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Immersion-free, single-pass, commercial fresh-cut produce washing system: An alternative to flume processing

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ABSTRACT

Fresh-cut vegetable processing in the USA typically involves submerging produce in chlorinated water that is often reused and re-circulated. However, this washing practice is water and chemical intensive and subject to rapid decreases in free chlorine concentration, which may increase the probability of water mediated microbial cross-contamination. An immersion-free, single-pass produce washing system was recently developed to address these challenges by over-head spraying clean (retreated) water, rather than spent wash water. The objective of this study was to compare single-pass and flume systems during commercial processing of fresh-cut vegetables in terms of wash water physicochemical and microbiological quality and cut produce microbiological and sensorial quality. Two products, shredded iceberg lettuce and diced cabbage, were selected; processes were evaluated for each product on three separate days. Wash water and produce were sampled every 30 min during production for 2.7 h. Water that was used to wash the produce was collected from representative locations in the single-pass (input water, pre-wash, cutter, incline wash, vibra-wash) and flume (flume A, flume A catch tank, flume B, flume B catch tank) systems. Physicochemical (free chlorine, total chlorine, pH, total dissolved solids (TDS), chemical oxygen demand (COD), turbidity) and microbial analyses (aerobic plate count (APC)) were conducted on the wash water samples. Produce samples collected after cutting and after washing were analyzed onsite for APC immediately after collection. Final packaged products were analyzed weekly for sensorial quality (visual, olfactory, overall acceptability) during three weeks of storage at 1 °C by a trained panel using a 9-point hedonic scale. Results show that the organic load indicators in wash water samples from the single-pass system were consistent over time for most sampling locations, with no statistically significant increases in turbidity, TDS, or COD during production. In contrast, the organic load indicators in wash water samples from the flume system increased significantly during production by 13–45 NTU h^{-1} for turbidity, 382–1094 mg L^{-1} h^{-1} for TDS, and 597–2772 mg L^{-1} h^{-1} for COD. For the single-pass system, the wash water from the cutter had the largest APC of 3.8–4.2 log CFU/100 mL and the highest values of organic load indicators (152–186 NTU for turbidity, 623–904 mg L^{-1} for TDS, and 4420–4673 mg L^{-1} for COD) compared to the wash water from all the other processing stages (input water, pre-wash, incline, vibra-wash), which ranged from < 0.6–2.4 log CFU/100 mL for APC, 0.3–97 NTU for turbidity, 245–471 mg L^{-1} for TDS, and 62–1942 mg L^{-1} for COD. There were no significant differences ($p > 0.05$) in APC between the single-pass and flume washed product samples; APC on the final product samples ranged from 3.2 to 3.4 log CFU g^{-1} for lettuce and 3.9–4.1 log CFU g^{-1} for cabbage. Panelists rated the quality of the products washed using the single-pass system as comparable to those washed using the flume system within the first two weeks and slightly better after three weeks of storage. Results from this study could be used by the produce industry to further optimize the single-pass system and develop additional processing innovations to improve the safety, efficacy, economics, and environmental impacts of produce washing systems.

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1. Introduction

Immersion-based fresh-cut produce washing in chlorinated water has been widely used in the United States, since the inception of the fresh-cut produce industry. However, this process generally requires substantial water and chemical use (Manzocco et al., 2015; Castro-Ibanez et al., 2017). A typical immersion-based process for fresh-cut produce includes cutting, a sequential double flume wash using chlorinated water, water removal, and packaging (Maffei et al., 2016; Gil et al., 2015; Artés et al., 2009). At the start of a typical flume washing operation in the USA, fresh, potable water is mixed with chlorine in the form of sodium hypochlorite and the pH is adjusted using an acidulant. Economic and environmental considerations make it necessary to reuse spent wash water during production (Manzocco et al., 2015). Many batches of cut produce (thousands of kilograms) are washed in these same tanks of water during each shift; a small amount of fresh chlorinated water is periodically added back to the tanks to maintain a constant volume. This practice results in the accumulation of organic matter in the wash water, including dirt and produce exudate from the cut tissue, which readily neutralizes free chlorine (Gil et al., 2009; Gombas et al., 2017; Holvoet et al., 2012; Gòmez-López et al., 2013; Allende et al., 2008). For this reason, chlorine must be added to the flume water regularly in order to maintain the sanitizer efficacy and prevent the survival of microorganisms in the wash water. The rapid consumption of free chlorine in the presence of a high organic load makes maintaining a stable, free chlorine level challenging; it also increases the probability that a food safety hazard will occur, as failure to maintain a minimal free chlorine level may provide opportunities for the survival and spread of foodborne pathogens (Gombas et al., 2017; Luo et al., 2011; Murray et al., 2018).

Commercially available control systems can maintain a desired free chlorine level during industrial produce washing in flume systems for some products, such as chopped lettuce or baby spinach. However, these control systems may not be as effective in maintaining a stable free chlorine level for other types of products with higher organic loads, such as shredded carrot, chopped onion, and diced cabbage. Due to the challenge of maintaining a stable free chlorine level in the wash water, there could be an increased probability of microbial cross-contamination over time, as more product is washed in the same water. Additional challenges of using flume systems include a decline in wash water quality over time and a build-up of chlorination disinfection by-products in the wash water (Gil et al., 2015; Luo et al., 2018).

To address these challenges, McEntire et al. (2016) developed and patented a single-pass commercial system that uses retreated, spent wash water (solids and organics removed to produce clean, fresh water) in a series of over-head sprayers. This newly developed immersion-free washing system sprays chlorinated water onto fresh-cut produce in a single-pass, avoiding the recirculation of spent wash water with its accumulated organic load. While the system is referred to as single-pass because the water is not recirculated, the produce is sprayed multiple times as it is conveyed along a belt under a series of overhead spray bars. The system is also designed to tumble the produce so both sides are exposed to the chlorinated wash water. The spent wash water is collected at an onsite water treatment facility and the reclaimed water is reused to wash produce. By using clean chlorinated wash water in a single-pass approach, a higher concentration of sanitizer can be more easily maintained while decreasing the total chemical consumption compared to traditional fresh-cut washing methods (McEntire et al., 2016). The single-pass system includes an optional pre-wash of the whole heads of produce (e.g., lettuce or cabbage), cutting, spraying water on the product using an inclined belt and a series of vibrating screens, water removal, and packaging (McEntire et al., 2016).

Several studies conducted in commercial fresh-cut produce operations have published results focused on the characteristics and dynamic changes in flume washing systems (Barrera et al., 2012; Luo et al., 2018; Murray et al., 2018; Holvoet et al., 2012; Maffei et al., 2016; Allende et al., 2004; Meireles et al., 2017; Salomonsson et al., 2014). The recently developed single-pass system has not been characterized previously nor has it been compared to a flume system. Therefore, the objective of this study was to compare single-pass and flume systems during commercial processing of fresh-cut lettuce and cabbage. Specifically, we aimed to compare the wash water physicochemical and microbiological quality, and the cut produce microbiological and sensorial quality between the two systems.

2. Materials and methods

2.1. Fresh-cut processing plant operation

This study was conducted during the regular commercial operation of a medium-size fresh-cut produce processor in the USA; this unique processing plant used both single-pass and flume washing systems for fresh-cut produce processing. Field-cored iceberg lettuce (*Lactuca sativa* var. *capitata*) and whole cabbage (*Brassica oleracea* var. *capitata*) were stored for less than two days at 5 °C before processing.

Iceberg lettuce was sliced into 6 mm strips using a TranSlicer® 2510 Cutter (Urschel Laboratories Inc., Chesterton, IN, USA). Cabbage, after onsite coring, was diced into 6 mm squares using a Diversa Cutter (Urschel Laboratories Inc.) with water injection. The cut vegetable pieces were immediately washed using either the single-pass or the flume system (described in Section 2.2) with a targeted residence time of 30 s. Input water was pre-chilled to 4 °C, chlorinated with sodium hypochlorite, and pH adjusted with a phosphoric acid-based acidulant (Lemons, 2016; Luo et al., 2012). The temperature of the processing facility was approximately 4 °C. The processing throughput was approximately 20 and 30 kg min^{-1} in the single-pass system and 30 and 50 kg min^{-1} in the flume system for iceberg lettuce and cabbage, respectively. After washing in chlorinated water and rinsing in potable water, the same centrifugal water removal and packaging methods were employed for products from both washing processes.

2.2. Vegetable washing systems

The single-pass system (McEntire et al., 2016) consisted of a series of over-head sprayer manifolds installed over a pre-cutter incline belt (pre-wash), post-cutter incline belt (incline wash), and a cascade of vibrating screens (vibra-wash) designed to tumble the cut product (Fig. 1A). Chlorinated, pH adjusted potable water chilled to 4 °C was used in this single-pass, non-recirculated spraying system. The spent wash water was collected at an ancillary water treatment facility, reclaimed (treated to generate potable water), and re-used in the single-pass system to conserve and improve water usage efficiency. The water treatment facility (approximately 750 L min^{-1} capacity) was equipped with conventional coagulation, flocculation, and sedimentation treatments, as well as advanced ultrafiltration, reverse osmosis, and ultraviolet treatments (AVANTech, Inc., Columbia, SC, USA). After conventional and advanced treatments, the water was chlorinated and blended with city potable water or well water. This blended water was transferred to a batch tank connected to the single-pass system; the final water chlorination was controlled in the batch tank using an automated pH and free chlorine feedback system (Automated Analytic Platform™, Smart Wash Solutions Inc, Salinas, CA, USA).

The flume system consisted of a primary flume (9000 L, flume A) and a secondary flume (7000 L, flume B) (Luo et al., 2018). A de-watering shaker with a 1 mm screen at the end of each flume allowed the spent wash water to be collected into catch tanks, both primary (catch tank A) and secondary (catch tank B), where it was reconditioned (fresh water added, chlorine replenished, pH controlled) and recirculated back into the respective flumes (Fig. 1B). A portion of the recirculated wash water was chilled to 4 °C and the water from flumes A and B was kept in separate lines inside the chiller and were not mixed. Wash water chlorination in each flume was controlled using automated pH and free