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Quality of Iceberg (*Lactuca sativa L.*) and Romaine (*L. sativa L. var. longifolial*) lettuce treated by combinations of sanitizer, surfactant, and ultrasound

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ABSTRACT

The effects of sonication, sanitizers and sodium dodecyl sulfate (SDS) on the quality of fresh-cut Iceberg and Romaine lettuce were examined. Lettuce samples were treated for 1 min with and without ultrasound with one of the following solutions: tap water, chlorine, Tsunami, and a combination of Tsunami with 1 g/L SDS. Washed samples were packed under modified atmosphere conditions and stored at 4 °C for up to 14 days. Changes in headspace gases, texture, color, tissue damage, visual quality, and natural flora were determined. The O_2 concentrations and CO_2 accumulation in Romaine lettuce were not significantly different among the treatments. In Iceberg lettuce, a lower O_2 and high CO_2 content in the headspace of samples treated with Tsunami and Tsunami + SDS were recorded. After 14-day storage, the tissue damage expressed by electrolyte leakage, total color difference, firmness, and total aerobic plate counts were not significantly different among treatments in two types of lettuce samples. Treatment of Iceberg lettuce with sonication in combination with Tsunami or Tsunami + SDS did not degrade quality compared to samples treated with chlorine alone, whereas for Romaine lettuce, chlorine-treated samples had a significantly higher overall quality score than that from the other treatments.

1. Introduction

Consumption of lettuce in the U.S. has increased over the last decade due to new trends in diet that emphasize the importance and popularity of vegetable salads, the convenience offered by fresh-cut products, and increases in salad bar patronage and meals eaten outside the home (Buck, Walcott, & Beuchat, 2003; USDA, 2002). This increase in lettuce consumption has led to annual U.S. production of nearly 3950 Gg of lettuce in 2010, while in the same year 3270 Gg were imported from Mexico and Canada to meet demand (Boriss & Brunke, 2011). Increased production and consumption of lettuce has drawn significant public interest to the potential for foodborne illness associated with lettuce and other leafy green vegetables. During the period 2010–2012, three multi-state outbreaks of Shiga toxin-producing *Escherichia coli* O157:H7 and *E. coli* O145 associated with consumption of lettuce were reported (CDC-Centers for Disease Control and Prevention, 2012). These high-profile foodborne illness outbreaks highlight the importance of further improving the microbial safety of fresh produce.

Currently, the produce industry processes lettuce by cutting it into bite-size pieces, washing the cut lettuce with chlorinated water, followed by rinsing, dewatering or drying, and packaging. However, washing produce with chorine in industrial-scale operations, for instance at a throughout of 45 kg/min, has been reported to reduce the survival count of *E. coli* O157:H7 by no more than one log cycle (Luo et al., 2012). In addition, chlorine is consumed when organic matter is present, leading to an increase in turbidity of the wash water (Luo et al., 2012; O'Beirne & Zagory, 2009). The presence of organic matter in wash water can also enhance formation of chloroform ($CHCl_3$), haloacetic acids or other trihalomethanes (THM), all of which are known to be harmful to human health (Artés, Gómez, Aguayo, Escalona, & Artés-Hernández, 2009). Efforts have thus been made to find alternative and/or more effective sanitization agents/methods to enhance reduction of microbial populations.

Treatments that create an acidified environment in a washing system through the use of organic acids such as lactic, citric, peroxyacetic, and levulinic acids, or their salts, have been reported as an alternative to the traditional chlorine wash (Oms-Oliu et al.,

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2010). In tests performed in a beaker, 1.74 log CFU/g reduction of *E. coli* O157:H7 on lettuce washed with 20 g/L lactic acid for 5 min was achieved (Sagong et al., 2011). Another study reported more than a 6 log CFU/g reduction of *E. coli* O157:H7 population on lettuce when treated with 30 g/L levulinic acid in combination with the surfactant sodium dodecyl sulfate (1 g/L SDS) for 1 min (Zhao, Zhao, & Doyle, 2009). The use of a surfactant aims to allow the (dissolved) sanitizer to penetrate small cracks and crevices on the complex topography of lettuce. The combination of a chemical wash with a physical process, such as sonication, has also been tested for enhancing the efficacy of a sanitizer wash (Zhou, Feng, & Luo, 2009; Zhou, Feng, & Pearlstein, 2012).

Lettuce, unlike other fresh produce, lacks an external protective tissue, and processes like cutting expose its tissues to air, leading to a series of chemical reactions that cause damage and make the plant material vulnerable to dehydration. Several studies have shown that many sanitizing agents, such as chlorine, organic acids, ozone and some surfactants are excellent antimicrobials, especially for planktonic microorganisms. However, many of these compounds have a detrimental effect on the quality of leafy produce when used beyond certain critical concentrations, leading to quality degradation through browning, tissue damage, color changes, water segregation, and overall poor appearance (Garcia, Mount, & Davidson, 2003). For instance, Guan, Huang, and Fan (2010) reported that treatment with 5 g/L to 30 g/L levulinic acid plus 0.5 g/L SDS rendered fresh-cut Iceberg lettuce sensorially unacceptable beyond seven days due to development of sogginess and tissue damage. In general, for the development of any sanitizer or sanitization method, the effect of the treatment on produce quality is a primary consideration. The only meaningful microbial count reductions are those that are achieved for treatment times and sanitizer concentrations below the threshold for unacceptable quality changes during storage long enough to be consistent with retail sale. For this reason, this study was undertaken to examine the effects of sonication in combination with two sanitizers (chlorine and Tsunami 100®) and a surfactant (sodium dodecyl sulfate) on the quality of fresh-cut Iceberg and Romaine lettuce during 14-day refrigerated storage.

2. Materials and methods

2.1. Ultrasound-wash system

This study was carried out in a custom-made ultrasonic washing tank. The tank was made of welded aluminum sheet, with a capacity of 115 L. Two ultrasound (US) transducer blocks (each operating at 25 kHz, and with 2 kW nominal power), with sound emitting planes facing each other, were vertically placed in the tank against two walls. Prior to the start of each test the wash tank was filled with chilled tap water (10 °C) to which was added chlorine (active ingredient sodium hypochlorite), Tsunami 100® (active ingredient peroxyacetic acid), or Tsunami 100®+ sodium dodecyl sulfate (SDS). To minimize "blockage" (Zhou et al., 2012) and allow ultrasonic waves to reach each piece of the cut lettuce, a plastic holder (Fig. 1) measuring 30.48 cm × 15.25 cm × 12.70 cm ($L \times W \times H$) with mesh size of 1.21 cm × 1.21 cm was used to hold lettuce samples. The walls of the holder were made of stretchable molded polyethylene mesh (McMaster-Carr, Elmhurst, IL, USA) and the holder can hold up to 450 g of cut lettuce. The holder was submerged in the tank during treatment.

2.2. Preparation of lettuce samples

Iceberg (*Lactuca sativa L.*) and Romaine (*L. sativa L. var. longifolial*) lettuce were purchased at a local supermarket and

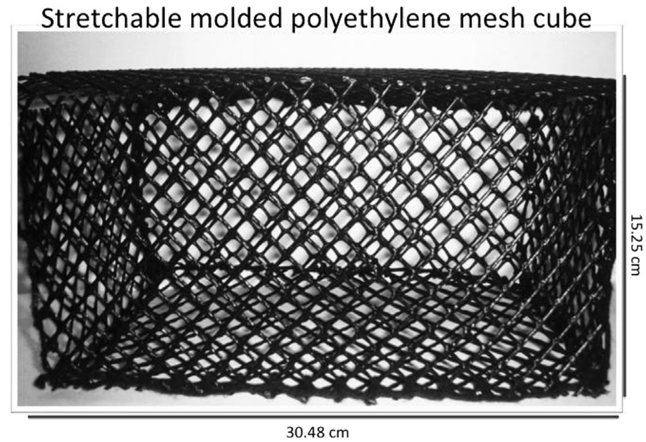

Fig. 1. Ultrasound wash system.

immediately transported to the laboratory, where they were stored at 6 ± 1 °C and used within 24 h of purchase. The three outermost leaves of each head of lettuce were removed. A kitchen knife was used to cut lettuce into pieces of 6.45 cm^2. The lettuce pieces were randomized at the beginning of the experiment and divided into batches of 300 g each for treatment.

2.3. Treatment procedure

Three hundred grams of fresh-cut lettuce were submerged in the water tank containing one of the following solutions: tap water (control), sodium hypochlorite (final free chlorine concentration 100 mg/L), Tsunami 100® (peroxyacetic acid as active ingredient, final acid concentration 80 mg/L), and Tsunami100® in combination with 1 g/L SDS. For each washing solution, samples were treated for 1 min with and without ultrasound, except for the tap-water control. After the one-minute treatment the samples were rinsed with tap water for 1 min and de-watered with a manual salad spinner (OXO, New York, NY, USA). One hundred grams of each de-watered sample were placed in polypropylene plastic film bags (OTR 7000 cc/m^2/day and CO_2 21,000 cc/m^2/day) (PD-961 EZ, Cryovac, Duncan, SC). The lettuce bags were vacuumed, flushed with N_2 using an Audionvac 101/151 packaging machine (Audion Elektro, Hogeweyselaan, Netherlands), sealed, and stored at 4 ± 1 °C until further analysis. Nine bagged samples were set aside for sampling, with three bags taken at days 0, 7 and 14 to perform triplicate quality analyses, including electrolyte leakage rate, texture, color, sensory evaluation, headspace O_2 and CO_2 content, total aerobic plate count, and yeasts and molds.

2.4. Analysis of headspace O_2 and CO_2 in package

Headspace gas in the packages was analyzed at days 0, 7 and 14 of storage. To measure the content of O_2 and CO_2 inside the packages, gas from the headspace was withdrawn through a needle using a built-in pump into a portable dual headspace analyzer (model 650, Mocon Inc. Minneapolis, MN, U.S.A.)

2.5. Visual quality

Visual quality was assessed immediately after headspace analysis of packages by a 5-member trained panelists using the same parameters as Guan et al. (2010). Overall visual quality was rated on a 9 to 1 scale: 9 = excellent, essentially free from defects; 7 = good,