers of mesophilic bacteria increased 2 to 3 log during storage. Final mold and yeast populations were significantly higher than initial counts for chlorine dioxide- and ozone-treated produce. Using the nonextended triangle test, whole apples exposed to chlorinated trisodium phosphate (200 ppm chlorine) and shredded lettuce exposed to peroxyacetic acid were statistically different from the other treated samples.

77. Saftner, R.A., et al., *Sanitary dips with calcium propionate, calcium chloride, or a calcium amino acid chelate maintain quality and shelf stability of fresh-cut honeydew chunks*. *Postharvest Biology and Technology*, 2003. **29**(3): p. 257-269.

Freshly cut honeydew chunks were dipped for 30 s in a solution containing 1.9 mM hypochlorous acid (ClO) without or with a 40 mM concentration of calcium (Ca) propionate, Ca amino acid chelate formulation (Ca chelate), calcium chloride (CaCl<sub>2</sub>), or not treated. Respiration and ethylene production rates, firmness, translucency, microbiological and sensory characteristics, surface colour, volatile abundance, and tissue calcium content were evaluated during 7 d at 10 °C. Nontreated samples developed the highest respiration and ethylene production rates during storage, followed by samples dipped in ClO, ClO+CaCl<sub>2</sub> or ClO+Ca chelate, and ClO+Ca propionate. Calcium salt and chelate treatments more than doubled tissue Ca content and inhibited changes in melon firmness, surface colour, and the development of tissue translucency during storage. Treatment with ClO alone increased tissue translucency development, but inhibited surface microbial development. Microbial development was higher on nontreated melon samples than on ClO+Ca propionate-treated samples. Total quality-associated volatile abundance increased throughout storage and was higher in ClO+Ca propionate-treated samples than in other treated and nontreated samples. No sensorial preference was observed by consumer panels among ClO-, ClO+Ca propionate-, or ClO+Ca chelate-treated samples. The results indicate that a sanitary dip with Ca is a better alternative to a sanitary dip alone for quality maintenance and shelf-life stability of fresh-cut honeydew melon tissue.

Effects of dipping in various Ca-containing solutions were investigated on the quality and shelf life of honeydew melon chunks. Freshly cut chunks were dipped in solutions of 1.9mM hypochlorous acid, either alone or containing 40mM CaCl<sub>2</sub>, 40mM of a Ca amino acid chelate formulation or 40mM calcium propionate for 30 s, after which the chunks were stored for 7 days at 10°C. Respiration and ethylene production rates were highest in untreated samples and

lowest in those dipped in calcium propionate. All Ca treatments led to >2x increases in the Ca contents of melon tissue and inhibited changes in surface colour, melon firmness and development of translucency. Dipping in calcium propionate solutions decreased microbial growth in comparison to untreated samples and led to higher levels of desirable flavour-related volatile compounds. Treatment with hypochlorous acid alone delayed microbial development, but led to increases in tissue translucency during storage. Sensory analysis did not reveal any significant differences in preference for melon chunks dipped in different solutions. It is concluded that addition of Ca to hypochlorous acid solutions improves the quality and shelf life of dipped melon chunks.

78. Sapers, G.M., et al., J Food Sci, 2001. **66**: p. 345-349. *Antimicrobial treatments for minimally processed cantaloupe melon*

Efficacy of decontamination treatments in reducing endogenous microbial populations on cantaloupe and in extending fresh-cut shelf-life were investigated. Composite rind plug samples were washed with water or solutions of sodium hypochlorite, H<sub>2</sub>O<sub>2</sub>, commercial detergent formulations containing dodecylbenzene sulfonic acid and phosphoric acid, or trisodium phosphate, and surviving microbial populations determined. Fresh-cut cubes were prepared aseptically from whole melons given similar treatments, and their visual appearance and bacterial population determined during storage at 4 °C. Population reductions on washed rind plugs were < 1 log with water, 1 to 2 logs with washing and sanitizing agents applied individually, and 3 logs with some sequential treatments with H<sub>2</sub>O<sub>2</sub>. H<sub>2</sub>O<sub>2</sub> applied at 50 °C was superior to other whole-melon treatments, yielding a fresh-cut shelf-life of > 2 weeks.

79. Sapers, G.M. and J.E. Sites, *Efficacy of 1% hydrogen peroxide wash in decontaminating apples and cantaloupe melons*. Journal of Food Science, 2003. **68**(5): p. 1793-1797.

Improved decontamination methods for fruits and vegetables contaminated with human pathogens are needed to reduce the risk of produce-related foodborne illness. The efficacy of 1% H<sub>2</sub>O<sub>2</sub> in decontaminating apples and cantaloupes containing *Escherichia coli* was investigated. Apples inoculated with *E. coli* (ATCC 25922) were washed with 1% H<sub>2</sub>O<sub>2</sub> at 20 or 40°C for 15 or 30 min. Population reductions approaching 3 logs were obtained with all treatments. Comparable reductions were obtained with apples inoculated with 3 strains of *E. coli* O157:H7, associated with cider outbreaks, and a 5-strain cocktail. The 1% H<sub>2</sub>O<sub>2</sub> treatment was not effective in treating cantaloupes inoculated with *E. coli* 766 (ATCC 9637; similar to *Salmonella* Poona). Treatment of apples with 1% H<sub>2</sub>O<sub>2</sub> was carried out successfully in a wet dump tank. It is concluded that application of 1% H<sub>2</sub>O<sub>2</sub> is an effective decontamination technique for *E. coli* infected apples, but that the same technique is less effective in cantaloupes.

80. Selma, M.V., et al., *Effect of gaseous ozone and hot water on microbial and sensory quality of cantaloupe and potential transference of Escherichia coli O157:H7 during cutting*. Food Microbiol, 2008. **25**(1): p. 162-8.

The effect of gaseous ozone and hot water, alone or in combination, on the sensory and microbial quality of cantaloupe melon was investigated. Escherichia coli O157:H7 transmission from the rind to edible melon flesh during cutting practices was also investigated. Four different treatments consisting of hot water (75 degrees C, 1min), gaseous ozone (10,000ppm, 30min), gaseous ozone supplied by carbon monoxide gas and the combination of hot water and gaseous ozone were evaluated. Sensory quality and growth evolution of aerobic mesophilic and psychrotrophic bacteria, coliforms and molds were studied. In general, hot water, gaseous ozone, and the combination of hot water and gaseous ozone were effective in reducing total microbial population. The combination of hot water and gaseous ozone was the most effective treatment to control microbial growth achieving 3.8, 5.1, 2.2 and 2.3log reductions for mesophilic and psychrotrophic bacteria, molds and coliforms, respectively. However no significant differences were observed between gaseous ozone and gaseous ozone supplied by with carbon monoxide gas. There was no evidence of damage in melons treated with hot water, ozone or their combination and they maintained initial texture and aroma. Therefore, the combination of hot water and gaseous ozone may be an efficient and promising treatment for controlling microbial growth and maintaining sensory quality of melons.

81. Selma, M.V., et al., *Reduction by gaseous ozone of Salmonella and microbial flora associated with fresh-cut cantaloupe*. Food Microbiology. In Press,

This research investigates the efficacy of gaseous ozone, applied under partial vacuum in a controlled reaction chamber, for the elimination of Salmonella inoculated on melon rind. The performance of high dose, short duration treatment with gaseous ozone, in this pilot system, on the microbial and sensory quality of fresh-cut cantaloupes was also evaluated. Gaseous ozone (10,000 ppm for 30 min under vacuum) reduced viable, recoverable Salmonella from inoculated physiologically mature non-ripe and ripe melons with a maximum reduction of 4.2 and 2.8 log CFU/rind-disk (12.6 cm<sup>2</sup>), respectively. The efficacy of ozone exposure was influenced by carrier matrix. Salmonella adhering to cantaloupe was more resistant to ozone treatment when suspended in skim-milk powder before aqueous inoculation to the rind. This indicated that organic matter interferes with the contact efficiency and resultant antimicrobial activity of gaseous ozone applied as a surface disinfectant. Conversely, in the absence of an organic carrier, Salmonella viability loss was greater on dry exocarp surfaces than in the wetted surfaces, during ozone treatment, achieving reductions of 2.8 and 1.4 initial log CFU/rind-disk, respectively. Gaseous ozone treatment of 5000 and 20,000 ppm for 30 min reduced total coliforms, Pseudomonas fluorescens, yeast and lactic acid bacteria recovery from fresh-cut cantaloupe. A dose Ct-value (concentration × exposure time) of 600,000 ppm min achieved maximal

log CFU/melon-cube reduction, under the test conditions. Finally, fresh-cut cantaloupe treated with gaseous ozone, maintained an acceptable visual quality, aroma and firmness during 7-day storage at 5 °C. Conclusions derived from this study illustrate that gaseous ozone is an effective option to risk reduction and spoilage control of fresh and fresh-cut melon. Moreover, depending on the timing of contamination and post-contamination conditions, rapid drying combined with gaseous ozone exposure may be successful as combined or sequential disinfection steps to minimize persistence of *Salmonella* on the surface of cantaloupe melons and transference during fresh-cut processing of home preparation. Based on these results, greater efficacy would be anticipated with mature but non-ripe melons while ripe tissues reduce the efficacy of these gaseous ozone treatments, potentially by oxidative reaction with soluble refractive solids.

82. Solomon, E.B., et al., *Thermal Inactivation of Salmonella on Cantaloupes Using Hot Water*. 2006. *Journal of Food Science* 71 (2) p. M25-M30.

The inactivation of *Salmonella* on cantaloupes using hot water was investigated. Whole melons, inoculated with a cocktail of *Salmonella* isolates, were subjected to thermal treatments of various lengths in water at 65 °C, 75 °C, and 85 °C. Treatment with water at 85 °C for 60 and 90 s resulted in reductions of up to 4.7 log colony forming units (CFU) per square centimeter of rind. However, the rind of melons treated at 85 °C for 90 s were noticeably softer than the rind of melons treated for 60 s. Thermal penetration profiles were measured and computer simulations were conducted to verify the effect of hot water treatment conditions on the internal temperatures of cantaloupe melons. Experimental and simulation data indicated that the internal temperature of melons treated with hot water did not increase rapidly compared with the rind temperature. Regardless of the process temperature used, the temperature of the edible flesh, 10 mm from the surface of the rind, remained at least 40 °C cooler than the surface temperature of cantaloupe melons. These results demonstrate the utility of hot water for the inactivation of *Salmonella* on cantaloupes and provide a framework to producers of fresh-cut melon for the potential use of hot water as an intervention treatment.

83. Stine, S.W., et al., *Effect of relative humidity on preharvest survival of bacterial and viral pathogens on the surface of cantaloupe, lettuce, and bell peppers*. *J Food Prot*, 2005. **68**(7): p. 1352-8.

The purpose of this study was to compare the effects of humidity on the preharvest survival of microbial pathogens on cantaloupe, lettuce, and bell peppers. An additional goal was to evaluate *Clostridium perfringens* as an indicator of fecal contamination on produce. The microorganisms used in this study included *Escherichia coli*, *E. coli* O157:H7, *Shigella sonnei*, *Salmonella enterica* subsp. *enterica*, *Clostridium perfringens*, hepatitis A virus (HAV), feline calicivirus (FCV), and coliphage PRD1. The study took place in a controlled environment chamber that allowed for the control of temperature (18 to 26

degrees C) and relative humidity. Survival rates under high (mean, 85.7 to 90.3%) and low (mean, 45.1 to 48.4%) relative humidity were compared. The surfaces of the edible portion of each plant were inoculated with the study microorganisms. Samples were collected throughout 2 weeks. More microorganisms survived significantly longer ( $P < 0.05$ ) on cantaloupe than on lettuce and bell peppers. The type of produce on which each organism experienced the highest inactivation rate tended to change with relative humidity. The survival of microorganisms on produce surfaces was not uniformly affected by relative humidity. Of the studied microorganisms, HAV, PRD1, and *C. perfringens* were found to have the lowest inactivation rates, whereas FCV and *E. coli* ATCC 25922 tended to become inactivated most rapidly. *C. perfringens* generally survived longer than all other bacteria and FCV in all experiments. This trend suggests that *C. perfringens* may be an acceptable indicator of bacterial contamination and survival in various environments and on different types of crops.

85. Suslow, T.V., *Production practices affecting the potential for persistent contamination of plants by microbial foodborne pathogens*, in *Phyllosphere Microbiology*, S.E. Lindow, Editor. 2001, APS Press: St Paul, MN. p. 234-248.
86. Suslow, T.V., et al., *Production Practices as Risk Factors in Microbial Food Safety of Fresh and Fresh-Cut Produce*. 2003. p. 38-77.
87. Suslow, T.V. 2004. Minimizing the risk of foodborne illness associated with cantaloupe production and handling in California: Overview of Industry Practices and Risk Assessment. CCAB. 24pp. <http://ucgaps.ucdavis.edu>
88. Tamplin, M., *Salmonella and cantaloupes*. Dairy, Food and Environmental Sanitation, 1997. **17**: p. 284-286.
89. Tauxe, R., et al., *Microbial hazards and emerging issues associated with produce: A preliminary report to the National Advisory Committee on Microbiologic Criteria for Foods*. J Food Prot, 1997. **60**: p. 1400-1408.
90. Ukuku, D.O., *Effect of hydrogen peroxide treatment on microbial quality and appearance of whole and fresh-cut melons contaminated with Salmonella spp.* Int J Food Microbiol, 2004. **95**(2): p. 137-46.

The efficacy of hydrogen peroxide treatment on the inactivation of *Salmonella* spp. inoculated on the external surface of cantaloupe and honeydew melon was investigated. *Salmonella* was inoculated onto whole cantaloupe and honeydew melon to a final concentration of 4.65 log(10) CFU/cm<sup>2</sup> and 3.13 log(10) CFU/g, respectively. Inoculated whole melons stored at 5 degrees C for up to 7 days were washed with water, 2.5% and 5% hydrogen peroxide at day 0 and 5.

Hydrogen peroxide (2.5% and 5%) treatments of whole melon for 5 min caused a 3 log(10) CFU/cm<sup>2</sup> reduction of the indigenous surface microflora and a 3.0 log(10) CFU/cm<sup>2</sup> reduction in *Salmonella* spp. on all melon surfaces. The efficacy of the hydrogen peroxide treatments was less when the interval between inoculation and treatment of cantaloupe exceeded 24 h. Unlike cantaloupe fresh-cut pieces, *Salmonella* was not recovered from fresh-cut pieces prepared from treated whole honeydew melon. Growth of *Salmonella* occurred in cantaloupe fresh-cut pieces stored at 10 or 20 degrees C, and by 2 weeks, levels reached approximately 1 log CFU/g. A rapid decline in appearance and overall acceptability was observed in fresh-cut pieces prepared from untreated whole cantaloupe. While *Salmonella* was recovered from fresh-cut pieces from and whole treated cantaloupe, sanitizing the surface of contaminated whole melons with hydrogen peroxide before and after cutting and storage of the fresh-cut pieces at 5 degrees C can enhance the microbial safety and acceptability rating for about 2 weeks after processing.

91. Ukuku, D.O., *Effect of sanitizing treatments on removal of bacteria from cantaloupe surface, and re-contamination with Salmonella*. Food Microbiology, 2006. **23**(3): p. 289-293.

There are many reports of disease due to consumption of cantaloupes contaminated at the surface with enteric pathogens. *Salmonella* is among the most frequently reported cause of foodborne outbreaks of gastroenteritis in the United States. Research was undertaken to determine the effects of sanitizer and hot water treatments on microbial populations on cantaloupe surfaces and to determine whether prior decontamination of melons by sanitizer treatment affects vulnerability to recontamination by *Salmonella*. Cantaloupes were sanitized with 200 ppm chlorine or 2.5% hydrogen peroxide solution for 2 min, or hot water (96 °C) for 2 min and were held at 5 °C for 24 h. Hot water treatments reduced the microbial populations on cantaloupe surface by 4.9 log reduction while H<sub>2</sub>O<sub>2</sub> or chlorine caused approximately 2.6 log unit reduction on cantaloupe surfaces. When sanitized or hot water treated whole cantaloupes were re-inoculated with *Salmonella*. Higher populations of *Salmonella* were recovered from sanitized cantaloupes than from the untreated controls; recovery was greater from hot water treated cantaloupes than from cantaloupes treated with chlorine or hydrogen peroxide. The results of this study clearly show that sanitized cantaloupes are susceptible to recontamination if exposed to a human bacterial pathogen during subsequent handling.

92. Ukuku, D.O., et al., *Use of hydrogen peroxide in combination with nisin, sodium lactate and citric acid for reducing transfer of bacterial pathogens from whole melon surfaces to fresh-cut pieces*. International Journal of Food Microbiology, 2005. **104**(2): p. 225-233.

Hydrogen peroxide (2.5%) alone or hydrogen peroxide (1%) in combination with nisin (25 [ $\mu$ ]g/ml), sodium lactate (1%), and citric acid (0.5%) (HPLNC) were investigated as potential sanitizers for reducing *Escherichia coli* O157:H7 or *Listeria monocytogenes* populations on whole cantaloupe and honeydew melons. Whole cantaloupes inoculated with *E. coli* O157:H7 and *L. monocytogenes* at 5.27 and 4.07 log<sub>10</sub> CFU/cm<sup>2</sup>, respectively, and whole honeydew melons inoculated with *E. coli* O157:H7 and *L. monocytogenes* at 3.45 and 3.05 log<sub>10</sub> CFU/cm<sup>2</sup>, respectively, were stored at 5 °C for 7 days. Antimicrobial washing treatments were applied to inoculated whole melons on days 0 or 7 of storage and surviving bacterial populations and the numbers transferred to fresh-cut pieces were determined. At days 0 and 7 treatment with HPLNC significantly ( $p < 0.05$ ) reduced the numbers of both pathogens, by 3 to 4 log CFU/cm<sup>2</sup> on both types of whole melon. Treatment with HPLNC was significantly ( $p < 0.05$ ) more effective than treatment with 2.5% hydrogen peroxide. While fresh-cut pieces prepared from stored whole melons were negative for the pathogens by both direct plating and by enrichment, fresh-cut pieces from cantaloupe melons treated with 2.5% hydrogen peroxide were positive for both pathogens and pieces from honeydew melons were positive for *E. coli* O157:H7. The native microflora on fresh-cut melons were also substantially reduced by HPLNC treatment of whole melons. The results suggest that HPLNC could be used to decontaminate whole melon surfaces and so improve the microbial safety and quality of fresh-cut melons.

93. Ukuku, D.O., X. Fan, and M.F. Kozempel, *Effect of vacuum-steam-vacuum treatment on microbial quality of whole and fresh-cut cantaloupe*. J Food Prot, 2006. **69**(7): p. 1623-9.

Minimally processed fruits and vegetables have a limited shelf life because of deterioration caused by spoilage microflora and physiological processes. Cutting may increase microbial spoilage of fruits through transfer of microflora on the outer surfaces to the interior tissue. The objectives of this study were to use the vacuum-steam-vacuum (VSV) process to reduce indigenous spoilage microflora on the surface of cantaloupes and to investigate the effects of such treatments on transfer of spoilage microflora from the cantaloupe surface to the fresh-cut melon during rind removal and cutting. Whole cantaloupes were treated in the VSV processor, and fresh-cut pieces prepared from treated and control samples were stored at 5 and 10 degrees C for up to 9 days. Presence and growth of mesophilic bacteria, yeasts and molds, and *Pseudomonas* spp. were determined in fresh-cut samples during storage. Texture and color (CIE L\*, a\*, and b\*) also were measured during storage. VSV treatment resulted in a 1.0-log reduction of aerobic mesophilic bacteria, a 2.0-log reduction of yeasts and molds, and a 1.5-log reduction of *Pseudomonas* spp. on cantaloupe surfaces. VSV treatment significantly reduced transfer of yeasts and molds and *Pseudomonas* spp. from whole cantaloupe surface to fresh-cut pieces during preparation ( $P < 0.05$ ). Texture and color of the fresh-cut pieces prepared from the VSV-treated whole melons were similar to those of the controls. The results of this study indicate

that the use of the VSV process to reduce the surface populations of yeasts and molds and *Pseudomonas* spp. on whole cantaloupes will reduce subsequent transfer of these microbes to fresh-cut pieces and enhance the microbial quality of the fresh-cut product.

94. Ukuku, D.O. and W. Fett, *Behavior of Listeria monocytogenes inoculated on cantaloupe surfaces and efficacy of washing treatments to reduce transfer from rind to fresh-cut pieces*. J Food Prot, 2002.

Attachment and survival of *Listeria monocytogenes* on external surfaces (rind) of inoculated cantaloupe, resistance of the surviving bacteria to chlorine or hydrogen peroxide treatments, transfer of the pathogen from unsanitized and sanitized rinds to fresh-cut tissues during cutting and growth, and survival of *L. monocytogenes* on fresh-cut pieces of cantaloupe were investigated. Surface treatment with 70% ethanol to reduce the native microflora on treated melon, followed by immersion in a four-strain cocktail of *L. monocytogenes* ( $10^8$  CFU/ml) for 10 min, deposited  $4.2 \log_{10}$  CFU/cm<sup>2</sup> and  $3.5 \log_{10}$  CFU/cm<sup>2</sup> of *L. monocytogenes* on treated and untreated cantaloupe rinds, respectively. *L. monocytogenes* survived on the treated or untreated cantaloupe rinds for up to 15 days during storage at 4 and 20°C, but populations declined by approximately 1 to 2  $\log_{10}$  CFU/cm<sup>2</sup>. Fresh-cut pieces prepared from inoculated whole cantaloupes stored at 4°C for 24 h after inoculation were positive for *L. monocytogenes*. Washing inoculated whole cantaloupes in solutions containing 1,000 ppm of chlorine or 5% hydrogen peroxide for 2 min at 1 to 15 days of storage at 4°C after inoculation resulted in a 2.0- to 3.5-log reduction in *L. monocytogenes* on the melon surface. Fresh-cut pieces prepared from the sanitized melons were negative for *L. monocytogenes*. After direct inoculation onto fresh-cut pieces, *L. monocytogenes* survived, but did not grow, during 15 days of storage at 4°C. Growth was evident by 4 h of storage at 8 and 20°C. It is concluded that sanitizing with chlorine or hydrogen peroxide has the potential to reduce or eliminate the transfer of *L. monocytogenes* on melon surfaces to fresh-cut pieces during cutting.

95. Ukuku, D.O. and W.F. Fett, *Relationship of cell surface charge and hydrophobicity to strength of attachment of bacteria to cantaloupe rind*. J. Food Protection, 2002. **65 (7)**: p. 1093-1099.

The cantaloupe melon has been associated with outbreaks of *Salmonella* infections. It is suspected that bacterial surface charge and hydrophobicity may affect bacterial attachment and complicate bacterial detachment from cantaloupe surfaces. In this study, surface charge and hydrophobicity of strains of *Salmonella*, *Escherichia coli* (O157:H7 and non-O157:H7) and *Listeria monocytogenes* were determined by electrostatic and hydrophobic interaction chromatography, respectively. Initial bacterial attachment to cantaloupe surfaces and the ability to resist removal by washing with water were then compared with their surface charge and hydrophobicity. Whole cantaloupes were submerged in

inocula containing individual strains or cocktails of Salmonella, E. coli and L. monocytogenes, either as a mixture of strains containing all 3 genera or as a mixture of strains belonging to a single genus, for 10 min. Inoculated cantaloupes were dried for 1 h in a biosafety cabinet and then stored for up to 7 days at 4 degree C. Inoculated melons were washed with water, and bacteria still attached to the melon surface, as well as those in the wash water, were enumerated. Initial bacterial attachment was highest for individual strains of E. coli and lowest for L. monocytogenes, but Salmonella exhibited the strongest attachment on days 0, 3 and 7. When mixed-genus cocktails were used, the relative degrees of attachment of the 3 genera were altered. The attachment of Salmonella strains was the strongest, but the attachment of E. coli was more extensive than that of L. monocytogenes on days 0, 3 and 7. There was a linear correlation between bacterial cell surface hydrophobicity ( $r^2 = 0.767$ ), negative charge ( $r^2 = 0.738$ ) and positive charge ( $r^2 = 0.724$ ) and the strength of bacterial attachment to cantaloupe surfaces.

96. Ukuku, D.O. and W.F. Fett, *Method of applying sanitizers and sample preparation affects recovery of native microflora and Salmonella on whole cantaloupe surfaces*. Journal of Food Protection, 2004. **67**(5): p. 999-1004.

Standardized methods for applying sanitizer treatments to cantaloupes and for recovering surviving native microflora or Salmonella on inoculated cantaloupe after sanitizing are lacking. Accordingly, the objectives of this study were to compare four methods for applying sanitizers (dipping, dipping with rotation, dipping with agitation, and dipping with rubbing) using 200 ppm of chlorine or 5% H<sub>2</sub>O<sub>2</sub>, two recovery methods (homogenization of rind plugs in a stomacher or blender), and five selective recovery media for Salmonella. Whole cantaloupes were submerged in a cocktail of five strains of Salmonella (each at approximately  $2 \times 10^8$  CFU/ml) for 10 min and allowed to dry for 1 h inside a biosafety cabinet and stored at 20 degrees C for approximately 23 h before sanitizing. The recovery of Salmonella from whole cantaloupe without sanitizing averaged 5.09 log CFU/cm<sup>2</sup> by blending and 4.30 log CFU/cm<sup>2</sup> by homogenization in a stomacher for the five selective agar media. Microbial populations (Salmonella or the indigenous aerobic mesophilic bacteria, gram-negative bacteria, lactic acid bacteria, Pseudomonas spp., and yeast and mold) were not significantly ( $P > 0.05$ ) reduced by treating with water regardless of the treatment method used. Sanitizing with chlorine or H<sub>2</sub>O<sub>2</sub> by dipping, with or without rotation for 2 min, also did not reduce microbial populations. However, populations of all classes of native microflora and Salmonella were significantly ( $P < 0.05$ ) reduced by sanitizer treatments (2 min) applied with agitation or by rubbing. In general, sanitizer treatments applied by rubbing resulted in greater log reductions (by up to 1.7 log unit) than for treatments applied with agitation. Populations of native microflora and Salmonella recovered from cantaloupe were higher (by up to 1.8 log unit) by blending compared to homogenization in a stomacher. In most instances, selective media used did not differ significantly ( $P > 0.05$ ) for recovery of Salmonella after washing treatments.

97. Ukuku, D.O. and W.F. Fett, *Effect of nisin in combination with EDTA, sodium lactate, and potassium sorbate for reducing Salmonella on whole and fresh-cut cantaloupe*. J Food Prot, 2004. **67**(10): p. 2143-50.

Nisin (50 microg/ml), EDTA (0.02 M, disodium salt), sodium lactate (NaL, 2%), and potassium sorbate (KS, 0.02%) were tested individually and in various combinations as sanitizer treatments for reducing Salmonella on whole and fresh-cut cantaloupe. Whole cantaloupe and fresh-cut pieces were inoculated with a five-strain cocktail of Salmonella to give 4.76 +/- 0.23 log CFU/cm<sup>2</sup> and 3.42 +/- 0.13 log CFU/g, respectively. Inoculated whole melons and fresh-cut pieces were stored at 5 degrees C for 7 days. Washing treatments were applied to inoculated whole melons at days 0, 3, and 7 of storage, and surviving bacterial populations were determined. The effect of the washing treatments on transfer of Salmonella to fresh-cut pieces prepared immediately after treatment was also determined. Directly inoculated fresh-cut pieces were treated at day 0, and surviving bacteria were enumerated at days 0, 3, and 7 of storage. The combination treatments of nisin-EDTA, nisin-NaL, nisin-KS, NaL-KS, and nisin-NaL-KS all resulted in reductions of approximately 3 log CFU/cm<sup>2</sup> at day 0 for whole melons. When tested alone, all compounds, along with water washes, were ineffective. After 3 and 7 days of storage, the five combination washing treatments were less effective, resulting in reductions of approximately 2 log CFU/cm<sup>2</sup>. None of the combination treatments completely eliminated transfer of pathogen survivors to fresh-cut pieces. The combination treatments nisin-NaL, nisin-KS, NaL-KS, and nisin-NaL-KS, but not nisin-EDTA, gave significant (P < 0.05) reductions of Salmonella directly inoculated onto fresh-cut pieces. Washing with nisin-NaL-KS was significantly (P < 0.05) more effective than the other three combination treatments, resulting in a reduction of 1.4 CFU/g. Inhibition by the four effective treatments carried over from day 0 through day 7 of storage, with no increase in the population of Salmonella on the stored fresh-cut pieces. Sensory evaluations indicated that treatment of fresh-cut pieces with nisin-NaL and NaL-KS, but not nisin-KS or nisin-NaL-KS, were acceptable in terms of appearance, odor, and overall acceptability. After the required regulatory approval, treatment of whole cantaloupe with nisin in combination with EDTA, NaL, KS, or NaL and KS and of fresh-cut pieces with nisin-NaL or NaL-KS could help ensure the microbiological safety of fresh-cut cantaloupe.

98. Ukuku, D.O., V. Pilizota, and G.M. Sapers, *Influence of washing treatment on native microflora and Escherichia coli population of inoculated cantaloupes*. J Food Safety, 2001. **21**: p. 31-47.

The influence of chlorine or hydrogen peroxide treatment on populations of Escherichia coli 25922 on the external surface of inoculated cantaloupe was investigated. Surface treatment with 70% EtOH, followed by immersion in 10<sup>8</sup> CFU/mL E. coli inoculum deposited an average of 4.4 log<sub>10</sub>CFU/cm<sup>2</sup> cell

population on the cantaloupe surface. The efficacy of washing inoculated cantaloupe was dependent on storage interval between inoculation and treatment. Dipping the cantaloupes in solutions containing 1000 mg/L chlorine or 5% peroxide for 5 min, within 24 h of inoculation, caused a 2 log<sub>10</sub> CFU/cm<sup>2</sup> reduction of the indigenous surface microflora and a 3–4.0 log<sub>10</sub> CFU/cm<sup>2</sup> reduction in *E. coli*. The efficacy was less when the interval between inoculation and treatment exceeded 24 h. Chlorine appeared to be a better antimicrobial agent than hydrogen peroxide against *F. coli* ATCC 25922 inoculated on cantaloupe surfaces while hydrogen peroxide was better in reducing surface microflora of cantaloupe.

99. Ukuku, D.O., V. Pilizota, and G.M. Sapers, *Bioluminescence ATP assay for estimating total plate counts of surface microflora of whole cantaloupe and determining efficacy of washing treatments*. *J Food Prot*, 2001. **64(6)**: p. 813-9.

The surface microflora of cantaloupes were estimated using a bioluminescence ATP assay, and results were compared to plate count data. Cantaloupes were treated as follows: (i) water washed, or (ii) washed in solutions of sodium hypochlorite (1,000 mg/liter) or hydrogen peroxide (5%) for 5 min. Bioluminescence ATP assay results showed differences in ATP level/cm<sup>2</sup> of cantaloupes dipped in chlorine or hydrogen peroxide solution; ATP levels in these washed samples were lower than in controls due to antimicrobial action of the treatments on the cantaloupe surface. Linear correlations were found between the bioluminescence ATP assay and aerobic plate counts of unwashed cantaloupe ( $r^2 = 0.995$ ) and those washed with water ( $r^2 = 0.990$ ) determined before storage. Lower correlations between the bioluminescence ATP assay and the aerobic plate counts were observed on cantaloupes stored for 120 h at 20°C ( $r^2 = 0.751$ ) than at 4°C ( $r^2 = 0.980$ ) without washing treatment. Lower correlation at 20°C may be the result of clusters or growth that occurred in chains. ATP levels of washed cantaloupes correlated well with bacterial plate counts ( $r^2 = 0.999$ ). A reliable minimum detectable threshold using the bioluminescence ATP assay was established at 3 log<sub>e</sub> fg/cm<sup>2</sup> corresponding to 4 log<sub>10</sub> CFU/cm<sup>2</sup>. Bioluminescence ATP assay is not recommended for washed samples where the microbial load is near or below the threshold. Therefore, the bioluminescence ATP assay will be recommended for quick estimation of total microbial load on cantaloupe surfaces where the population is expected to exceed this threshold. The assay can save the industry time by eliminating the required incubation required by the conventional methods.

100. Ukuku, D.O., V. Pilizota, and G.M. Sapers, *Effect of hot water and hydrogen peroxide treatments on survival of salmonella and microbial quality of whole and fresh-cut cantaloupe*. *J Food Prot*, 2004. **67(3)**: p. 432-7.

Cantaloupe melon has been associated with outbreaks of salmonellosis. Contamination might be introduced into the flesh from the rind by cutting or by contact of cut pieces with contaminated rinds. Our objectives were to investigate

the efficacy of hot water or hot 5% hydrogen peroxide treatments in reducing the population of native microflora and inoculated *Salmonella* on cantaloupe rind and transfer to fresh-cut tissue during cutting. Whole cantaloupes, inoculated with a cocktail of *Salmonella* serovars to give 4.6 log CFU/cm<sup>2</sup> and stored at 5 or 20 degrees C for up to 5 days, were treated with hot water (70 or 97 degrees C) or 5% hydrogen peroxide (70 degrees C) for 1 min at 0, 1, 3, or 5 days postinoculation. Aerobic mesophilic bacteria and yeast and mold on treated whole melon and fresh-cut pieces were significantly ( $P < 0.05$ ) reduced by all three treatments. Treatments with hot water (70 and 97 degrees C) caused a 2.0- and 3.4-log CFU/cm<sup>2</sup> reduction of *Salmonella* on whole cantaloupe surfaces irrespective of days of post-inoculation storage prior to treatment up to 5 days at 5 or 20 degrees C, respectively. Treatment with 5% hydrogen peroxide (70 degrees C) caused a 3.8-log CFU/cm<sup>2</sup> reduction of *Salmonella*. Fresh-cut pieces prepared from untreated inoculated melons and those treated with 70 degrees C hot water were positive for *Salmonella*. However, fresh-cut pieces prepared from inoculated whole melon dipped in water (97 degrees C) or hydrogen peroxide (70 degrees C) for 60 s were negative for *Salmonella*, as determined by dilution plating onto agar medium, but were positive after enrichment at days 3 and 5 of storage at 5 degrees C. The ability to detect *Salmonella* in fresh-cut pieces was dependent on the initial level of inoculation. The results of this study indicate that the use of hot water (97 degrees C) or heated hydrogen peroxide to reduce the population of *Salmonella* on contaminated whole cantaloupes will enhance the microbial safety of the fresh-cut product.

101. Ukuku, D.O. and G.M. Sapers, *Effect of Sanitizer Treatments on Salmonella stanley Attached to the Surface of Cantaloupe and Cell Transfer to Fresh-cut Tissues During Cutting Practices*. J Food Prot, 2001. **21**: p. 31-47.

The ability of *Salmonella* Stanley to attach and survive on cantaloupe surfaces, its in vivo response to chlorine or hydrogen peroxide treatments, and subsequent transfer to the interior tissue during cutting was investigated. Cantaloupes were immersed in an inoculum containing *Salmonella* Stanley ( $10^8$  CFU/ml) for 10 min and then stored at 4 or 20°C for up to 5 days. Periodically, the inoculated melons were washed with chlorine (1,000 ppm) or hydrogen peroxide (5%), and fresh-cut tissues were prepared. The incidence of *Salmonella* Stanley transfer from the rinds to the fresh-cut tissues during cutting practices was determined. A population of 3.8 log<sub>10</sub> CFU/cm<sup>2</sup> of *Salmonella* Stanley was recovered from the inoculated rinds. No significant ( $P < 0.05$ ) reduction of the attached *Salmonella* population was observed on cantaloupe surfaces stored at 4 or 20°C for up to 5 days, and the population was not reduced after washing with water. *Salmonella* Stanley was recovered in fresh-cut pieces prepared from inoculated whole cantaloupes with no sanitizer treatment. Washing with chlorine or hydrogen peroxide solutions was most effective immediately after inoculation, resulting in an approximate 3.0-log<sub>10</sub> CFU/cm<sup>2</sup> reduction, and the level of recovered *Salmonella* population transferred to fresh-cut samples was reduced to below detection. The effectiveness of both treatments diminished when inoculated

cantaloupes stored at 4 or 20°C for more than 3 days were analyzed, and the fresh-cut pieces prepared from such melons were Salmonella positive. *Salmonella* outgrowth occurred on inoculated fresh-cut cubes stored above 4°C.

102. Ukuku, D.O. and G.M. Sapers, *Effect of time before storage and storage temperature on survival of Salmonella inoculated on fresh-cut melons*. Food Microbiology, 2007. **24**(3): p. 288-295.

The effects of a waiting period at room temperature (~22 °C) before refrigerating fresh-cut watermelon, cantaloupe and honeydew pieces contaminated with Salmonella on survival of the inoculated pathogen were investigated. Whole cantaloupes, honeydew melons and watermelons were washed with water, and fresh-cut pieces from individual melons were prepared and inoculated with a five strain cocktail of Salmonella at 10<sup>5</sup> cfu/ml. Populations of aerobic mesophilic bacteria, yeast and mold and *Pseudomonas* spp. were higher for fresh-cut cantaloupe than for fresh-cut watermelon and honeydew immediately after preparation. Populations of Salmonella, aerobic mesophilic bacteria, yeast and mold and *Pseudomonas* spp. in fresh-cut melons left at room temperature for up to 5 h before refrigeration were significantly ( $P < 0.05$ ) higher than populations in fresh-cut melons stored at 5 °C immediately after preparation. Populations of Salmonella recovered in fresh-cut melon after inoculation with the cocktail of Salmonella strains averaged 2 log<sub>10</sub> cfu/g for all three types of melons. Populations in fresh-cut watermelon and honeydew pieces declined by 1 log when stored immediately at 5 °C for 12 days, while the populations in fresh-cut cantaloupe did not show significant ( $P > 0.05$ ) changes. Populations of Salmonella in fresh-cut melons stored immediately at 10 °C for 12 days increased significantly ( $P < 0.05$ ) from 2.0 to 3.0 log<sub>10</sub> cfu/g in watermelon, 1.9 to 3.0 log<sub>10</sub> cfu/g in honeydew and 2.0 to 3.6 log<sub>10</sub> cfu/g in cantaloupe pieces. Holding freshly prepared, contaminated fresh-cut melon pieces at 22 °C for 3 h or more prior to refrigerated storage would increase the chances of Salmonella proliferation, especially if the fresh-cut melons were subsequently stored at an abusive temperature.

103. Ukuku, D.O., G.M. Sapers, and W.F. Fett, *ATP bioluminescence assay for estimation of microbial populations of fresh-cut melon*. J Food Prot, 2005. **68**(11): p. 2427-32.

Estimation of microbial numbers in foods by conventional microbiological techniques takes days, so there is a need for faster methods that can give results in minutes. Research was undertaken to investigate the use of bioluminescent ATP determination and a firefly luciferase assay to estimate the initial population of aerobic mesophilic bacteria on fresh-cut melons immediately after preparation and during storage at 5 or 15 degrees C for up to 12 days. Populations of aerobic mesophilic bacteria on fresh-cut cantaloupe prepared immediately from unsanitized whole melons averaged 3.42 log CFU/g, corresponding to an ATP value of 5.40 log fg/g. Populations for fresh-cut honeydew prepared from

unsanitized whole melon averaged 1.97 log CFU/g, corresponding an ATP value of 3.94 log fg/g. Fresh-cut pieces prepared from cantaloupe or honeydew melons sanitized with either chlorine (200 ppm free chlorine) or hydrogen peroxide (2.5%) had similar ATP values: 3.1 log fg/g (corresponding to bacterial counts 1.7 log CFU/g) for cantaloupes and 2.6 log fg/g (corresponding to bacterial counts of 0.48 CFU/g) for fresh-cut honeydew. Positive linear correlations for ATP concentrations and microbial populations were found for fresh-cut cantaloupe ( $R^2 = 0.99$ ) and honeydew  $R^2 = 0.95$ ) during storage at 5 degrees C for up to 12 days. ATP values in fresh-cut melons inoculated with either aerobic mesophilic bacteria or yeast and mold were significantly higher ( $P < 0.05$ ) than control values and parallel total plate counts on plate count agar. Results of this study indicate that the bioluminescent ATP assay can be used to monitor total microbial populations on fresh-cut melon after preparation and during storage for quality control purposes to establish specific sell-by or consume-by dates.

104. Wang, H., et al., *Modeling of the effect of washing solution flow conditions on Escherichia coli O157:H7 population reduction on fruit surfaces*. J Food Prot, 2007. **70**(11): p. 2533-40.

Washing produce with sanitizing solutions is an important step in reducing microbial populations during postharvest handling. Little information exists regarding the effects of washing solution flow conditions on the efficacy of pathogen reduction during washing. This study was undertaken to investigate the effects of washing conditions such as flow velocity, agitation rate, and contact time on the reduction of *Escherichia coli* O157:H7 populations from the surfaces of cantaloupe rind and cut apples. Top surfaces of cylindrical samples were spot inoculated with *E. coli* O157:H7 and treated with peroxyacetic acid (POAA; 80 mg/liter) solution under different flow velocities and agitation rates and with different washing modes. Test results indicate that the reduction rate of *E. coli* O157:H7 increased with the increase in flow velocity and agitation rate under the testing conditions. In a 3-min treatment in the flow-through chamber, the *E. coli* O157:H7 count reduction on cantaloupe rind and cup apples reached 2.5 and 2.3 log CFU/cm<sup>2</sup>, respectively, when the flow velocity increased from 0.0 to 0.8 m/min. Agitation conducted at the bottom of the treatment chamber reduced the *E. coli* O157:H7 population on cut apples by 1.2 log CFU/cm<sup>2</sup> in 3 min, whereas in the treatment with the agitation over the top of the chamber, the survival count of *E. coli* O157:H7 was reduced by only 0.8 log CFU/cm<sup>2</sup>. The experimental data were used to fit four microbial reduction kinetic models. It was found that *E. coli* O157:H7 reduction from the fruit surfaces was best described by the Weibull model. These findings may be useful in designing produce wash systems for achieving enhanced pathogen reduction and improved produce quality and safety.