Effect of alternatives to chlorine washing for sanitizing fresh coriander

Haiyan Gao^{1,2,3} · Xiangjun Fang^{1,2,3} · Yunlong Li^{1,2} · Hangjun Chen^{1,2,3} · Qi Fa Zhao⁴ · Tony Z. Jin⁵

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Abstract Fresh coriander leaves are highly perishable in nature and their sensory quality and nutritional value decreases without proper processing or preservation. In the present study, three aqueous solutions of sodium hypochlorite (SH, 100 mg/L), chlorine dioxide (CD, 10 mg/L), and sodium butyl *p*-hydroxybenzoate (SBPH, 12 mg/L), and tap water, were used to treat fresh coriander for 15 min. The treated samples were packed in PVC boxes with ambient air under packaged under passive modified atmosphere packaging conditions and stored at 4 °C for 10 days. Effects of washing treatments on color, total chlorophyll contents, ascorbic acid contents, total contents of phenolic compounds, and total aerobic bacterial counts (APC) were investigated. CD treatment has the least detrimental effects on color, total chlorophyll contents and ascorbic acid contents of fresh coriander, followed by SH treatment. In addition, CD treatment showed a greater

reduction in APC and maintained the microbial load at lower levels than other treatments during the 10-day storage period.

Keywords Fresh produce · Decontamination solutions · Quality · Shelf life · Microbial load

Introduction

Coriander (*Coriandrum sativum* L.) is an annual herb belonging to the Apiaceae (Umbelliferae) family (Purse-glove et al. 1981). The fresh green leaves, commonly known as cilantro or Chinese parsley (Potter 1996), are widely featured in the cuisines of China, Mexico, South America, India and Southeast Asia. They possess unique aroma and also are widely used as food flavoring or to mask unpleasant odors of certain foods (Potter 1996; Gil et al. 2002).

Fresh coriander leaves are highly perishable in nature and require immediate processing or preservation, hence, drying is the major processing technology used for coriander leaves. However, drying has a limitation on aromatic herbs as it results in considerable losses of flavonoid components and attractive color pigments (Baranowski 1985; Pezzutti and Crapiste 1997). Therefore, there is a need for alternate processes for shelf-life extension of coriander.

Currently, most fresh or fresh-cut products are washed in chlorinated water (50–200 mg/L of active chlorine) to reduce levels of microorganisms and avoid cross-contamination between batches of produce as well. Sodium hypochlorite (NaClO) is the most widely used sanitizer in the fresh-cut industry (Lee and Baek 2008). Nevertheless, concerns about its limited efficacy and the toxicity of chlorination by-products formed in the presence of organic

✉ Hangjun Chen
spshangjun@sina.com

✉ Tony Z. Jin
tony.jin@ars.usda.gov

¹ Food Science Institute, Zhejiang Academy of Agricultural Science, Hangzhou 310021, Zhejiang, P.R. China

² Key Laboratory of Fruits and Vegetables Postharvest and Processing Technology Research of Zhejiang Province, Hangzhou 310021, P.R. China

³ State Key Laboratory Breeding Base for Zhejiang Sustainable Pest and Disease Control, Hangzhou 310021, P.R. China

⁴ Zhejiang Zhongfa Agricultural Science and Technology Development Co., Ltd., Hangzhou, P.R. China

⁵ Eastern Regional Research Center, Agricultural Research Service, U.S. Department of Agriculture, 600 E. Mermaid Lane, Wyndmoor, PA 19038, USA

matter stimulate the continuous search for more effective and more innocuous alternative sanitization strategies (Ölmez and Kretzschmar 2009). One of the postulated alternatives to sodium hypochlorite is an aqueous solution of chlorine dioxide (ClO_2), which possesses higher oxidation capacity and forms fewer halogenated by-products (Richardson et al. 2000; Hua and Reckhow 2007; Gómez-López et al. 2009). Butyl *p*-hydroxybenzoate and its salt have been widely used as preservatives in foodstuffs due to their broad spectrum of antimicrobial activity, stability over a broad pH and temperature range and overall safety (Wang et al. 2011). However, little information has been published regarding a comparison of the efficacy of these three sanitizer washing treatments and storage time on total aerobic bacterial counts and quality of fresh coriander, especially on the contents of bioactive compounds, which are highly relevant in leafy greens (Gómez-López et al. 2008).

Therefore, the objective of this study was to evaluate the impact of three sanitizer washing treatments (aqueous chlorine dioxide, sodium hypochlorite, and butyl *p*-hydroxybenzoate) on total aerobic bacterial counts, sensory quality (color), total chlorophyll content, ascorbic acid (vitamin C) content, and total phenolic compounds of fresh coriander during storage at 4 °C and 80% relative humidity over a 10d period. Regular tap water washing was used as a control.

Materials and methods

Plant material

Coriander samples were purchased from a local supermarket (Hangzhou, China) and transported within 30 min to the laboratory and then were allowed to equilibrate at 6–8 °C for 2 h. Damaged and yellow colored leaves were discarded. The coriander samples were washed under running tap water to remove any dirt before further treatment.

Sanitizing washing, packaging and storage

Aqueous solutions of sodium hypochlorite (100 mg/L), chlorine dioxide (10 mg/L) and sodium butyl *p*-hydroxybenzoate (12 mg/L) were prepared onsite before the experiments. Washing solutions were prepared immediately before application and used within 30 min. All chemicals were purchased from Hangzhou East China Pharmaceutical Group Co., Ltd.

Each batch of coriander (1000 g) was washed for 15 min at 22 ± 2 °C under constant agitation in 20 L of tap water (TW), sodium hypochlorite (SH), chlorine

dioxide (CD) and sodium butyl *p*-hydroxybenzoate (SBPH). The washing time of 15 min was referred to the method of Singh et al. (2002) and Fang et al. (2016). After washing, coriander was rinsed for 1 min in tap water. Excess water was eliminated by the use of a manually operated spinner for 1 min. All the procedures were conducted in a processing room at 4 °C under sanitary conditions. 100 g samples of washed coriander were randomly selected, packed in a 1 L PVC box, and sealed with polyamide-cast polypropylene (PA-CPP) film (O_2 permeability $44.7 \text{ cm}^3/\text{m}^2 \text{ 24 h 0.1 MPa}$). All boxes were stored at 4 °C for up to 10 days. Samples were analyzed at 2-day intervals. At each sampling time, five boxes from each group were randomly selected and analyzed for changes in color, ascorbic acid contents, chlorophyll contents, total phenolic compounds and total aerobic bacterial counts.

Color determination

The color of coriander samples was determined using a handheld portable Chroma Meter (HYGROLAB CR-400, Konica Minolta, NJ, USA). Prior to use, the instrument was calibrated using black and white standard tiles. The results were expressed in terms of L^* , a^* , and b^* values, where L^* represents lightness, a^* represents chromaticity on a green (–) to red (+) axis and b^* represents chromaticity on a blue (–) to yellow (+) axis.

Analysis of ascorbic acid

Ascorbic acid (AA) contents were determined as described by Arakawa et al. (1981). Briefly, 1 g of coriander sample was extracted in 5.0 mL of 5% trichloroacetic acid (TCA), and then 1.0 mL of the sample extract solution was added with 1.0 mL of 5% TCA, 1.0 mL of ethyl alcohol (EtOH), 0.5 mL of 0.4% H_3PO_4 -EtOH, 1.0 mL of 0.5% Bathophenanthroline (BP)-EtOH, and finally 0.5 mL of 0.03% FeCl_3 -EtOH. After addition of FeCl_3 -EtOH, the solution was allowed to stand at 30 °C for 90 min for the Fe_2^+ -BP complex to develop. The absorbance of the color solution is read at 534 nm in the spectrophotometer. The results were expressed as mg AA per 100 g fresh sample weight (fw).

Analysis of total phenolic compounds

The total phenolic content of coriander was determined spectrophotometrically by the Folin-Ciocalteu method according to the procedure reported by Matejić et al. (2013) with some modifications. Briefly, 300 μL of methanol and water extracts solution and 1500 μL of 1:10 Folin-Ciocalteu reagent were mixed and after 6 min in darkness, 1200 μL of sodium carbonate (7.5%) were added.

After 2 h of incubation in the dark at room temperature, the absorbance at 740 nm was measured (UV-754, Shanghai Precision & Scientific Instrument Co., Ltd., Shanghai, China). The total phenolic concentration was calculated from gallic acid (GA) calibration curve (10–100 mg/L). Data were expressed as gallic acid equivalents (GA)/g of extracts averaged from 3 measurements. Results are expressed as mg per 100 g fresh sample weight (fw).

Analysis of total chlorophyll contents

Chlorophyll was extracted from 5 g macerated coriander by homogenizing it in 20 mL of 80% acetone with a tissue homogenizer (DS-1, Shanghai Sample Model Factory, Shanghai, China) at 35,000 rpm for 30 s. The homogenate was filtered through four layers of cheesecloth, centrifuged at $15,000 \times g$ for 15 min, and absorbance (Abs.) was read at 652 nm with an UV–vis recording spectrophotometer (UV-754, Shanghai Precision & Scientific Instrument Co., Ltd., Shanghai, China). The total chlorophyll content was calculated by the following equations, where V is total volume used for extraction (mL); m is sample weight (g); n is dilution times:

$$\begin{aligned} \text{Total Chlorophyll concentration, Ct} \\ = (A_{652} \times 1000) / 34.5 \text{ (mg/mL)} \end{aligned}$$

$$\begin{aligned} \text{Chlorophyll concentration in leaf sample, Cs} \\ = (Ct \times V \times n) / (m \times 1000) \text{ (mg/g fresh weigh)} \end{aligned}$$

Microbial Analysis

Coriander samples from each box were evaluated to determine microbial load per the standard plate count method. Total plate count agar (PCA, Shanghai Dingguo biotechnology Co. China) was used to determine total aerobic bacterial counts. A 10 g sample was diluted with 90 mL of 0.1% sterile peptone water and homogenized with a sterilized kitchen blender homogenizer for 10 min. The sample was serially diluted and one mL of each dilution was transferred to a sterile petri plate. 15–20 mL of sterile total plate count agar media at temperature 40–45 °C was poured into each petri plate, mixed well and allowed to set. Plates were incubated at 37 °C for 48 h. At the end of the incubation period the colony forming units (CFU) were counted and multiplied by the appropriate dilution factor to obtain total plate counts.

Statistical analysis

The experiments were triplicate in different days, three packages were sampled in each experimental trial, and all data were pooled and analyzed by SAS software 9.1 (SAS

Institute, Cary, NC, USA). Statistical comparisons between variables (control and washing treated samples) were performed with Least Square Differential method (LSD). Differences were considered significant at $p < 0.05$.

Results and discussion

Effect on color

Figure 1 shows the effects of washing treatments on color of coriander during storage at 4 °C for 10 days. Coriander samples with SH and CD washing treatments had significantly lower L^* , a^* , and b^* values than those with TW and SBPH washing treatments throughout the 10 days storage period (Fig. 1). Hunter 'a' and 'b' color values of the coriander samples in storage were not significantly affected until day 6 (Figs. 1b, c). Coriander samples subject to CD and SH washing treatments had highly negative 'a' values that denote a high degree of product greenness (Fig. 1b). Coriander samples subject to CD and SH washing treatments maintained samples at low b^* values that denote a low degree of crop yellowness throughout the 10 day storage period. In addition, there was no significant difference ($p < 0.05$) between CD and SH washing treatments in color changes. The data indicates that CD and SH washing treatments are more effective than other washing treatments in keeping color stable during storage at 4 °C.

Effect on chlorophyll content

Decreases in chlorophyll content for all coriander samples during storage were observed (Fig. 2). Samples with SH and CD washing treatments had significantly lower decreases in chlorophyll content than those with TW and SBPH treatments. There was no significant difference ($p > 0.05$) between SH and CD treatments in chlorophyll content of the coriander through the 10 days storage. SBPH treatment caused the greatest decrease in chlorophyll content, followed by TW treatment after 6 days. The reduction of the chlorophyll content in coriander caused the samples to turn yellow, corresponding to the increase of a^* and b^* values (Fig. 1).

Effect on ascorbic acid and phenolic compounds

Changes of ascorbic acid (vitamin C) and phenolic compounds contents in coriander after washing treatments and during storage are shown in Figs. 3 and 4, respectively. The content of ascorbic acid was 43 mg/100 g fw at Day 0. For all the samples, ascorbic acid contents were reduced

Fig. 1 Effect of washing treatments on color of coriander stored for 10 days at 4 °C. Values are the mean of three replicates and vertical bars represent the standard deviation ($n = 9$). TW: tap water; SH:

sodium hypochlorite; CD: chlorine dioxide; and SBPH: sodium butyl *p*-hydroxybenzoate. **a** L^* value; **b** a^* value; **c** b^* value

after washing and throughout storage regardless of the washing solution. However, after 10 days, the ascorbic acid contents of coriander were 26, 23, 19, 15 mg/100 g for CD, SH, TW, and TW, respectively, indicating that CD and SH washing treatments had less impact on ascorbic acid than SBPH and TW (Fig. 3). Phenolic contents of all samples were reduced after washing and throughout storage (Fig. 4). Similar to ascorbic acid, CD washing treatment had the least impact ($p < 0.05$) on phenolic contents, followed by SH washing treatment.

Other studies also indicated that gaseous chlorine dioxide might have an impact in decreasing the content of phenolic compounds and vitamin C (Gómez-López et al. 2008; Vandekinderen et al. 2009a, b). In this study, washing treatments and storage time had a significantly ($p < 0.05$) detrimental effect on the ascorbic acid (VitC) and phenolic contents of coriander. However, aqueous chlorine dioxide (CD) and sodium hypochlorite (SH) washing treatments had significantly less impact than other two washing treatments.

Effect on microbial growth

The initial aerobic bacterial loads in coriander samples were around 7.00 log CFU/g. Washing treatments resulted in microbial reductions by 2.8–4.5 log CFU/g (Fig. 5), depending on the washing solution. CD washing treatment achieved the greatest reduction in initial aerobic bacterial loads followed by SH washing treatment. However, bacterial growth on all washed samples during storage was observed. CD washing treatment significantly reduced the bacterial growth rate during storage compared to the other washing treatments. Consequently, coriander samples after CD washing had the lowest bacterial counts at 6, 8, and 10 days of storage.

Unwashed coriander showed typically high initial microbial loads. Aerobic bacterial counts (APC) on coriander before washing were very similar in all the replications, with an average value of 7.00 log CFU/g. The obtained bacterial counts agree with the initial aerobic mesophilic bacterial counts reported by Allende et al.

Fig. 2 Effect of washing treatments on the content of chlorophyll in coriander stored for 10 days at 4 °C. Values are the mean of three replicates and vertical bars represent the standard deviation (n = 9). TW tap water, SH sodium hypochlorite, CD chlorine dioxide, and SBPH sodium butyl *p*-hydroxybenzoate

Fig. 3 Effects of washing treatments on the content of ascorbic acid of coriander stored for 10 days at 4 °C. Values are the mean of three replicates and vertical bars represent the standard deviation (n = 9). TW tap water, SH sodium hypochlorite, CD chlorine dioxide, and SBPH sodium butyl *p*-hydroxybenzoate

(2009) (7.0 log CFU/g) and Wang et al. (2004) (6.7 log CFU/g). Babic and Watada (1996) attributed this elevated contamination to the fact that coriander is a low-growing crop. The coriander leaf pattern also contributes to its susceptibility to microbial growth by providing a large exposed surface area for microbial attachment and growth. In order to prevent microorganisms from reaching undesirable levels in fresh produce, microbial contamination should be minimized and initial counts before storage can be decreased by using decontamination treatments. Therefore, a sanitizing procedure is often used in the

Fig. 4 Effects of washing treatments on the total phenol content of coriander stored for 10 days at 4 °C. Values are the mean of three replicates and vertical bars represent the standard deviation (n = 9). TW tap water, SH sodium hypochlorite, CD chlorine dioxide, and SBPH sodium butyl *p*-hydroxybenzoate

Fig. 5 Effects of washing treatments on total aerobic bacterial growth of coriander stored for 10 days at 4 °C. Values are the mean of three replicates and vertical bars represent the standard deviation (n = 9). TW tap water, SH sodium hypochlorite, CD chlorine dioxide, and SBPH sodium butyl *p*-hydroxybenzoate

production of fresh coriander for improved quality, shelf-life and safety, and also for cross contamination avoidance.

The washing process helped to reduce the total microbial load. It was found that washing the coriander with tap water (TW) significantly reduced APC by 2 logs. As expected, addition of sanitizers in the washing step exerted greater microbial reductions than washing with tap water. CD washing was the most effective in reducing the microbial load, followed by SH washing (Fig. 5). Although microbial growth during storage was observed, the reduction of the microbial load after washing helped to maintain the quality of coriander. Allende et al. (2009) studied the impact of four sanitizer washing treatments on aerobic mesophilic bacterial populations of fresh-cut cilantro and reported a 1–1.3 log CFU/g reduction in these bacterial

populations after SH washing for 1 min, which is less than the results obtained in the present study. The variations in the results are possibly due to the different washing times used (15 vs. 1 min).

Consumers take product appearance into consideration as a primary criterion (Kays 1999). Color is one of the main attributes that characterizes the freshness of most vegetables. Browning of fresh fruit and vegetables reduces quality (Shewfelt 1994) and is often the factor limiting shelf-life and marketability of fresh-cut lettuce (Bolin and Huxsoll 1991; Couture et al. 1993; López-Gálvez et al. 1996). Sothornvit and Kiatchanapaibul (2009) also used the visual quality as a key factor to determine the shelf-life of fresh-cut asparagus. As shown in Fig. 1, the a^* and b^* values of coriander samples increased during storage, which indicated the decrease in greenness (a^* value) and the increase in yellowness (b^* value). This study shows the CD washing treatment improved the color stability of coriander (Fig. 1) along with slowest deposit rate of chlorophyll (Fig. 2) during storage at 4 °C. In addition, the greater retention of ascorbic acid and total phenolic compounds in samples with CD washing treatment than other washing treatments suggested that CD washing could also preserve the nutritional quality of coriander. As few studies reported the use of SBPH as washing solution for fresh produce, there was no published explanation why SBPH caused the stronger decrease in ascorbic acid (vitamin C) and phenolic compounds contents during storage than other washing treatments (Figs. 3, 4). The possible explanation could be relating to the microbial growth. As shown in Fig. 5, SBPH treated samples had highest microbial populations after 10 d storage.

Fresh plant products consist of living tissues with respiratory activity, which consume O_2 and generate carbon dioxide. The O_2 levels that cause anaerobic reactions vary among commodities. As a general rule of thumb, a minimum of 1 to 3% O_2 is required around a commodity to avoid a shift from aerobic to anaerobic respiration (Arvanitoyannis and Gorris 1999). In the present study, the O_2 concentration decreased from 20 to 5.3% and the CO_2 concentration increased from 0 to 16.7% after 10 d storage, suggesting that the passive MAP slowed the respiratory activity of corianders without triggering anaerobic respiration. Similar results were observed by Waghmare and Annapure (2015) who used the similar packaging materials for coriander. Nevertheless, active MAP with different gas composites will be conducted to optimize the packaging conditions with CD washing.

Conclusion

The present study demonstrates that the use of aqueous chlorine dioxide (CD) treatment at the applied dose of 10 mg/L was equally or more effective than sodium

hypochlorite (SH) treatment at the applied dose of 100 mg/L. Aqueous chlorine dioxide treatment had the least detrimental effect on the sensory and nutritional quality of fresh coriander during storage at 4 °C for 10 days. Aqueous chlorine dioxide washing can be an effective alternative to sodium hypochlorite for washing fresh coriander, thus preventing the loss of sensory and nutritional quality and extending the shelf-life. Since only one washing condition and one packaging condition were investigated in this study, more research is needed to obtain the optimal combination of MAP and CD washing for corianders.

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