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Review

# Sustainable sanitation techniques for keeping quality and safety of fresh-cut plant commodities

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ABSTRACT

The minimal processing industry for fruit and vegetables needs appropriate selection of raw materials and operation of improved sustainable strategies for reducing losses and providing high quality and safe commodities. The most important target for keeping overall quality of these commodities is a decrease in microbial spoilage flora as these cause both decay and safety problems. Every step in the production chain will influence microbial load and the implementation of an accurate disinfection program should be the main concern of commercial processing. The only step that reduces microbial load throughout the production chain is washing disinfection, and the keys are proper handling and optimizing existing techniques or a combination of them. Chlorine is a common efficient sanitation agent but there is the risk of undesirable by-products upon reaction with organic matter and this may lead to new regulatory restrictions in the future. Moreover, its efficacy is poor for some products. Consequently the minimal processing industry wants safer alternatives. Several antimicrobial washing solutions, $O_3$, UV–C radiation, intense light pulses, super high $O_2$, $N_2O$ and noble gases, alone or in combination, are presently considered promising treatments. However, change from use of conventional to innovative sanitizers requires knowledge of the benefits and restrictions as well as a practical outlook. This review addresses some recent results obtained with these eco-innovative sanitizers on fresh-cut plant commodities.


## 1. Introduction

The current worldwide drive for a healthier lifestyle has led to a rising demand for convenient fresh foods, free from additives, with high nutritional value, including antioxidant and free-radical scavenging properties, to be consumed both at home and in food services. In this way, minimally fresh processed or fresh-cut (FC) fruit and vegetables offer great advantages for consumers (Wiley, 1994; Artés, 2004). In addition to convenience, consumers perceive FC plant commodities as good because of their high quality and less wastage coupled with a reasonable price (Beuchat, 2002; Bruhn, 2002).

However, the operations required for preparing FC products result in an increase in the number of microorganisms, some of which may be potentially harmful to human health (Leistner and Gould, 2002). Although this kind of minimal processing keeps commodities alive, it destroys plant structure and therefore increases the rate of senescence of tissues and reduces their resistance to microbial spoilage (Artés et al., 2007a). Ethylene production, respiratory activity, enzymatic and non-enzymatic browning and nutrient release from cells are stimulated by plant injuries. These lead to lowered quality and shorter shelf-life compared to that expected from the whole intact product (Wiley, 1994). Moreover, shelf-life of FC plant commodities is affected by pre-processing factors (crop varieties, cultivation conditions, harvesting, ripening stage), processing factors (precooling, trimming, cleaning, conditioning, cutting, peeling, coring, handling, washing, disinfecting, draining, rinsing, drying, packaging) and distribution conditions (temperature, relative humidity, atmosphere composition and duration). Because of these issues, FC fruit and vegetables must be processed under highly integrated systems where all processing steps are considered in combination (Shewfelt and Prussia, 1993; Artés, 2004).

In order to achieve FC produce with fresh-like quality, safety and high nutritional value, the industry needs to implement improved strategies by introducing or combining sustainable techniques, especially standard procedures for sanitation. The major preservation techniques applied to prevent or delay spoilage are chilling storage and modified atmosphere packaging (MAP), combined with chemical treatments (antimicrobial solutions, acidulants, antioxidants, etc.), and application of moderate heat treatments (Leistner

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and Gould, 2002). The keys for the production of safe FC plant produce include screening materials entering the processing chain, suppressing microbial growth, reducing the microbial load during processing and preventing post-processing contamination (Artés and Allende, 2005).

The aim of the present work was to review the main sustainable sanitation strategies which can be used for keeping quality and safety of FC plant commodities: antimicrobial solutions, $O_3$, UV–C light, intense light pulses, and innovative MAP under superatmospheric $O_2$ and novel gases. Some important results obtained with these eco-innovative sanitizers are also presented.

## 2. Antimicrobial solutions

Chlorination is considered the main way to minimize the transmission of pathogens from infested plant produce or debris to non-infested surfaces such as those mechanically injured during harvesting, transportation or processing, wounds, or the natural plant surface openings (Artés et al., 2007b). NaClO is a very potent disinfectant with powerful oxidizing properties, being the most commonly used by the food industry for sanitizing both products and equipment of the processing area (Nieuwenhuijsen et al., 2000). It is generally effective, comparatively inexpensive, and may be implemented in operations of any size (Suslow, 1997). Its effectiveness against microorganisms depends on pH, temperature, concentration, organic matter present in the washing water and plant product, time of exposure, and initial microbial load (Boyette et al., 1993). Efficacy increases with increasing concentration of available chlorine, but high levels may cause product tainting (Adams et al., 1989) and sodium residue on the product and equipment (Ritenour and Crisosto, 1996). When NaClO is added to water, it increases pH and generates hypochlorous acid (HOCl), which is the active antimicrobial species. The acid dissociates readily to hypochlorite ions ($OCl^-$) at high pH, or chlorine gas ($Cl_2$) at low pH, thus the pH must be kept in the range of 6.5–7.5 for HOCl to be stable and efficient (Boyette et al., 1993; Suslow, 1997). In addition, even if NaClO is more efficient at low pH levels, the range of 6–7.5 should be selected for reducing the risk of corrosion of metallic processing equipment (Beuchat, 2000).

However, NaClO may incompletely oxidize food constituents that contain natural organic materials to produce unhealthy by-products in process water, such as chloroform ($CHCl_3$), haloacetic acids or other trihalomethanes (THM) that have known or suspected carcinogenic or mutagenic effects, with proven toxicity to liver and kidneys (Nieuwenhuijsen et al., 2000). At high pH, NaClO reacts with organic nitrogen-based materials to produce chloramines (Suslow, 1997). Due to this, in some European countries such as Germany, The Netherlands, Denmark, Switzerland and Belgium, the use of chlorine in FC products has been forbidden (Betts and Everis, 2005; Carlin and Nguyen-the, 1999). To reduce THM levels it has been proposed to change from chlorine to chloramine disinfection because chloramines do not combine with organic matter in the water to form THM. Adding ammonia to a chlorination system converts the chlorine to chloramine (Capece, 2001). But chloramines may be less acceptable alternatives because their efficacy as disinfection agents is lower and could provide risks for workers with regard to damage of eyes and the respiratory tract. Moreover, effectiveness of NaClO is limited to some products (Beuchat and Brackett, 1990). As well, while chlorine compounds are helpful in reducing the aerobic microbial counts in many leafy vegetables, this is not necessarily the case in root vegetables. It has also been reported that NaClO is not very effective for inhibiting *L. monocytogenes* growth in shredded lettuce or Chinese cabbage (Ahvenainen, 1996).

Consequently, these concerns have encouraged the search for alternatives to NaClO in water solutions. Among them some organic acids formulations, such as peroxyacetic acid combined with citric and ascorbic acids, $ClO_2$ and $H_2O_2$, calcium lactate, electrolyzed water (EW), steamer jet injections and biological compounds have been tested with varying results and these will be described below.

### *2.1. Peroxyacetic acid*

Peroxyacetic acid is a combination of peracetic acid ($CH_3CO_3H$) and $H_2O_2$, usually commercialized as a liquid. Its break-down products, acetic acid, $O_2$, $CO_2$, and water, are not particularly harmful for the ecosystem. It is applied for surface cleaning in concentrations ranging from 85 to 300 ppm, and the U.S. Food and Drug Administration (FDA, 1997) has set a minimum of 85 ppm peracetic acid for cleaning hard surfaces where food is handled. Stampi et al. (2001) indicated that for cleaning the surface of foods, 50 ppm is commonly enough, while, by comparison, concentrations used in the environmental and medical areas range from 1200 to 2600 ppm.

Because of peroxyacetic acid tolerance to several factors such as temperature, pH (from 1 to 8), hardness and soil contamination, its current main area of application is in fruit and vegetable processing (Artés et al., 2007b). For the treatment of plant surfaces, recommended formulations combine 11% $H_2O_2$ and 15% $CH_3CO_3H$, at 80 ppm, followed by rinsing with tap water (Suslow, 1997). It has been reported that this was effective for controlling *E. coli* and *L. monocytogenes* in FC products (Rodgers et al., 2004). *Enterobacter sakazakii* counts decreased 5 log units in lettuce with applications of peroxyacetic acid (Kim et al., 2006). Compared to 150 ppm NaClO, 68 ppm of peroxyacetic acid reduced psychrotrophic counts by 2 log units and mesophilic counts by 1 log unit in FC Galia melon, resulting in the fruit pieces having a shelf-life of 10 d at 5 °C (Silveira et al., 2007).

### *2.2. Chlorine dioxide*

Chlorine dioxide is a stable dissolved gas, that is environmentally friendly (FDA, 1998), having a higher oxidation and penetration power than NaClO, and being more effective against spores (EPA, 1999). $ClO_2$ is a strong bactericide and virucide at levels as low as 0.1 ppm. It attacks planktonic and sessile bacteria, fungi and viruses, disinfects surfaces, and prevents and rapidly removes biofilms, avoiding bacterial re-growth (EPA, 1999). With minimal contact time, it is highly effective against pathogenic organisms such as *Legionella*, amoebal cysts, *Giardia* cysts, *E. coli*, and Cryptosporidium (Xie, 2003). Organic substances in bacterial cells react with $ClO_2$, causing several cellular processes to be interrupted (EPA, 1999). Chlorine dioxide reacts directly with amino acids and the RNA in the cell but it is not clear whether it attacks the cell structure or the acids inside the cell. The production of proteins is prevented and the cell membrane affected by changing membrane proteins and lipids (EPA, 1999). Viruses are eliminated in a different way; $ClO_2$ reacts with peptone, a water-soluble substance that originates from hydrolysis of proteins to amino acids. Chlorine dioxide kills viruses by prevention of protein formation, and is more effective against viruses than chlorine or ozone (EPA, 1999).

The $ClO_2$ does not ionize to form weak acids (as chlorine and bromine do) or to form carcinogenic by-products like THM. This allows $ClO_2$ to be effective over a wide pH range. However, chlorine dioxide and its disinfection by-products chlorite and chlorate can create problems for dialysis patients (EPA, 1999). One of the most important qualities of $ClO_2$ is its high water solubility, especially in cold water. Chlorine dioxide does not hydrolyze when it enters water; it remains as a dissolved gas in solution and it is approximately 10 times more soluble in water than chlorine. Its