# CHLORINATION IN THE PRODUCTION AND POSTHARVEST HANDLING OF FRESH FRUITS AND VEGETABLES

Trevor Suslow
Extension Specialist Postharvest Pathology, Transportation & Distribution
University of California - Davis
Email tvsuslow@ucdavis.edu

Phone: 530-754-8313
Fax: 530-752-4554
http://vric.ucdavis.edu
http://postharvest.ucdavis.edu
http://ucgaps.ucdavis.edu

## TABLE OF CONTENTS

## Introduction

Disinfection by chlorination has had many applications in the propagation, production, harvest, postharvest handling, and marketing display of fresh fruits and vegetables for many decades (2, 4, 18, 24, 30, 39, 55). In the past, maintaining wash tank and flume concentrations of 3,000 µg/ml for tomatoes and 6,000 µg/ml for citrus were recommended to control decay (55). The primary uses of chlorine have been to inactivate or destroy pathogenic bacteria, fungi, viruses, cysts, and other propagules of microorganisms associated with seed, cuttings, irrigation water, farm or horticultural implements and equipment, contact surfaces, and human contact with fresh produce. Chlorination has been routinely used to treat postharvest cooling water, in postharvest treatments (i.e. calcium for firmness enhancement) and during rehydration at shipping destinations. Chlorine, primarily as sodium or calcium hypochlorite, has been an important part of a properly managed horticultural sanitation program for several decades. In conjunction with other disease and worker hygiene management programs, chlorination is generally very effective, comparatively inexpensive, immediately available, and may be implemented in operations of any size or scale of use. The Environmental Protection Agency is the federal body that has primary responsibility for governing the use of chlorine in the handling of raw fruits and vegetables which are consumed without processing (FDA controls them if they are to be canned, frozen, or otherwise processed).

The primary applications are intended to minimize the redistribution and transmission of pathogens from adhering soil, infested fruit or vegetable surfaces or debris to non-infested surfaces such as harvest and trimming cuts, or natural plant surface openings. Another critical use continues to be in water disinfection, primarily for harvest and postharvest handling and cooling.

In the past, very high rates of chlorine were often used because it was felt that no residue was left on produce at consumption (2, 14, 18, 39). It has since been well established that chlorine may incompletely oxidize organic materials to produce undesirable byproducts, such as chloroform ($CHCl_3$) or other trihalomethanes, that have known or suspected carcinogenic potential at high doses (40). At high pH, chlorine reacts with organic nitrogen-based materials to produce mildly toxic chloramines. From an U.S. regulatory perspective, the expressed view has been that the benefits of proper chlorination far outweigh concern for the potential presence of these byproducts. Concern for the potential hazards associated with chlorine reaction by-products and issues of wastewater disposal have heightened efforts to evaluate and register alternative water sanitation and surface disinfestation treatments for produce.

## Forms of Chlorine Used for Fresh Fruits and Vegetables

In the past, crop consultants and extension agents have recommended the use of household bleach or swimming pool formulations of sodium and calcium hypochlorite for growers and small-scale packing operations (39). In reality, this practice continues since these products are less expensive than formulations that are registered and have agricultural product use labels. Chlorinated water sanitation of field bins or totes as well as water used in field packing operations is often commercial household bleach. Legally, agricultural chlorine is commercially available in three forms that have been approved for use (registered) by the U.S. Environmental Protection Agency (EPA) and by individual states such as California (California Department of Pesticide Registration).

1) Chlorine gas ($Cl_2$) -- the least expensive but most demanding source of chlorine from a safety and monitoring standpoint. Generally restricted to use in very large operations, the use of chlorine gas requires automated, controlled injection systems with in-line pH monitoring. Chlorine gas reduces the pH of water to below 6.5. Chlorine gas is commonly used for situations were soil, plant debris, and decaying fruit or vegetables may enter early stages of washing and grading. Typically, individual packing or fresh-processing operations have multiple injection points from individual chlorine cylinders to maintain adequate levels in large volumes of water with potentially high chlorine demand from suspended inorganic and organic loads.

2) Calcium hypochlorite ($CaCl_2O_2$) -- the most common source of chlorine used for disinfection of produce and produce process water. Registered formulations are 65 percent or 68 percent active ingredient (a.i.). It is available as a granulated powder, compressed tablets, or large slow-release tablets. In dry storage, calcium hypochlorite is more stable than liquid sodium hypochlorite. Phytotoxicity (bleaching or burning) of produce can occur if calcium hypochlorite granules fail to dissolve in cool wash tank water or in a hydrocooler system. A "nurse-tank" of warm water is used to fully dissolve granules before adding them to cooling or wash water. Calcium hypochlorite, beyond disinfection benefits, is reported to improve the shelf-life and disease resistance of fruits and vegetables by adding calcium to the cell wall.

3) Sodium hypochlorite (NaOCl) -- the source of chlorine commonly used in small-scale operations. It is generally used in concentrations of 5.25 percent or 12.75 percent a.i. in liquid form, because the solid forms readily absorb water from air and release chlorine gas. Only registered formulations are approved for use on produce (household bleach is not a registered material for produce). Sodium hypochlorite is generally more expensive than other forms of chlorine due to the added shipping cost of the water-based formulations. Excess sodium build up from repeated applications of sodium hypochlorite to recirculating water may damage sensitive produce.

Chlorine Dioxide ($ClO_2$). A yellow to red gas with 2.5 times the oxidizing potential of chlorine gas, chlorine dioxide is explosive at concentrations above 10 percent a.i. or at temperatures above 130$^{o}$C (266$^{o}$F). On-site generation of chlorine dioxide is also available by combining both chlorine gas and sodium chlorite or sodium hypochlorite, hydrochloric acid, and sodium chlorite. As with chlorine gas, the safety hazards associated with the use of chlorine dioxide demand detailed attention to proper engineering controls to prevent or reduce exposure. Violent explosions can occur when chlorine dioxide comes into contact with ammonia compounds.

The disinfecting power of chlorine dioxide is relatively constant within a pH of 6 to 10. It is effective against most microbes at concentrations of 3 to 5 ppm in clean water. The need for on-site generation, specialized worker safety programs, and closed injection systems for containment of concentrate leakage and fumes from volatilization make chlorine dioxide relatively expensive for produce applications.

The examples of horticultural activities listed below in Table 1 are provided to define many of the potential lineage of applications of chlorination from seed to retail display.

Table 1. Uses of Chlorinated Disinfectants in Fresh Fruit and Vegetables from Production to Marketing

| TIMING | APPLICATION OR EXAMPLE | RATE (µG/ML) | PRIMARY TARGET MICROBE OR BENEFIT | IN USE |
|---|---|---|---|---|
| Seed | Soak<br>Soak with heated $H_2O$ | 200 to 2,000 | Seed-borne pathogen control (virus, bacteria, fungi) | Common |
| Cuttings/Slips | Spray<br>Soak | 20 to 40 | Bacteria, fungal spores | Limited |
| Cutting Implements | Dip<br>Spray | 25 to 100 | Bacteria, fungal spores, virus | Common |
| Grafting Implements | Dip<br>Spray | 25 to 100 | Bacteria, fungal spores, virus | Common |
| Automated Propagation | Potato seed-piece cutting blades | 50 to 100 | Bacteria | Limited |
| Transplant Production | Irrigation water | 1.0 to 2.5 | Bacteria, Pythium, Phytophthora, Colletotrichum spp. | Limited |
| Boot Dips<br>(walk-thru) | General disinfection | 25 to 50 | Soil borne fungi | No longer common |
| Hydroponic Culture | Irrigation, fertigation water. Nutrient Film Culture | 0.5 to 1.5 | Bacteria, Pythium, Phytophthora, Colletotrichum spp. | Limited |
| Drip Line Maintenance | Purge Injection | 50 to 150 acidified | Biofilm removal and prevention | Common |
| Pond Shocking | Impoundment treatment | Not available | Microbial elimination | Limited |
| Well Treatment | Purge treatment | 200 to 500 | Coliform elimination | Common |

| TIMING | APPLICATION OR EXAMPLE | RATE (μG/ML) | PRIMARY TARGET MICROBE OR BENEFIT | IN USE |
|---|---|---|---|---|
| Spray Tank Treatment | General sanitation | 50 to 150 | Biofilm removal and prevention | Limited |
| Field Equipment (discs, blades, tracks) | General sanitation | 50 to 100 with high pressure sprayer | Soil-borne pathogens | Limited |
| Harvest Totes | General sanitation | 50 to 150 | Bacteria, fungal spores | Common |
| Butt Spray | Celery, lettuce | 150 to 200 | Prevent bacterial rot and enzymatic browning | No longer common |
| Head Spray | Cauliflower | 50 to 100 with plastic over-wrap | Prevent floret browning (bacteria, fungi, and enzymatic browning from harvest damage) | Common |
| Drench Tanks | Wash water sanitation | 50 to 400 | Bacteria, fungal spores | Common |
| Dump Tanks and Flotation Tanks | Tomato, Pepper, Citrus, Apples, Pears | 50 to 400 | Bacteria, fungal spores surface microbial load reduction | Common |
| Flumes | Tomatoes, sweet potatoes | 150 to 200 with heat | Bacteria, fungal spores | Common |
| Wash Spray Bars | Wash water sanitation | 75 to 150 | Bacteria, surface microbial load reduction | Common |
| Glove Dips Boot Dips (Walk-Thru) | General sanitation for sorters and packers | 25 to 75 | Microbial elimination | Mostly replaced with iodine-based solutions |
| Ice Injection | Source ice disinfection | 25 to 50 | Coliform elimination, virus | Limited |
| Hydrocooler | Cooling water sanitation | 50 to 300 | Bacteria, surface microbial load reduction | Common |
| Calcium Pressure Infusion | Disinfection of $CaCl_2$ treatment water | 10 to 50 | Bacteria, fungi | Not common |
| Abrasive Peelers | Wash water sanitation | 50 to 200 | Bacteria, surface microbial load reduction | Common |
| Minimally Processed Vegetables | Wash and Cooling water sanitation | 50 to 200 | Bacteria, surface microbial load reduction | Common |
| Packing Line Sanitation | Conveyer belts, pads, diverters, shutes, etc. | Chlorinated foams or chlorinated water sprays (variable) | Biofilm prevention, general microbial reduction on contact surfaces | Limited |
| Misting Lines and Nozzles | Water sanitation Distribution centers, retail display | 5 to 10 | Biofilm prevention, Coliform elimination | Common |
| Retail Trim and Wash | Wash water sanitation | 25 to 50 | Bacteria, surface microbial load reduction | Not common |

**Production Applications:**

Seed Treatments

Disinfection of seed by soaking chlorinated water (often with heating) has been used for routine treatment of seed to reduce the potential for viral, bacterial, and fungal disease epidemics. Recently, in response to repeated outbreaks of *Salmonella* spp. and *Escherichia coli* O157:H7 on sprouted seeds, a protocol for the treatment of alfalfa seed with 20,000 µg/ml $Ca(OCl_2)$ was approved by the EPA and CDFA. This concentration was identified in a broad screen of seed disinfection treatments as most efficacious in achieving a 6-log reduction of combined external and internal contamination.

Irrigation and Fertigation

Chlorine is the treatment of irrigation water for control of plant pathogens such as *Phytophthora cinnamomi* (1, 25) and *P. capsisci* in mainlines, gated pipe, and drip lines. Chlorine is the treatment of trickle/drip irrigation lines to prevent bacterial slime and biofilm occlusion of emitters (1, 25). Chlorine is the treatment of "ebb and flow" or nutrient film culture (NFC) water in hydroponic production of vegetables to primarily control *Pythium* and *Phytophthora* root pathogens (16, 19, 22).

**Postharvest Applications**

Postharvest handling of many vegetables and fruits usually involves the use of flumes, water dump tanks, spray washers, or hydrocoolers. Most postharvest processes recirculate used water (called process water) to conserve water and energy. Dirt, organic matter, and disease causing pathogens can accumulate in process water during bin dumping, hydrocooling, and flume recirculation. Whereas chlorination of drinking water typically targets a free chlorine concentration of 1 to 2 µg/ml, dump tank, flume water, and hydrocooler reservoirs commonly attempt to maintain levels 10 to 25 times this rate.

Published research on postharvest efficacy and proper management of chlorination for specific fruits and vegetables has been largely focused on tomato ( 4, 5, 9, 24, 27, 39, 41, 44, 45, 49, 50), citrus (25, 30, 31), potato (3, 15), apple (12, 13, 14, 29, 43, 47), and pear (43, 48, 52, 53, 54, 55 ). Additional reports are available for avocado (1), carrots (2), yam (6, 34), sweet potatoes (17), strawberry (20, 21), peach (23), iceberg lettuce (10, 28), asparagus (33), cucumbers (37), peppers (46), sweet corn (2), celery (2), mushroom (56), and minimally processed fresh vegetables (10).

**Chlorination and Postharvest Food Safety**

The source and quality of water for postharvest operations is critical to control. Potable (suitable for human consumption) water should be used for all postharvest washing, grading, and cooling operations. Contaminated water used during postharvest operations can transmit diseases that decay the produce or adversely affect human health (43). Several incidents of food-borne illness associated with fresh produce (green onions, parsley, cilantro, melons, leaf lettuce) have been linked to unsanitary wash water or ice or used for cooling during transportation and distribution.

For both on-farm uses and postharvest handling, “shock” treatment by hyperchlorination of spring, creek, well, or impoundment water is often practiced. Water taken directly from rivers or holding ponds should not be used for postharvest washing or cooling without filtration and disinfection with chlorine. Some pathogens in surface water of concern to human safety are not easily killed by chlorination (i.e. *Cryptosporidium*, *Giardia*), even under optimal conditions, beginning with clean potable water is the best preventive step available. The effectiveness of other disinfectant options, such as ozonation of process water, is currently being evaluated against these chlorine-resistant microorganisms.

**Chlorine Demand and Fruit and Vegetable Handling**

Under typical harvest operations of many fruits and especially leafy vegetables adhering soil and organic debris can be a problem and greatly reduce disinfection efficiency. Vegetables, in particular, are often harvested on heavy ground after rainfall and may arrive at a packing facility with problematic volumes of soil on totes, bins, cartons, pallets, and the product itself. Chlorine is highly reactive with leaves, soil, and any plant or vegetable matter whenever oxygen is present. Each chemical reaction reduces the amount of active chlorine in the water. The chlorine demand of agricultural water sources is often far higher and more prone to rapid fluctuations than sources for drinking water. Changing chlorinated water frequently or filtering out organic matter and debris is essential for effective sanitation. Pre-washing harvest bins, palletized totes, pallet skids, and, if possible, very dirty produce can prolong the useful life of chlorinated cooling water. Removing field soil before sending bins or palletized loads of harvested crop into flotation tanks, chemical treatment showers, or hydrocoolers will greatly aide in pathogen inactivation, chlorine use efficiency, and minimize the production of chlorinated disinfection by-products.

The issue of disinfection by-products may be of particular concern for vegetables grown in organic or muck soils with a high humic fraction.

**Improving Chlorination Efficacy: Surfactants**

The efficacy of chlorination on water disinfection and microbial load reduction on product surfaces may be enhanced by the use of surfactants (44, 52, 53). Typically the extent of microbial population reduction on plant surfaces is limited to a 10 to 100 fold reduction, dependent on many factors (10). Water films that form on very small contours on plant surfaces may prevent the chlorinated water from directly contacting target microorganisms. To increase the penetration of hypochlorous acid into plant contours and natural openings, approved detergents are added to the process water reducing water surface tension and increasing the effectiveness of chlorination in some situations. Recently, further enhancement of disinfection has been achieved by using ultrasound equipment attached to wash tanks.

**Monitor, Control, and Documentation Practices**

Accurate monitoring, control and recording of disinfection procedures and performance are important components of a sound postharvest quality and safety program. Oxidation-Reduction Potential (ORP), measured in millivolts (mV), has recently been introduced to fresh produce packers and shippers as an easily standardized approach to water disinfection for harvest and postharvest handling. Operationally, much like a digital thermometer or pH probe, ORP sensors allow the easy monitoring, tracking, and automated maintenance of critical disinfectant levels in water systems that fits in well to a foundation of Good Agricultural Practices (GAPs) and the evolving agricultural equivalents of Hazard Analysis Critical Control Point (HACCP) programs (41).

Traditionally chlorine or hypochlorite have been monitored by qualitative assessments of ppm (parts per million) total and/or free available chlorine. Titration kits, or more commonly chemical impregnated paper strips, estimate the range of antimicrobial forms of chlorine (the most effective is hypochlorous acid or HOCl) in the water solution. There is no test kit that differentiates the more active HOCl from the far less active ionic form, hypochlorite ($OCl^{-}$).

Practical experience provides compelling concerns that proper process control and protocols are not always followed. Accurate chlorine estimation generally requires more detailed and time consuming procedures than many operators will commit. Since chlorine tests do not distinguish HOCl and $OCl^2$, it is also important to monitor and control the pH of the water system. The dynamic balance of the two forms of hypochlorite in water changes dramatically between pH 6.5 and 8.0. The faster acting antimicrobial form, HOCl, exists as 95 to 80% of the "free chlorine" detected with the paper test strips at pH 6.5 to 7.0. This level drops to less than 20% at pH higher than 8.0. Therefore, although a strong color reaction on the test paper or colorimetric kit is observed during monitoring, the effectiveness of the disinfectant is far less at high pH. This is particularly problematic for fruit and vegetable applications, which typically have, short contact times. Continuous flow systems employed without monitoring may apply unnecessary, undesirable, potentially unhealthy, or unlawful levels of disinfectant to water systems. Even when monitoring is practical, too often no record of disinfection potential of the water is kept.

## Advantages of Oxidation-Reduction Potential

Oxidation-Reduction Potential (ORP) offers many advantages to "real time" monitoring and recording of water disinfection potential, a critical water quality parameter. Improvements in probe design and continuous analog recording (paper strip or revolving chart) or computer-linked data input are available. Probes have been integrated to audible, visual and remote alarm systems to notify the operator of out-of-range operation. ORP is ideal for automated injection systems and can be combined with pH control injections to optimize performance. Hand-held devices are affordable and essential back up to cross-reference the operation of an in-line probe.

A primary advantage is that using ORP for water system monitoring provides the operator with a rapid and single-value assessment of the disinfection potential of water in a postharvest system. Research has shown that at an ORP value of 650 to 700 mV, spoilage bacteria and bacteria such *as E. coli* and *Salmonella* are killed within a few seconds. Spoilage yeast and the more sensitive type of spore-forming fungi are also killed at this level after a contact time of a few minutes or less.

Table 2. Chlorine Concentrations Commonly Used for Postharvest Sanitation of Fresh Produce

| **Vegetable** | **TAC[1] (µg/ml)** |
|---|---|
| Artichoke | 100-150 |
| Asparagus | 125-250 |
| Bell Peppers | 150-400 |
| Broccoli | 100-150 |
| Brussel Sprouts | 100-150 |
| Cabbage (shredded) | 100-150 |
| Carrots | 100-200 |
| Cauliflower | 100-150 |
| Celery | 100-150 |
| Sweet Corn | 75-100 |
| Chopped leafy greens | 100-150 |
| Cucumbers | 100-150 |
| Garlic (peeled) | 75-150 |
| Lettuce –Iceberg (whole, shredded) | 100-150 |
| Lettuce (Butterhead) | 100-150 |
| Lettuce (Romaine) | 100-150 |
| Melons (all types) | 100-150 |
| Mushrooms | 100-150 |
| Onions (green) | 100-150 |
| Peas (pod-type) | 50-100 |
| Peppers (chili or bell) | 250-400 |
| Potatoes (red or brown) | 200-300 |
| Potatoes (White) | 100-250 |
| Pumpkins | 100-200 |
| Radishes | 50-150 |
| Spinach | 75-150 |
| Sweet Potatoes | 100-150 |
| Squash (all types) | 75-100 |
| Tomatoes | 200-350 |
| Turnips | 100-200 |
| Yams | 100-200 |

1 – Total available chlorine

| **Fruit** | **TAC (µg/ml)** |
|---|---|
| Apples | 100-150 |
| Cherries | 75-100 |
| Grapefruit | 100-150 |
| Kiwi | 75-100 |
| Lemon | 40-75 |
| Oranges | 100-200 |
| Peaches, Nectarines & Plums | 75-150 |
| Pears | 200-300 |
| Prunes | 100-150 |

**Background Literature**

1. Alexander, G. P. (1983). "'Return to roguing' hygiene for avocado propagators." Orchardist of New Zealand **56**(8): 313-314.

2. Anon (1970). "Prolong produce freshness." Food Eng, **42**(1): 115-16.

3. Anon (1997). "Safety first." Potato Business World **5**(6): 13-14.

4. Bartz, J. A., R. E. Lill, et al. (1988). "Potential for postharvest disease in tomato fruit infiltrated with chlorinated water and Chlorination of asparagus hydrocooling water for the control of post-harvest decay organisms." Plant Dis, **12**(1): 9-13.

5. Bender, R. J., S. A. Sargent, et al. (1992). "Effect of tomato grade on incidence of decay during simulated shipping." Proc Fla State Hort Soc, **105**: 119-121.

6. Bikomo, M. R. (1994). "Influence of variety, maturity at harvest, chlorination, and packaging on cocoyam (Xanthosoma spp.) in storage." Acta Hortic, **380**: 478-482.

7. Blatchley, E. R., III (1994). "Disinfection and antimicrobial processes." Water Environ Res, **66**(4): 361-368.

8. Boyette, M. D., D. F. Ritchie, et al. (1993). "Chlorination and postharvest disease control." AG NC Agric Ext Serv.. pp. 414-416.

9. Boyette, M. D., D. F. Ritchie, et al. (1993). "Chlorination and postharvest disease control: Tomatoes." AG NC Agric Ext Serv. Raleigh : North Carolina Agricultural Extension Service,. Aug: 1-73.

10. Brackett, R.E. (1994). "Microbiological spoilage and pathogens in minimally processed refrigerated fruits and vegetables." in Minimally Processed Refrigerated Fruits and Vegetables. ed. R. C. Wiley. Chapman and Hall: New York. pp 269-312.

11. Chang, T. L., R. P. Streicher, et al. (1988). "The interaction of aqueous solutions of chlorine with malic acid, tartaric acid, and various fruit juices: A source of mutagens." Anal Letters **21**(11): 2049-2068.

12. Combrink, J. C. and C. J. Grobbelaar (1984). "Influence of temperature and chlorine treatments on post-harvest decay of apples caused by Mucor piriformis." Technical Communication, 0(192), South Africa Department of Agriculture and Water Supply, **No.** 192: 19-20.

13. Combrink, J. C. and C. J. Grobbelaar (1984). "Influence of temperature and chlorine treatments on post-harvest decay of apples caused by Mucor piriformis." Horticultural Science **No.1**: 19-20.

14. Combrink, J. C. and T. R. Visagie (1982). "Chlorination of dump tank water to reduce post-harvest rot in apples." Deciduous Fruit Grower **32**(pt. 2): 61-63, 66.

15. Combrink, N. J. J., K. P. Prinsloo, et al. (1974). "Improving the keeping quality of potatoes by sorting or chlorination of mechanically damaged tubers." Technical Communication, **No.** 125**,** Department of Agricultural Technical Services, South Africa, 3pp.

16. Cook, R. and K. Devine (1979). "Chlorine clean-up for NFT still risky." Grower **91**(8): 41.

17. Delate, K., J. K. Brecht, et al. (1985). "Impact of curing, film-wrapping and chlorination on the storability of boniato sweet potatoes." Proc Fla State Hort Soc, **98**: 187-189.

18. Endemann, G. E. F. (1969). "The chlorination of dump tanks." S Afr Citrus J, **422**(21): 23-24.

19. Ewart, J. M. and J. R. Chrimes (1980). "Effects of chlorine and ultra-violet light in disease control in NFT." Acta Horticulturae **No. 98**: 317-323.

20. Ferreira, M. D., J. A. Bartz, et al. (1996). "As assessment of the decay hazard associated with hydrocooling strawberries." Plant Dis, **80**(10): 1117-1122.

21. Ferreira, M. D., J. K. Brecht, et al. (1994). "Physiological responses of strawberry to film wrapping and precooling methods." Proc Ann Meet Fla State Hort Soc, 1995: **107**: 265-269.

22. Frink, C. R. and G. J. Bugbee (1987). "Response of potted plants and vegetable seedlings to chlorinated water." HortSci **22**(4): 581-583.

23. Ginting, C., E. I. Zehr, et al. (1996). "Inoculum sources and characterization of isolates of Gilbertella persicaria from peach fruit in South Carolina." Plant Dis, **80**(10): 1129-1134.

24. Goodin, P. L. (1977). "Chlorine for sick tomatoes (*Erwinia carotovora).*" Agri Res, **26**(4): 8-10.

25. Grech, N. M., R. T. Frean, et al. (1989). "UV Water Treatment an Alternative To Chlorination in Citrus and Sub-Tropical Fruit Nurseries." Citrus and Subtropical Fruit Journal: 22-23.

26. Grubinger, V. (1993). "Water chlorination for postharvest vegetable treatment." Grower, **93**(6): 4-5.

27. Grubinger, V., R. H. Segall, et al. (1993). Soft rot of tomatoes resulting from dump-tank and washer-water contamination and its control by chlorination." Grower U. of Conn.(Cooperative Extension Service)

28. Hagenmaier, R. D. and R. A. Baker (1997). "Low-dose irradiation of cut iceberg lettuce in modified atmosphere packaging." J Agric Food Chem, **45**(8): 2864-2868.

29. Hendrix, F. F., Jr. (1991). "Removal of sooty blotch and flyspeck from apple fruit with a chlorine dip." Plant Dis, **75**(7): 742-743.

30. Hough, A. and C. Kellerman (1971). "Chlorinating dump tanks for citrus." S Afr Citrus J, **445**(7): 9-10.

31. Kellerman, C. R. and K. C. McOnie (1969). "Dump tanks and decay." S Afr Citrus J **422**(17): 20-21.

32. Kim, Y. H. and R. Hensley (1997). "Effective control of chlorination and dechlorination at wastewater treatment plants using redox potential." Water Environ Res, **69**(5): 1008-1014.

33. Lill, R. E. and G. Laundon (1984). "Chlorination of asparagus hydrocooling water for the control of post-harvest decay organisms [Botrytis cinerea, Fusarium sambucinum var coerulleum, Fusarium oxysporum]." N Z J Exp Agric. **12**(1): 43-45.

34. Mbonomo, R. B., J. K. Brecht, et al. (1991). "Curing, wash water chlorination and packaging to improve the post-harvest quality of Xanthosoma cormels." Scientia Horticulturae **47**(1-2): 1-14.

35. Montano, A., A. H. Sanchez, et al. (1993). "Controlled fermentation of Spanish-type green olives." J Food Sci, **58**(4): 842-844.

36. Noval, C. (1989). "Bacterial diseases of Gramineae in Spain." Bulletin OEPP **19**(1): 131-135.

37. Ozcelik, F. and E. Ic (1996). "Controlled fermentation of cucumbers." Gida **21**(1): 49-53.

38. Pyle, B. H., S. C. Broadaway, et al. (1992). "Efficacy of copper and silver ions with iodine in the inactivation of Pseudomonas cepacia." J Appl Bacteriol, **72**(1): 71-79.

39. Rabin, J. (1986). "Pack tomatoes for higher profits - chlorinating packing shed wash water improves quality." American Vegetable Grower 34(8): 12.

40. Richardson, S. D., A. D. Thruston, Jr., et al. (1996). "Future use of chlorine, chlorine dioxide, and other chlorine alternatives." 140: 1082-1236.

41. Rushing, J. W., J. J. Angulo, et al. (1996). "Implementation of a HACCP program in a commercial fresh-market tomato packinghouse: a model for the industry." Dairy Food Environ Sanit **16**(9): 549-553.

42. Sadovski, A. Y. and A. Farber (1980). "Streptococcus faecalis and Streptococcus faecium in frozen vegetables. Incidence and survival after treatments commonly used at the vegetable freezing plants." J Food Saf, **2**(2): 59-73.

43. Sanderson, P. G. and R. A. Spotts (1995). "Postharvest decay of winter pear and apple fruit caused by species of Penicillium." Phytopathology, **85**(1): 103-110.

44. Segall (1968). "Reducing postharvest decay of tomatoes by adding a chlorine source and the surfactant Santormerse F85 to water in field washers." Fla State Hort Soc Proc, **81**: 212-214.

45. Segall, R. H. and A. Dow (1976). "Soft rot of tomatoes resulting from dump-tank and washer-water contamination and its control by chlorination." Proc Fla State Hort Soc, **89**: 204-205.

46. Sherman, M. and J. J. Allen (1983). "Impact of postharvest handling procedures on soft rot decay of bell peppers." Proc Fla State Hort Soc, **96**: 320-322.

47. Sholberg, P. L. and G. R. Owen (1990). "Populations of propagules of Penicillium spp. during immersion dumping of apples." Can Plant Dis Surv, **70**(1): 11-14.

48. Sholberg, P. L. and G. R. Owen (1991). "Populations of propagules of Mucor spp. during immersion dumping of Anjou pears." Can Plant Dis Surv, **71**(1): 33-35.

49. Showalter, R. K. (1993). "Postharvest water intake and decay of tomatoes." HortTechnology **3**(1): 97-98.

50. Showalter, R. K. and J. A. Bartz (1979). "Postharvest water intake and decay of tomatoes." Citrus and Vegetable Magazine **43**(4): 7, 28.

51. Spotts, R. A. and L. A. Cervantes (1986). "Populations, pathogenicity, and benomyl resistance of Botrytis spp., Penicillium spp., and Mucor piriformis in packinghouses." Plant Dis, **70**(2): 106-108.

52. Spotts, R. A. and L. A. Cervantes (1989). "Evaluation of disinfestant-flotation salt-surfactant combinations on decay fungi of pear in a model dump tank." Phytopathology **79**(1): 121-126.

53. Spotts, R. A. and B. B. Peters (1982). "Use of surfactants with chlorine to improve pear decay control." Plant Dis, **66**(8): 725-727.

54. Sugar, D. and R. A. Spotts (1993). "Dispersal of inoculum of Phialophora malorum in pear orchards and inoculum redistribution in pear immersion tanks." Plant Dis, **77**(1): 47-49.

55. Winston, J.R.,Johnson, H.B., and E. M. Harvey (1953). "Using chemicals to stop spoilage". in Yearbook of Agriculture. USDA Printing Office. Washington D.C.pp 842-843

56. Wong, W. C. and T. F. Preece (1985). "Pseudomonas tolaasii in cultivated mushroom (Agaricus bisporus) crops: effects of sodium hypochlorite on the bacterium and on blotch disease severity." J Appl Bacteriol, **58**(3): 259-267.