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Treatment of fresh produce water effluents by non-thermal technologies

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ABSTRACT

Washing is the traditional technique applied by the fresh produce industry to reduce the bacteria load. However, this method requires a high volume of water and a big challenge for the food industry is to minimize the use of water by for example recycling the water effluents. However, in order to avoid any possible cross-contamination, a disinfection step has to be carried out before the recirculation of the water. Non-thermal technologies (i.e. ultrasound (US) and ultraviolet-C (UV-C) light) were applied in this research for the disinfection of fresh produce water effluents. Lettuce wash water was recirculated (3 L/min) for 30 min in a closed system which consisted of an US device (26 kHz, 90 μm, 41.85 W/L) and an UV-C light system (1.64 kJ/m^2). Disinfection processes of (i) US, (ii) UV-C light and (iii) US combined with UV-C light were applied (US/UV-C), and aliquots were taken at different time intervals to analyze the microbial load, the colour and the suspended particles. The US/UV-C treatment was the most efficient process tested, regarding bacteria inactivation (3.57 ± 0.39 log CFU/mL), colour reduction (43.31%) and reduction of suspended particles (30%). Moreover, chemical oxygen demand (COD) was determined at the beginning and at the end of each disinfection process. The US/UV-C treatment was reported to cause the highest COD reduction (79%) in lettuce wash water. The energy requirements of US, UV and US + UV were found to be 0.107, 0.040, 0.114 kW/h, respectively while corresponding microbial reduction in relation to the energy spent was 4.15×10^{-6} CFU/mL/J for US, 21.53×10^{-6} CFU/mL/J for UV and 8.72×10^{-6} CFU/mL/J for US/UV. These results prove that the combined effect of US and UV-C light may be a promising energy efficient disinfection technology for fresh cut wash water effluents when taking into account quality and safety parameters.

1. Introduction

One of the main problems for the food industry, and especially for the fresh produce industry is the high volume of water consumption and the high rate of waste water discharge (Ölmez & Kretzschmar, 2009). Water consumption by the fruit and vegetable industry is in the range of 2.4–11 m^3/t of fresh produce production with almost 70% being used for washing and sanitation operations (Gómez-López et al., 2014a; Lehto et al., 2014; Ölmez, 2013). In order to minimize the water consumption for the industry, water recycling systems have been proposed (Gil et al., 2009). However, the risk of cross-contamination of the fresh produce when washed in a washing tank should be taken into consideration as the recirculated water may result in an increment of the microbial loads. Using tap water that is renewed continuously could be a possible solution but it will generate a high expense for the fresh produce industry (Manzocco et al., 2015). In order to reduce the risk of cross contamination, sanitizers based on chlorine compounds have been widely applied by the fresh produce industry. These agents, in the presence of organic matter which are in high quantity in water effluents as they come from the exudates of the cut tissues (Gil et al., 2016), can generate some disinfection by-products (DBPs) which have been defined as carcinogenic compounds (trihalomethanes, haloacetic acids, haloketones and chloropicrin)

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(Nikolaou et al., 1999) and other toxic compounds without a proven carcinogenic potential such as chlorate (WHO, 2003). The generation and accumulation of DBP can occur in the wash water effluents but also in the final fresh produce. In order to reduce the formation of DBPs, growers and producers try to avoid the use of chlorine based compounds for the disinfection of process water. In the last years some alternative disinfection methods have been proposed (refer for examples to Meireles et al. (2016)). Physical disinfection technologies (i.e., US and UV-C light) have been reported as environmentally friendly processes due to their benign effects (i.e., not producing disinfection-by-products). The main advantages commonly associated to these technologies are the low cost of the equipment, the absence of toxic DBP harmful to humans and less environmental concerns (Linden et al., 1998; Lazarova et al., 1999). Recently, UV-C light has been applied for the decontamination of waste water for the food industry. Ignat, Manzocco et al. (2015) reported a reduction of more than 3.5 log CFU/mL of natural flora and more than 5 log CFU/mL on inoculated microorganisms (*Salmonella enterica*, *Listeria monocytogenes* and *Escherichia coli*) when an UV-C light system (15 W, 0.4 kJ/m^2) was applied for 60 s for the disinfection of lettuce wash water. Wulfkuehler et al. (2013) applied UV-C at 174.2 J/L on iceberg lettuce and oak leaves lettuce wash water, achieving 3.2 and 2.1 log CFU/mL of reduction of total bacteria, respectively. Similarly, Selma et al. (2008) observed 2.4 and 3.9 log CFU/mL of natural microflora reduction when an UV-C light system (15 W fluence) was applied for 60 min for the disinfection of onion and escarola wash water, respectively. In the same study, UV-C light was combined with ozone in order to enhance the bacteria inactivation. When both technologies were combined for the same amounts of time as described previously, inactivation levels increased between 3.2 and 6.6 log CFU/mL of total viable bacteria in onion and escarola wash water, respectively.

However, the antimicrobial efficacy of UV-C light is highly related to the presence of suspended particles. This is especially important in wash water coming from the fresh produce industry as the effluents contain a high level of organic load, limiting the antimicrobial efficacy of UV-C light. In order to overcome this limitation, previous studies have shown that US, which has been proved to breakdown agglomerates of bacteria (Mason et al., 1996; Vercet et al., 2001; Piyasena et al., 2003; Awad et al., 2012), can be combined with UV-C light. Naddeo, Landi, Belgiorno, and Napoli (2009) treated wastewater from domestic and industrial discharges into an US/UV-C reactor (39 kHz and 2 lamps of 150 W) reducing the presence of *E. coli* to 10 CFU/100 mL after 15 min of treatment. In the same way, Blume and Neis (2004), pre-treated wastewater with an ultrasonic system (50 W/L and 310 W/L) for 5 s in order to reduce the particle sizes before applying an UV-C treatment (37 μW/cm^2). The application of the UV-C system alone reduced fecal coliforms by 2.5 log CFU/mL while pre-US treatments (50 W/L and 310 W/L) followed by a UV-C process inactivated 3.3 and 3.7 log CFU/mL of fecal coliforms.

The combined process of US and UV-C light (US/UV-C) has been applied to disinfect wastewater. However, to the knowledge of the authors there is no published research that explored the combination of these technologies in order to disinfect wash water of fresh produce. Therefore, the purpose of this study was to assess the efficacy of US, UV-C light, and US/UV-C on the disinfection of lettuce wash water. Moreover, physicochemical properties of the treated lettuce wash water were also investigated.

2. Materials and methods

2.1. Preparation of lettuce process water

A similar procedure to that described by López-Gálvez et al. (2012) was followed for preparing the simulated lettuce wash water. For this purpose, Romain lettuce (*Lactuca sativa* L. var. longifolia) was purchased from local suppliers. Damaged outer leaves were removed and discarded. Medium and inner leaves were cut for experimental purposes. 50 g of the cut lettuce was placed into a stomacher bag (BagFilter O, Interscience, France) along with 200 mL of distilled water. The simulated waste water was homogenized in a stomacher (BagMixer 400P, Interscience, France) for 2 min. The final volume of the wash water was 2L.

2.2. Disinfection of simulated lettuce wash water

Simulated fresh produce waste water (2 L) was recirculated (3 L/min) for 30 min through a closed system which consisted of an US device (UP 200ST, Hielscher Ultrasonic, Germany) (26 kHz, 90 μm, 41.85 W/L measured by a calorimetric method following the same procedure as Millan-Sango et al. (2015)/the immersion depth was 3 cm and the probe diameter of 14 mm) and an UV-C light system (sample passes around the UV-C lamp) (LIT, The Netherlands) (1.64 kJ/m^2). Three different disinfection processes of (i) US, (ii) UV-C light and (iii) US/UV-C were applied. The applied treatments resulted in temperature increases (ΔT) that did not exceed 12.3 °C, 0.5 °C, and 12.7 °C (40 °C was the highest temperature reached), respectively. Before any disinfection process, the pump was switched on in order to circulate the lettuce wash water through the system. Preliminary studies have shown no effect on the microbial levels during the circulation of wash water because of cavitation occurred in pumps or flow restriction. A diagram of the US/UV-C disinfection process is shown in Fig. 1. Three repetitions for each process were carried out.

2.3. Bacterial sampling and enumeration

Aliquots (1 mL) were collected from the (naturally contaminated) lettuce wash water of each disinfection process at different time intervals (i.e., 0, 1, 2, 5, 10, 15, 20, 30 min). Serial dilutions of wash water samples at the different times were performed and the appropriate dilution was spread on Tryptic Soy Agar (TSA) (Oxoid, UK) plates. Samples were incubated at 30 °C for 48 h. Low microbial population counts were assessed by plating 1 mL of the sample over three TSA plates according to ISO 7218:2007. Microbial counts were expressed as log CFU/mL.

2.4. Optical density determination

Samples were collected at the same time intervals as previously described and transferred on to a spectrometric plastic cuvette (Kartell, Italy). Optical density at wavelengths of 540 nm and

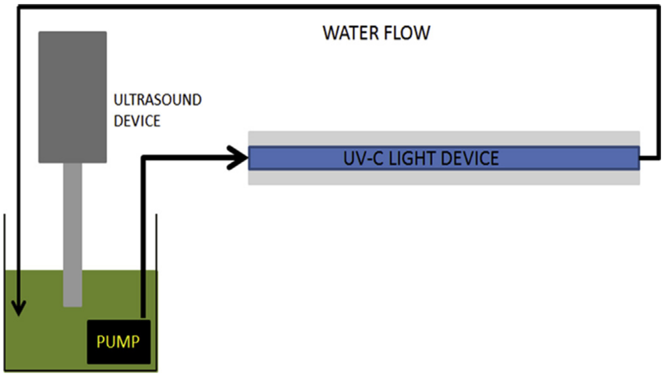

Fig. 1. Schematic diagram for the lettuce wash water processes.