



## Disinfecting agents for controlling fruit and vegetable diseases after harvest



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### ABSTRACT

Disinfection of fresh fruit and vegetables after harvest is an essential first step of postharvest handling. The minimal requirement from disinfection procedures is to maintain commodities and facilities free of fungal postharvest pathogens and bacterial human pathogens and thus improve food safety. Disinfection of postharvest pathogens that accumulate on the fruit surface before and during harvest is a direct benefit and in particular cases it can by itself prevent decay after storage. The current review includes historical, chemical, and regulatory background on some of the major disinfectants available for usage today. These include chlorine, chlorine dioxide, ozone, ethanol, hydrogen peroxide, organic acids, and electrolyzed water. Some of the disinfectants described in this review are in wide usage for many years and some are considered 'alternative' and are at initial levels of usage. Information is given on experimental reports, practical application, phytotoxicity, residues, advantages, disadvantages and mode of action of the compounds and technologies. Special emphasis is given to vapor and gas phase applications due to their unexploited potential and to some complementary technologies that have been reported in recent years. The conclusion from the many details in this review is that disinfection is an important tool to ensure management of postharvest decay of fresh produce. In some cases, disinfection is a precondition to successful implementation of major postharvest technologies and in particular cases it can become the major technology. An important aspect arising from this review is also that some of the bad reputation of chemical disinfectants is unjustified because they leave no or non-toxic levels of residues and their environmental impact is minor in view of their potential benefits.

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## 1. Introduction

### 1.1. Importance of produce sanitation

Sanitation after harvest is critically important for all fresh products, where it can reduce spoilage losses by 50% or more (Sargent et al., 2000). This occurs primarily by the sanitation of wash water, produce surfaces, equipment, and storage rooms rather than direct control of infections of the decay pathogens within the produce. The most common disinfecting agent is chlorine applied as a spray or dip. Sanitation may be followed by treatment with one or more fungicides, which deposit a residue in the product that inhibits decay pathogens that infect later or

escaped the action of the sanitizers. Sanitizers are also widely employed to minimize contamination of produce with pathogens of human health concern (Gómez-López, 2012). Fungal decay pathogens differ in many ways from human pathogens. Unlike *Salmonella* spp., *Listeria* spp., *Escherichia coli*, and other human pathogens and viruses, plant pathogens can grow rapidly within and digest the host tissue because the plant is a primary food source. Populations of human pathogens are composed of single cells, so their control is expressed as a reduction in colony forming units. In contrast, fungal postharvest pathogens exist as discrete propagules and later they become an interconnected fungal mass deep within the host. Their control is best quantified as a reduction in the percentage of infected individual pieces of produce.

A fundamental need when fruit and vegetables are handled is sanitation of harvest bins, wash solutions, rotary brushes, belts, grading and other processing equipment (Adaskaveg et al., 2002). All sanitizers that inactivate pathogen propagules can accomplish

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this if used properly. However, pathogens survive if they reside within the wounds on the host or if they are present as incipient, latent, or quiescent infections within host tissue (Korsten and Wehner, 2003). Even very high rates of sanitizers fail to control these pathogens once infection has occurred (Eckert and Eaks, 1989; Spotts and Cervantes, 1992; Spotts and Peters, 1980; Smilanick et al., 2002a), although some gases may be exceptions. Sanitizers differ in two fundamental aspects from postharvest fungicides (Adaskaveg et al., 2002). Sanitizers cause rapid mortality of pathogens they contact and do not deposit a persistent antimicrobial residue in treated products. In contrast, most fungicides are primarily fungistatic in action, arresting pathogen growth when present in sufficient concentration, and many confer persistent protection from decay often long after treatment. Many move systemically within the host tissue, while all sanitizers do not.

This review will address the most popular sanitizer, chlorine (hypochlorite), and a number of alternative sanitizers proposed or in minor use for washing or the storage of fresh produce, such as chlorine dioxide, ozone, ethanol, hydrogen peroxide, organic acids and electrolyzed water. Organic acids differ from the others in that rapid mortality only occurs at relatively high concentrations and their action is primarily biostatic (Gardam and Conly, 2001). All are non-selectively toxic, so their risk of injury to treated products should be rigorously evaluated before adoption. All of these compounds are approved for use in some food contact roles. Some specific aspects of these approvals are discussed for all of them but others are beyond the scope of this review. In the USA, sanitizers are regulated by the United States Environmental Protection Agency (EPA), the Food and Drug Administration (FDA), and state agencies. In Europe, Food Safety Authority (EFSA) is the independent advisory agency concerning risks associated with the food chain and the safety of all food additives and plant protection products that are authorized in Europe. European Member States are responsible to control the usage of sanitizers according to recommendations by EFSA.

Both aqueous and gas applications will be reviewed, with emphasis on sanitizers with unexploited potential or recent technical developments. For example, gases can sanitize products continuously or repeatedly without the expense and product harm risks associated with product handling (dumping, wetting, drying, re-boxing). Other disinfectants such as peracetic acid, quaternary ammonium and many other potential disinfectants from chemical or natural sources warrant consideration but require more attention that could be offered within the scope of the current review.

### 1.2. Units of concentration in aqueous and gaseous phases

Quantification of the amount of sanitizers employs differing units (particularly gases) and is important to understand these in order to compare results among studies. Materials in solution are most often expressed in terms of weight to volume as  $\mu\text{g mL}^{-1}$ ,  $\text{mg L}^{-1}$ , or parts per million (ppm), and these are all equivalent to each other. An exception are ethanol solutions, these are routinely quantified in percent volume to volume units. Materials as gases are most often expressed in terms that are not equivalent to each other, either as weight to volume ( $\text{mg m}^{-3}$ ) or in volume to volume ( $\mu\text{L L}^{-1}$  or parts per million). For example, one part per million of ozone in solution, a weight to volume term, contains approximately 500 times more ozone molecules than one part per million of ozone gas, a volume to volume term. One part per million (volume to volume) of chlorine gas, chlorine dioxide gas, or ozone gas contains 2.9, 3.0, or  $2.14 \text{ mg m}^{-3}$ , respectively, of these compounds in solution.

## 2. Chlorine compounds

### 2.1. Chlorine (hypochlorite)

Chlorine ( $\text{Cl}_2$ ), or hypochlorite ( $\text{OCl}^-$ ) when in solution, is the most commonly employed aqueous sanitizer (Suslow, 1997). It is in ubiquitous use in the food industry and for drinking water disinfection. Pathogen propagules die rapidly and this is valuable to stop their distribution from infected, decaying fruit or vegetables to healthy products during processing (Adaskaveg et al., 2002). The oxidation state of chlorine gas is zero, however, when this gas dissolves in water it converts within seconds to the primary active form of hypochlorite (oxidation state +1, 1.630 V) (White, 1999). For commercial disinfection purposes, chlorine gas, sodium hypochlorite ( $\text{NaOCl}$ ) solutions, or calcium hypochlorite ( $\text{CaCl}_2\text{O}_2$ ) are used to make aqueous hypochlorite solutions of known concentration (Suslow, 1997).

Hypochlorite in solution is described in several terms. Total chlorine is the sum of combined (chlorine that has reacted with other constituents) and free chlorine (chlorine that remains unreacted in solution and is available in solution for disinfection). Hypochlorite in aqueous solution is a weak acid with a  $\text{pK}_a$  of approximately 7.5. Protonated hypochlorite (hypochlorous acid), which predominates below the  $\text{pK}_a$ , is the most active component within the free or available chlorine content. Its potency is far higher than that of its ion. For example, the time in seconds needed to inactivate 95% of the conidia of *Penicillium digitatum*, the causal agent of citrus green mold, at pH 7, 8, 9, or 10 was 13.2, 19.1, 29.4, and 88.4 s, respectively, in a solution containing  $200 \text{ mg L}^{-1}$  free chlorine (Smilanick et al., 2002a). Temperature has a marked influence on the rate of mortality. Inactivation of 95% of the conidia of *P. digitatum* in  $200 \text{ mg L}^{-1}$  free chlorine at pH 8.3 at  $24.0$  or  $5.0$  °C occurred after 29.4 and 88.4 s, respectively (Smilanick et al., 2002a).

### 2.2. Chlorine dioxide

This compound ( $\text{ClO}_2$ , oxidation state +5, 0.954 V) has equal or greater antimicrobial potency than chlorine. It is a monomeric free radical and readily dissolves in water without reacting with it, unlike chlorine. Because it does not ionize in water, it is little affected by pH (EPA, 1999). Its potency is similar to hypochlorite for the control of microorganisms, but since it is a dissolved gas with less oxidation strength it retains its activity better than the more reactive hypochlorite when suspended organic matter is high (White, 1999). A well-studied use of chlorine dioxide is disinfection of drinking water, although its use for this purpose is not common (White, 1999). Chlorine dioxide fumigation of buildings with "sick building syndrome" is done commercially to control the fungi *Stachybotrys chartarum*, *Penicillium chrysogenum*, *Cladosporium cladosporioides*, and others (Wilson et al., 2005).

### 2.3. Postharvest application of chlorine and chlorine dioxide

Chlorine and chlorine dioxide at similar concentrations kill propagules of pathogens on equipment and host surfaces. Spotts and Peters (1980) found that chlorine at  $2.5$  or  $5.0 \text{ mg L}^{-1}$  killed *Mucor piriformis* and *Penicillium expansum* conidia after 5 min. Roberts and Reymond (1994) found that aqueous chlorine dioxide at  $3.0$  or  $5.0 \text{ mg L}^{-1}$  killed >99% of *Botrytis cinerea*, *P. expansum*, *M. piriformis*, and *Cryptosporiopsis perennans* conidia within 1 min, and that a foam formulation containing  $14$  to  $18 \text{ mg L}^{-1}$  of chlorine dioxide solutions was an effective sanitizing agent for pear and apple packinghouses and equipment. However, even very high rates of chlorine or chlorine dioxide failed to control pathogens within wounds (Spotts and Peters, 1980; Eckert and Eaks, 1989;

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