



## **Food Antimicrobials, Cleaners, and Sanitizers**

### *A Review of the Scientific Literature*

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Food safety is ensured largely, but not exclusively, by controlling the presence and growth of pathogenic organisms in and on foods. Numerous cleaning compounds and processes have been developed to remove and destroy bacteria, viruses, and parasites from equipment and surfaces in food processing plants and from fresh produce and animal carcasses. Antimicrobial compounds are used to eliminate or limit the growth of pathogens in foods.

Pathogenic and spoilage organisms may be present in and on foods but only a few of these are a serious health concern because of their ability to cause human illness. These include viruses, notably noroviruses and hepatitis A, parasites such as *Cryptosporidium* and *Cyclospora*, molds such as *Aspergillus* spp. and *Penicillium* spp., and several bacteria. *Salmonella* spp., *E. coli* O157:H7, *Clostridium botulinum*, and *Listeria monocytogenes* are the most frequent or serious causes of foodborne bacterial infections. Other bacteria of concern include *Bacillus cereus*, *Campylobacter jejuni*, *Clostridium perfringens*, *Shigella* spp., *Staphylococcus aureus*, *Vibrio* spp., and *Yersinia enterocolitica*.

This review includes a brief overview of issues related to the effective cleaning of surfaces in food processing plants and the cleaning of animal products and fresh produce. Recent articles in the scientific literature from 2000 to 2005 that provide data on antimicrobial effects of various sanitizing compounds and processes are referenced below by categories of different foods and processing equipment/surfaces.

Destruction of vegetative cells of bacteria, molds, and parasites may not be very difficult as they are sensitive to heat and chemicals. However, many organisms excrete extracellular polysaccharides and form biofilms that protect individual cells and can be quite difficult to remove from surfaces. In addition, molds, *Clostridium* spp., and *Bacillus* spp. form spores that are resistant to heat, acids, and other compounds. Parasites also produce resistant cells called cysts, and virus particles are notoriously resistant to heat, chemicals, and drying. Over time microbes evolve to become resistant to some sanitizers and disinfectants. Thus, it is a significant challenge to maintain a clean environment in food processing plants.

Ready-to-eat foods should be free of pathogens. Processing facilities should be clean and organized to minimize opportunities for cross-contamination. Packaged RTE foods need to be stored properly. In addition,

RTE foods may require the addition of approved compounds that will prevent growth of pathogenic microbes that may be present such as spores and cold-tolerant species. A recent book on *Antimicrobials in Foods* (49) discusses antibacterial and antifungal additives, including organic acids, sulfites, nitrite, nisin and other bacteriocins, lysozyme, natamycin, parabens, dicarbonates, medium chain fatty acids and esters, and other natural plant and animal compounds. Antimicrobial effects, applications, toxicology and safety, and regulatory status of each group of compounds is presented. Development of resistance and adaptation to some antimicrobials necessitates continued research to identify new antimicrobial compounds and processes.

## Equipment and Surfaces in Plants

Cleaning of equipment and surfaces in plants is difficult because many microorganisms can adhere to these surfaces and may concentrate in crevices that remain moist (117). Surface composition and topography resulting from wear affect microbial attachment (28;71;76;98;131;201;244). Remnants of foods attached to surfaces enhance survival of bacteria (4;8) and therefore it is important to clean surfaces before disinfection. Some pathogens may survive the actions of alkaline cleaning products but then become more sensitive to disinfectants (197;224). In addition, many bacteria can secrete extracellular polysaccharides that protect them from cleaning agents and form biofilms (72;187). Several recent reviews discuss biofilms and treatments to remove them (96;166;196;243) and other reviews consider cleaning and sanitation practices (48;87;120;176).

Cleaning of surfaces and destruction of bacteria may be accomplished by alkaline detergents (75), ozone (46;102;103;144), hydrogen peroxide vapor (97), encapsulated lysozyme (21), chlorinated compounds (12;133;182), peroxyacetic acid (12;182), numerous commercial disinfectants (1;167;189;201), quaternary ammonium compounds (133), sunlight (152), and electrolyzed water (78).

Recent reports on removing biofilms from surfaces include data on the use of: (a) numerous commercial disinfectants (8;77;242); (b) acidic, neutral, and alkaline electrolyzed water (10;59); (c) alkaline based cleaning compounds (6;198); (d) chlorinated

compounds (29;63;65;98;129;131;140;151;178;186;191;198;210;217); (e) peroxyacetic acid (210;217;218); (f) nisin, lauricidin, and lactoperoxidase (65); (g) carvacol (107;108); (h) hydrogen peroxide (107;178); (i) chitosan (107); (j) ultrasound (157;158); (k) ozone (63;178); (l) irradiation (149); and (m) acidification (191).

Bacteria may develop resistance to some disinfectants (44), and it has been suggested that different types of disinfectants should be used alternately to prevent establishment of resistant house strains (25). Viruses, including hepatitis A, are generally much more resistant to disinfectants than bacteria (95).

## Animal Products

Raw meat remains a major source of foodborne pathogens, and a variety of techniques have been devised to reduce bacterial contaminants on animal carcasses and on pieces of raw meat. These include: (a) chemical decontamination with organic acids and trisodium phosphate; (b) physical processes such as irradiation, steam or hot water dips or sprays, UV and pulsed light, and high-pressure processing; (c) natural antimicrobials such as bacteriocins and iron chelating compounds; and (d) combination treatments (61;109).

Decontamination processes reduce microbial populations but if the meat is subsequently recontaminated with a pathogen during processing, then the pathogen may multiply rapidly because of the lack of competing bacteria (150). Some decontamination processes may cause undesirable effects on the color or texture of meats (91;128).

### Beef

Recent data have been reported on the effects of the following treatments on cattle hide or carcasses: (a) trisodium phosphate (TSP) (47); (b) lactic, peracetic and other organic acids (37;38;47;53;62;81;105;141;150;169); (c) hypochlorite and other chlorinated compounds (26;81;88;141); (d) steam or scalding water (45;47;82;83;136;137;142;150;169;173;177); (e) ozone (39); (f) commercial sanitizers (206); and (g) bacteriocins such as nisin (53).

Reported sanitizing treatments of pieces of meat and beef trimmings included: (a) organic acids (7;55;67;100;101;115;125;127;145;212;214;215;219); (b) chlorinated compounds (27;126;192;213;220);

(c) ozone (213); (d) nisin (7;145); (e) irradiation (11); (f) hot water or steam (55;100;101;115;130;214); (g) cetylpyridinium chloride (126;220); (h) acidic or basic oxidized water (215); and (i) ammonium hydroxide (215;220).

### Pork

Lactic acid dips lowered microbial counts on pork chops while preserving a good color (128). Organic acid washes added to the effectiveness of scalding (66) and irradiation (104) in reducing bacterial populations on meat. Saturated steam with rapid re-evaporation significantly reduced bacterial contaminants but adversely affected meat color (91) while spraying acidified electrolyzed oxidizing water on carcasses reduced levels of *Campylobacter coli* but not of other bacteria (70).

### Poultry

Data have been reported on the effects of the following treatments on poultry skin or carcasses: (a) trisodium phosphate (TSP) (16;32–36;40;155;238); (b) lactic, peracetic and other organic acids (41;57;155;205); (c) hypochlorite and other chlorinated compounds (16;41;159;185;205;238); (d) steam or scalding water (9;205;239;240); (e) hydrogen peroxide (232); and (f) an herbal extract (60).

Reported sanitizing treatments of chicken meat included TSP (85), organic acids (85), chlorinated compounds (85), ozone (3), yogurt and nisin (84).

### Sheep/Goat Meat

Organic acids (lactic, acetic, and propionic) have been reported to decrease populations of *E. coli* and other bacteria when sprayed on carcasses or used as washes (64;175). Steam condensate and hot water immersion, particularly chlorinated hot water, also decrease the bacterial load (94). Some spices, including cloves and cinnamon, inhibited bacterial growth on pieces of meat and extended shelf life (116).

### Fish

Acidified sodium chlorite reduced total bacterial count and numbers of *L. monocytogenes* on salmon fillets (221). Treatment of salmon fillets with ozonated water did not significantly reduce bacterial contamination and increased rancidity in the fish (46). However, ozone treatment of live *Tilapia* fish prolonged shelf life and reduced bacterial populations (80).

## Eggs

*Salmonella* spp., particularly *S. enteritidis*, has been an ongoing problem in egg safety. Improved sanitary processes at some farms and egg packing plants have decreased but not eliminated salmonellae from the surfaces of shell eggs (50). This has led to investigation of a number of sanitizing treatments to clean egg shells in the U.S. In Europe, cleaning of egg shells is not as commonly practiced (51).

Treatment of eggs with cleaning/sanitizing solutions has given mixed results for the elimination of salmonellae and their efficacy is dependent on total dissolved solids in wash water (106;165;209). Application of commercial sanitizers by an electrostatic spraying system was reported to be more effective (184). Several research groups reported that electrolyzed water decontaminated eggs (2;24;51;164;183) and exposure to ozone in a humid atmosphere and to ultraviolet light also appeared to effectively kill salmonellae on eggs (51;181).

## Fresh Produce

Fresh fruits and vegetables may harbor a variety of microbes originating in the environments where they grew, water used for cleaning, and handling and storage conditions. Cross contamination may also occur in kitchens and food preparation areas (231). Outbreaks of hepatitis, shigellosis, salmonellosis, *Cyclospora*, *Cryptosporidium*, and *E. coli* O157:H7 associated with fresh produce have demonstrated that pathogens may be present. Some of these organisms are more resistant than others to certain treatments and even serovars of *Salmonella* differ in their susceptibility.

Fruits and vegetables can be very difficult to clean because of their soft tissues that are easily damaged and irregular surfaces with microenvironments that protect microbes. Natural waxes on plant surfaces and oils and waxes commercially applied to plant surfaces may also affect the efficacy of cleaning procedures and sanitizers (31). Some treatments may be too harsh and destroy the appearance or integrity of fresh produce.

## Fruits

Research on sanitary issues related to fresh fruits has been targeted to address two concerns: cleaning of

whole, intact or slightly damaged fruits that will be sold as fresh fruit or used to produce juices and cleaning of sliced fruits that that may be sold or served fresh or as dried fruit. A review on extending shelf life of fresh cut fruits considered the impact of various aspects of processing (208).

**Apples.** Several studies have demonstrated that some commonly used sanitizers (acetic acid, potassium sorbate, sulfur dioxide, H<sub>2</sub>O<sub>2</sub>, and hypochlorite) are not very effective in reducing microbes on whole fruits (43;190;216). Other reports indicated that some treatments reduced populations of some microbes. These include treatment with: (a) hypochlorite and copper ions (180); (b) electrolyzed oxidizing water (156); (c) UV light (69;247); (d) acetic acid (43) ozone and chlorine dioxide (179); (e) chlorine combined with lactic acid (69).

Dipping of apple slices in organic acids (ascorbic, citric or lemon juice) was reported to prevent growth of bacteria (56). Washing apple slices in acetic acid, hypochlorite, H<sub>2</sub>O<sub>2</sub>, and sodium phosphate significantly reduced numbers of *Salmonella* spp. (123;124). A *Salmonella*-specific phage was found to be ineffective as a biocontrol agent on apples, possibly because of the acidic pH (122).

**Berries.** Sanitizing solutions, including hypochlorite, ozonated water, acidic electrolyzed water, peroxyacetic acid, and H<sub>2</sub>O<sub>2</sub>, were not very effective in destroying pathogens on strawberries and raspberries (52;86;112;132). Chlorine dioxide gas and ozone did reduce bacterial populations on strawberries (90;179).

**Cantaloupe and other melons.** Cut pieces of melon have been associated with foodborne illness. This was presumably a result of transfer of pathogens from the surface of melons to the slices during cutting. Washing melons appears to be most effective when surfaces are scrubbed with some sanitizer (13;168). Several sanitizer solutions appear to aid in reducing bacterial populations on melon surfaces. These include: H<sub>2</sub>O<sub>2</sub> (227;228;230), hot water (230), hypochlorite/chloramine (13;17;134;138;160;168;188;228), and organic acids (134;188). Nisin alone did not inactivate bacteria on melon surfaces but combined with organic acids it had some effect (229). A *Salmonella* phage inactivated *Salmonella* bacteria on honeydew melons (122). Electron beam irradiation (160) and chlorine dioxide gas and ozone (90;179) also decreased bacterial load on melons.

**Oranges.** Washing oranges with high pH solutions (pH 11.8) was reported to reduce surface bacterial contamination of oranges (162). Hot water washing, washing with sodium bicarbonate and biocontrol with yeast antagonists reduced spoilage organisms on citrus fruits (172). These treatments may reduce populations of potential pathogens and diminish contamination of citrus juices.

### Vegetables

**Cabbage.** Acidified sodium chlorite reduced populations of several bacterial pathogens on Chinese cabbage by 2–3 logs (92,93). Peroxyacetic acid and H<sub>2</sub>O<sub>2</sub> reduced *E. coli* populations, but not virus levels, on cabbage (5).

**Carrots.** Sanitizing treatments reported to reduce bacteria on carrots include lemon juice and lemon juice vinegar (193,195) and anolyte water and chlorinated water (245). Chlorine dioxide, ozone, and thyme essential oil have also been used to decontaminate carrots (204).

**Celery.** Ozonated water was reported to reduce microbial populations on celery (249).

**Cilantro.** Low-dose irradiation (99) and low-dose irradiation combined with chlorination (74) reduced bacterial levels on fresh cilantro while maintaining its quality. Aqueous ozone also reduced aerobic bacteria on fresh cilantro while preserving quality (233).

**Cucumber.** Sodium hypochlorite solution combined with emulsifiers disinfected shredded cucumber (146). Acidic electrolyzed water also reduced bacterial levels on cucumbers (112).

**Lettuce.** Chlorinated water has been reported to have modest effects on bacterial populations in several studies (18;19;22;23;30;54;119;139;147;153;170;231). Electrolyzed water and acidic electrolyzed water reduced bacterial populations on lettuce by 2–3 logs (110;111;113;114;246). Other sanitizers gave mixed results in decontaminating lettuce: peroxyacetic acid (132;154;179;222), H<sub>2</sub>O<sub>2</sub> (222), chlorine dioxide (121;179;204), ozone (179;204), and other commercial sanitizers (147;207). Other compounds tested include: thyme oil (204), NaCl-sodium bicarbonate (223), grapefruit seed extract (132), and chlorinated trisodium phosphate (179).

UV light (247) and gamma irradiation (148) were also reported to decrease populations of bacteria on lettuce. Tests demonstrated that neither commercial

disinfectants (86) nor peroxyacetic acid and H<sub>2</sub>O<sub>2</sub> (5) reduced virus levels on lettuce.

**Other greens.** A variety of sanitizing treatments have been reported to have some effect on bacterial populations on other salad greens. These include: (a) acidic electrolyzed water on green onions (248); (b) lemon juice and vinegar on rocket and green onion (194); (c) warm water with H<sub>2</sub>O<sub>2</sub> on field salad (235); (d) chlorinated water on parsley (119); and (e) oils of eucalyptus, tea tree, and clove on Swiss chard (171).

**Peppers.** Decontamination of peppers was accomplished by heating to 220°C for 15 minutes but this treatment destroyed the freshness of the vegetable. Rinsing in 70% ethanol partially reduced mold spore levels on peppers (79). Chlorine dioxide significantly reduced pathogen levels on green peppers but some bacteria survived in parts of the fruit that were injured (89).

**Potatoes.** Ozone alone did not control microbes on potato strips but ozone plus a commercial sanitizer containing peroxyacetic acid in combination with vacuum packaging did reduce levels of some bacteria by 3 logs (20).

**Tomatoes.** Spraying of tomato fruit with acidic electrolyzed water or 200 ppm Cl (15) was reported to reduce pathogens by 7.8 and 4.7 logs, respectively. Neutral electrolyzed water used to rinse tomatoes decreased pathogens by 5 logs (58). An alkaline ionic washing fluid (GC-100X) decreased pathogen levels by 4 logs (118) while aqueous chlorine reduced populations of yeasts and molds (135). UV light was also reported to decrease populations of bacteria on tomatoes (247).

### Nuts and Seeds

Over 15 outbreaks of illness due to *Salmonella* or *E. coli* O157:H7 contamination of sprouts have occurred in the past decade. Bacterial contaminants are present on seeds and inadequate disinfection of seeds is responsible for such outbreaks (225;226;241). Some seeds are more difficult to disinfect than others (14;42); bacteria which survive on treated seeds may multiply during germination (203) or become internalized in sprouts (234). Disinfection procedures for seeds to be used for sprouts must be a balance between killing a sufficient number of pathogens without significantly reducing germination of the seeds. Currently recommended methods include the use of

8% H<sub>2</sub>O<sub>2</sub>, 20,000 ppm Cl, and 1% calcium hydroxide (143).

Recent research described the effects of: electrolyzed oxidizing water (14;199;200;211), sonication (14), irradiation (14;174), chlorinated water (42;202;203;234), hot water (68;236;237), ozonated water (200;203), Salmonella bacteriophages (163), thyme oil (203), vinegar (202), sulfuric acid scarification (161), and commercial citrus products (73).

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