International Journal of Food Microbiology 134 (2009) 37–45

Contents lists available at ScienceDirect

International Journal of Food Microbiology

journal homepage: www.elsevier.com/locate/ijfoodmicro

Review

Fresh-cut product sanitation and wash water disinfection: Problems and solutions

Maria I. Gil, Maria V. Selma, Francisco López-Gálvez, Ana Allende *

Research Group on Quality, Safety and Bioactivity of Plant Foods, CEBAS-CSIC, P.O. Box 164, Espinardo, Murcia, 30100, Spain

ARTICLE INFO

Keywords:
Fruits and vegetables
Microbial growth
Minimally processed
Sanitizers
Processing aids
Disinfecting agents
Chlorine
Process water
Decontamination

ABSTRACT

It is well known that fresh-cut processors usually rely on wash water sanitizers to reduce microbial counts in order to maintain quality and extend shelf-life of the end product. Water is a useful tool for reducing potential contamination but it can also transfer pathogenic microorganisms. Washing with sanitizers is important in fresh-cut produce hygiene, particularly removing soil and debris, but especially in water disinfection to avoid cross-contamination between clean and contaminated product. Most of the sanitizing solutions induce higher microbial reduction after washing when compared to water washing, but after storage, epiphytic microorganisms grow rapidly, reaching similar levels. In fact, despite the general idea that sanitizers are used to reduce the microbial population on the produce, their main effect is maintaining the microbial quality of the water. The use of potable water instead of water containing chemical disinfection agents for washing fresh-cut vegetables is being advocated in some European countries. However, the problems of using an inadequate sanitizer or even none are considered in this manuscript. The need for a standardized approach to evaluate and compare the efficiency of sanitizing agents is also presented. Most new alternative techniques accentuate the problems with chlorine suggesting that the industry should move away from this traditional disinfection agent. However, the use of chlorine based sanitizers are presented as belonging to the most effective and efficient sanitizers when adequate doses are used. In this review improvements in water disinfection and sanitation strategies, including a shower pre-washing step and a final rinse of the produce, are suggested.

Contents

1. Introduction

Fresh-cut fruits and vegetables are no longer considered low risk in terms of food safety (Bhagwat, 2006; FSA, 2007). Recently, a number of outbreaks have been traced to fresh-cut fruits and vegetables that were processed under less than sanitary conditions. These outbreaks show that the quality of the water used for washing and chilling the produce after harvest is critical (CDC, 2009). It is well known that disinfection is one of the most critical processing steps in fresh-cut vegetable production, affecting the quality, safety and shelf-life of the end product. Washing is designed to remove dirt, pesticide residues and microorganisms responsible for quality loss, as well as to pre-cool cut produce and remove cell exudates that may support microbial growth (Zagory, 1999). The fresh-cut industry has used chlorine as one of the most effective sanitizers to assure the safety of their product. However, there is a trend in eliminating chlorine from the disinfection process because of the concerns about its efficacy on the produce and about the environmental and health risks associated with the formation of carcinogenic halogenated disinfection by-products (Ölmez and Kretzschmar, 2009). Most of the current investigations have been focused on the search for alternative sanitizers based on assuring the quality and safety of the produce.

* Corresponding author. Tel.: +34 968 396 275; fax: +34 968 396 213.
E-mail address: aallende@cebas.csic.es (A. Allende).

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doi:10.1016/j.ijfoodmicro.2009.05.021

However, the majority of the experiments are carried out in unrealistic conditions and the results obtained cannot be compared because of the differing experimental conditions. This review examines the need for a global approach to decontamination strategies in industry to identify solutions for the safety of produce. Additionally, the arguments for or against chlorine derived products are presented considering the sanitation of both the produce and the process water.

2. Fresh-cut product sanitation

In the last few years an important number of papers has been published concerning the efficacy of washing and sanitizing treatments in reducing microbial populations on fresh-cut produce. Some of the results are useless because of the extreme doses and excessive washing times used, the use of an unauthorized substance, e.g. (Zhang et al., 2009). A clear and well-documented comparison of different sanitation methods was compiled in the Food Safety Guidelines for the Fresh-cut Produce Industry (IFPA, 2001) and throughout the Forum on Washing and Decontamination of Fresh Produce (CCFRA, 2002–2008). The efficiency of numerous chemical and physical methods for assuring the microbiological safety of fresh-cut produce has been covered in several reviews (Parish et al., 2003; Sapers, 2003, Allende et al., 2006; Rico et al., 2007; Gómez-López et al., 2009; Ölmez and Kretzschmar, 2009).

Physical methods are effective at removing bacteria from plant surfaces by use of shear forces (Cutler, 2002). Modern aeration 'jacuzzi' washers reduce the bacterial loads on vegetables by between 1 and 2 log units. It should be consider that these reductions were obtained in lab experiments, but they are usually less evident in real processing conditions. Other physical methods include ultrasound, high pressure (HP), high-intensity electric field pulses (HELP), ultraviolet radiation (UV), radio frequency (RF) and ionizing radiation. All of these methods have been shown to be capable of killing or inhibiting bacterial growth. Ultrasound kills by intracellular cavitation but has problems in the presence of solids. It may, however, be useful to combine this technology with other methods such as aqueous ClO_2. Between 2.5 and 4.3 log reductions in *Salmonella* and *E. coli* O157:H7 counts on apples were achieved by combined ultrasound (170 kHz) and ClO_2 (20–40 mg/l) treatments depending on the exposure time (Huang et al., 2006). UV is also a promising technology but its antimicrobial efficacy can be influenced by product composition and soluble solid content of the process water (Selma et al., 2008a). Its application to a re-circulating water stream maintains the water at a reasonable bacteriological quality, but has no effect at all on surfaces either of the process machinery or on the product itself (EHEDG, 2007). As pathogens can survive for relatively long times in water, they can subsequently contaminate the product that passes through it before microbial inactivation with UV occurs. In addition, the efficacy of UV light systems as a wash water disinfectant is significantly impacted by turbidity due to the limited penetration capacity of UV, requiring filtration systems to eliminate suspended solids and absorbing compounds. New UV advanced disinfection technology systems result in a more efficient disinfection as they increase the amount of water that passes close to the UV lamp (Milly et al., 2007). The use of RF is technologically complex and rapidly raises the internal temperature of produce to be disinfected. Ionizing radiation has been shown to greatly reduce potential microbiological risk without damaging the texture/colour of the produce and does not lead to nutrient losses or have an adverse effect on the nutritional status (Niemira et al., 2003; Bari et al., 2004; Dhokane et al., 2006; Mintier and Folley, 2006). However, the long-term consumption of irradiated produce remains a cause of concern to the general public. In August 2008, U.S. Food & Drug Administration (FDA, 2008) gave its approval to use irradiation for killing pathogens on iceberg lettuce and spinach. The move comes in response to a petition filed by The National Food Processors Association, a trade group representing major food companies. Food irradiation uses high-energy Gamma rays, electron beams, or X-rays. Irradiation may be better than most technologies in penetrating fresh produce and it could be a powerful tool if used correctly in different produce items and among different varieties. The technology is publicized as the only solution for destroying internalized pathogens without cooking. In a recent study, Romaine lettuce and baby spinach were immersed in an *E. coli* O157 inoculum solution and vacuum perfusion to internalize the *E. coli* O157 (Niemira, 2008). This study showed that irradiation was effective in reducing *E. coli* O157 on lettuce and spinach, but the obtained reduction was dependent on the leaf type.

Chemical methods of cleaning and sanitizing produce surfaces usually involve the application of mechanical washing in the presence of sanitizers, followed by rinsing with potable water (Artés and Allende, 2005). A wide variety of chemical sanitizers have been tested with various degrees of effectiveness. Table 1 shows a review of the literature over the last 7 years on chlorine and alternative decontamination procedures to reduce pathogens and spoilage microorganisms on fresh-cut produce. Most of these studies examined their effect against pathogenic bacteria immediately after washing and only a few of them studied pathogen survival during storage. In general, microbial and visual quality of the washed product was evaluated and few studies examined water characteristics after treatment (Table 1).

Electrolysed Oxidising Water (EOW) has been shown to be a promising alternative decontamination technique with a strong bactericidal effect. This technique has been suggested as a valuable disinfection tool for wash water sanitation in the minimally processed vegetable industry (Ongeng et al., 2006). As an example, Ecodis® technology, based on the principles of anodic oxidation, consists in a highly efficient electrolysis cell equipped with coated permanent titanium electrodes. A direct low-voltage current passing across the electrodes causes the formation of potent oxidising agents principally derived from oxygen, as well as free chlorine when chloride ions are present in the solution. The oxygen and chloride radicals react with each other to form "free oxidants" such as hypochlorous acid (HOCl) and the hypochlorite ion (OCl^-). This technology differs from other physical decontamination technologies in that next to the direct decontamination, a residual disinfection capacity is also generated.

The combination of physical and chemical methods for washing fresh-cut vegetable produce is a useful way forward. The advanced oxidation processes (AOPs) represent the newest development in sanitizing technology, where two or more oxidants are used simultaneously (Selma et al., 2008a). The result is the on-site destruction of even refractory organics without the generation of residues. This is the case of the use of UV and hydrogen peroxide (H_2O_2) for decontaminating fresh produce (Hadjok et al., 2008). Samples of iceberg lettuce were inoculated with *E. coli* O157 and then sprayed with H_2O_2 and subjected to UV light. The same authors observed greater reductions achieved with UV/H_2O_2 treatments than with 300 mg/l chlorine for a range of products including Romaine lettuce, spinach, cauliflower, broccoli, Spanish onion and tomato (Hadjok et al., 2008).

Most of the available literature regarding the use of sanitizers has concluded that washing with water or with disinfectant solutions reduces the natural microbial populations on the surface of the produce by only 2 to 3 log units (Beuchat et al., 2004; Gonzalez et al., 2004; Inatsu et al., 2005; Ukuku et al., 2005; Allende et al., 2007; Gómez-López et al., 2007; Selma et al., 2008b). It was observed that, despite the initial differences, the total bacterial counts after storage were similar when the produce was washed with tap water or when a sanitizing solution was used (Allende et al., 2008a). Some authors have even suggested that washing with antimicrobial solutions initially reduces inoculated strains and the initial total mesophilic population, but they could increase more rapidly and even exceed the level on the water-washed counterpart during extended storage (Park and Lee, 1995; Francis and O'Beirne, 2002; Gonzalez et al., 2004; Beltrán et al., 2005; Gómez-López et al., 2007). The limitations of