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DEVELOPMENT OF A PRESERVATION TECHNIQUE FOR STRAWBERRY FRUIT (*FRAGARIA* × *ANANASSA* DUCH.) BY USING AQUEOUS CHLORINE DIOXIDE

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ABSTRACT

Effects of aqueous chlorine dioxide (ClO_2) treatment on preserving strawberry fruit (*Fragaria* × *ananassa* Duch.) were investigated. A stabilized ClO_2 powder was dissolved in water to prepare the ClO_2 solution. Strawberry fruit were then rinsed with ClO_2 solutions at different concentrations (20, 40, 60, and 80 mg/L) for different times (5, 10, and 15 min) at 22±2℃ and 70±5% RH. Following ClO_2 treatments, strawberries were stored at 4℃ for 9 days. ClO_2 could markedly delay changes in firmness, slow down weight loss, and decay, and maintain sensory quality of strawberry fruit. ClO_2 was also effective in retention of ascorbic acid, reducing sugar, and titratable acid. ClO_2 concentration and treatment time were two significant factors ($P<0.05$). Strawberry fruit treated by 60 mg/L ClO_2 for 15 min were effectively preserved, the shelf-life of which were prolonged to 9 days compared to 5 days for the untreated control. ClO_2 treatment was demonstrated to be a promising preservation technique for strawberry fruit.

Keywords: Chlorine dioxide, strawberry, *Fragaria* × *ananassa* Duch., preservation, storage, shelf-life, postharvest

INTRODUCTION

Strawberries are one of the most delicious and nutritious fruits. Strawberries are a non-climacteric fruit and must be harvested at full maturity to achieve the maximum quality according to flavor, nutritional value, sensory quality, and texture **(Hernández-Munñz *et al.*, 2006)**. Strawberry fruit are perishable after harvest due to their physiological characteristics and susceptibilities to be mechanically damaged and infected by phytopathogenic fungi, bacteria and viruses **(Schestibratov and Dolgov, 2005)**. As a consequence, strawberries may lose their sensory properties and nutrients during storage. Currently, varieties of chemical additives have been employed to maintain the postharvest storage quality of strawberry fruit **(Simpson *et al.*, 2003; Simpson *et al.*, 2004)**. However, these chemical treatments are usually high-cost, low-efficiency, and potentially harmful. Thus, physical methods such as heat, low temperature, modified atmosphere, and irradiation have been reported **(Vicente *et al.*, 2002; Ayala-Zavala *et al.*, 2004; Allende *et al.*, 2007; Zheng *et al.*, 2007; Martínez and Civello, 2008; Nielsen and Leufvén, 2008; Pombo *et al.*, 2009)**. Most of the physical treatments have showed potential negative effects on nutritional and flavor components of strawberry fruit **(Breitfellner *et al.*, 2003; Cordenunsi *et al.*, 2003; Sahari *et al.*, 2004; Terefe *et al.*, 2009)**. Therefore, exploring and utilizing new techniques to maintain the postharvest quality of strawberry fruit is necessary.

Chlorine dioxide (ClO_2) is a novel disinfectant and decontaminant. Because of its nontoxicity and not reacting with organic compounds to produce toxic chlorinated by-products **(Gómez-López *et al.*, 2007)**, aqueous ClO_2 has already been approved by FDA since 1998 for sanitizing fruits and vegetable surfaces **(FDA, 2014)**. Our previous research has demonstrated the beneficial effects of ClO_2 treatments on the storage quality of fresh-cut asparagus lettuce, mulberry fruit, plum fruit, and chestnut kernel **(Chen *et al.*, 2010; Chen *et al.*, 2011; Chen and Zhu, 2011a; Chen and Zhu, 2011b)**. However, research that mainly focuses on effects of ClO_2 on postharvest storage quality and nutritional components of strawberry fruit is extremely scarce. The objective of this study was thus to develop a preservation technique for strawberry fruit by using aqueous chlorine dioxide. This will be the first study on the effects of aqueous ClO_2 treatment on the storage quality and shelf-life of strawberry fruit.

MATERIAL AND METHODS

Fruit material and preparation

Strawberries (*Fragaria* × *ananassa* Duch. cv. Fengxiang) were harvested at full maturity (Total soluble solids: 7.5±0.2%) at an orchard at Taian, China and immediately transported to the laboratory. Fruits were then sorted to select the ones with uniform size and color but without physical damage or decay.

ClO_2 preparation

Stabilized ClO_2 powder (Charmstar, Tianjin Charmstar Technology Development Co., Ltd, Tianjin, China) was dissolved in deionized water to prepare a stock solution with the concentration of about 100 mg/L according to the manufacturer's instructions. The concentration was measured by a standard method using iodimetry right before use **(APHA, 1998)**. ClO_2 solutions at specified concentrations could be prepared through dilution with deionized water.

ClO_2 treatment

Strawberries were washed with tap water and drained well. Fruits were then immersed into ClO_2 solutions at different concentrations (20, 40, 60, and 80 mg/L) for different times (5, 10, and 15 min) with a ratio of 1 kg:5 L (Strawberry:ClO_2 solution) at 22±2℃. Solution residues on fruit surfaces were drained off after each treatment. Strawberries were then rinsed in potable tap water for 1 min according to the FDA information (FDA, 2014) and then air-dried. Each treated group was packaged into an individual aseptic polyethylene bags (350 mm × 250 mm, 0.02 mm thick; Baileyuan, Weifang Baileyuan Fresh-keeping Package Co., Ltd, Weifang, China) and stored at 4℃ for 9 days. Samples treated with potable tap water were regarded as the control to simulate the commercial industrial processing.

Firmness

Fruit firmness was measured every day during storage using a portable firmness tester (GY-1, Zhejiang Top Instrument Co., Ltd, Zhejiang, China). Each sample was tested twice on opposite sides of the equatorial zone.

Weight loss

Strawberries were weighed right after treatments, and thereafter each day during the 9-day storage. Weight loss was expressed as percentage loss of the initial total weight.

Decay rate

Decay degree was evaluated on a modified 0-3 decay scale based on the surface area of macroscopic lesions, where 3 = unacceptable, more than 30% of surface area showing decay; 2 = bad, 10-30% of surface area showing decay; 1 = acceptable, less than 10% of surface area showing decay; 0 = excellent, no visible decay detected **(Zheng *et al.*, 2005)**. The overall decay rate of each treatment was calculated using the following formula:

$$\text{Decay rate (\%)} = \frac{\sum(\text{Decay scale} \times \text{Number of fruit})}{\text{Highest decay scale} \times \text{Total number of fruit}} \times 100\%$$

Contents of ascorbic acid, reducing sugar, and titratable acid

The ascorbic acid, reducing sugar, and titratable acid contents of strawberry fruit were determined according to Li *et al.* **(2009)**. The ascorbic acid was titrated using 2,6-dichloroindophenol titration method and its content was expressed as mg per 100 g of strawberry fruit. The content of reducing sugars was determined by the Fehling's method and was calculated as g of glucose per 100 g of strawberry fruit. The content of titratable acids was obtained by titration with 0.1 mol/L sodium hydroxide to pH 8.2 and expressed as g of malic acid per 100 g of strawberry fruit.

Shelf-life

After the study on the effects of ClO_2 treatment on above storage quality parameters of strawberry fruit, the ideal ClO_2 treatment condition was obtained to conduct the shelf-life study. Both the untreated control and ClO_2 treated strawberries were stored at 4ºC for 60 d for the shelf-life study. Samples washed with potable tap water were used as the control. Fruits were taken for microbial growth assay and sensory quality evaluation on day 0, 3, 5, 7, and 9. Samples without being treated by potable tap water or ClO_2 were used to determine the inherent background microflora. The end of the shelf-life was defined as when the population of a microbial group reached an unacceptable level or the sensory quality evaluation panelists rejected the fruit sample.

To perform microbial enumeration, 30 g of fruit sample was homogenized using a Stomacher 400 Circulator (Steward Ltd., London, UK) for 2 min in 270 ml of sterile neutralizing phosphate buffer. Ten-fold dilution series were made in 0.1% peptone water for plating. The following media and conditions were used for microbial incubation: Plate Count Agar was incubated at 30ºC for 3 d for total aerobic mesophilic bacteria and also at 22ºC for 5 d for total aerobic psychrotrophic bacteria; de Man-Rogosa-Sharpe medium (0.14% sorbic acid) was incubated at 30ºC for 3 d for lactic acid bacteria; Rose Bengal Agar was incubated at 30ºC for 3 d for yeasts and moulds. Colonies were counted and results expressed as log cfu/g. The following microbiological specifications were used to determine the end of the shelf-life: 8 log cfu/g for aerobic mesophilic bacteria and aerobic psychrotrophic bacteria, 7 log cfu/g (plus sensory analysis) for lactic acid bacteria, and 5 log cfu/g for yeasts and moulds **(Gómez-López *et al.*, 2008)**.

Sensory quality was evaluated by a panel of ten trained judges. Overall visual quality (OVQ) was scored according to a 9-point hedonic scale **(Chen *et al.*, 2010)**: 9 = excellent, extremely fresh; 7 = very good, marketable; 5 = good, limit of marketability; 3 = fair, limit of usability; 1 = poor, unusable. The following sensory quality attributes were also evaluated according to Gómez-López *et al.* **(2008)**: off-odor (1 = none, 3 = acceptable, 5 = severe); flavor (1 = fresh, 3 = acceptable, 5 = spoiled); texture (1 = fresh, 3 = acceptable, 5 = spoiled). The end of the shelf-life from the sensory quality point of view was reached when at least one of the mean scores was above the acceptability limit.

Statistical analysis

All experiments were performed in three trials. Data were subjected to the analysis of variance (ANOVA) to determine whether significant differences ($P<0.05$) between means of different treatments existed by using SigmaPlot 12.0 (Systat Software Inc., San Jose, CA, USA).

RESULTS

Firmness

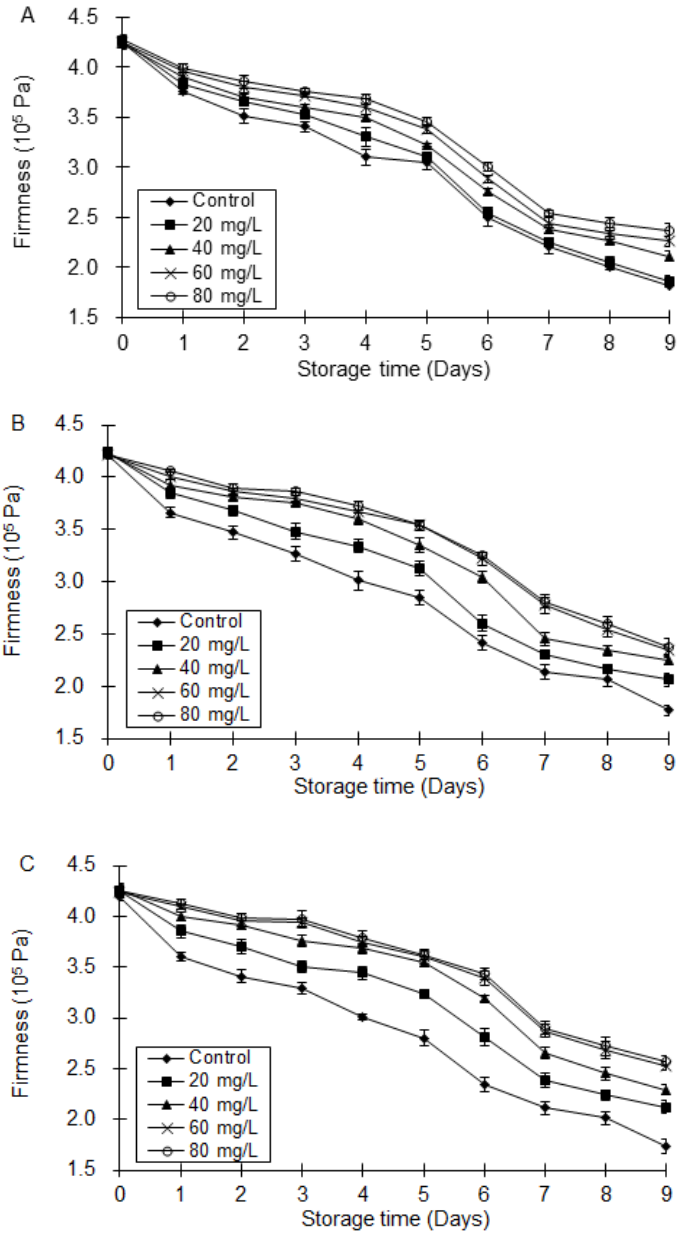

Figure 1 Effects of ClO_2 treatment on firmness of strawberry fruit. The samples were treated by different concentrations of ClO_2 (20, 40, 60, and 80 mg/L) for 5 min (A), 10 min (B), and 15 min (C). Vertical bars indicate standard deviation.

Firmness is one of the critical factors affecting the storage quality of strawberry fruit. The effects of ClO_2 treatment on firmness of strawberry is shown in Fig. 1. Firmness values of the untreated control and the ClO_2 treated samples decreased with prolonged storage time. Firmness of the control and the samples treated by 20 mg/L ClO_2 for 5 min was similar in the last 5 days ($P>0.05$) and dropped to less than 2.00×10^5 Pa on day 9. Treatments with 60 and 80 mg/L ClO_2 were more effective and significantly different from other ClO_2 treatments ($P<0.05$). When treatment time was prolonged to 15 min, firmness values of samples treated by 60 and 80 mg/L ClO_2 were similar during 9-day storage ($P>0.05$). For 60 and 80 mg/L ClO_2 treatments, firmness of the 15 min treated samples declined more slowly as compared to 5 and 10 min treated samples ($P<0.05$).

Weight loss

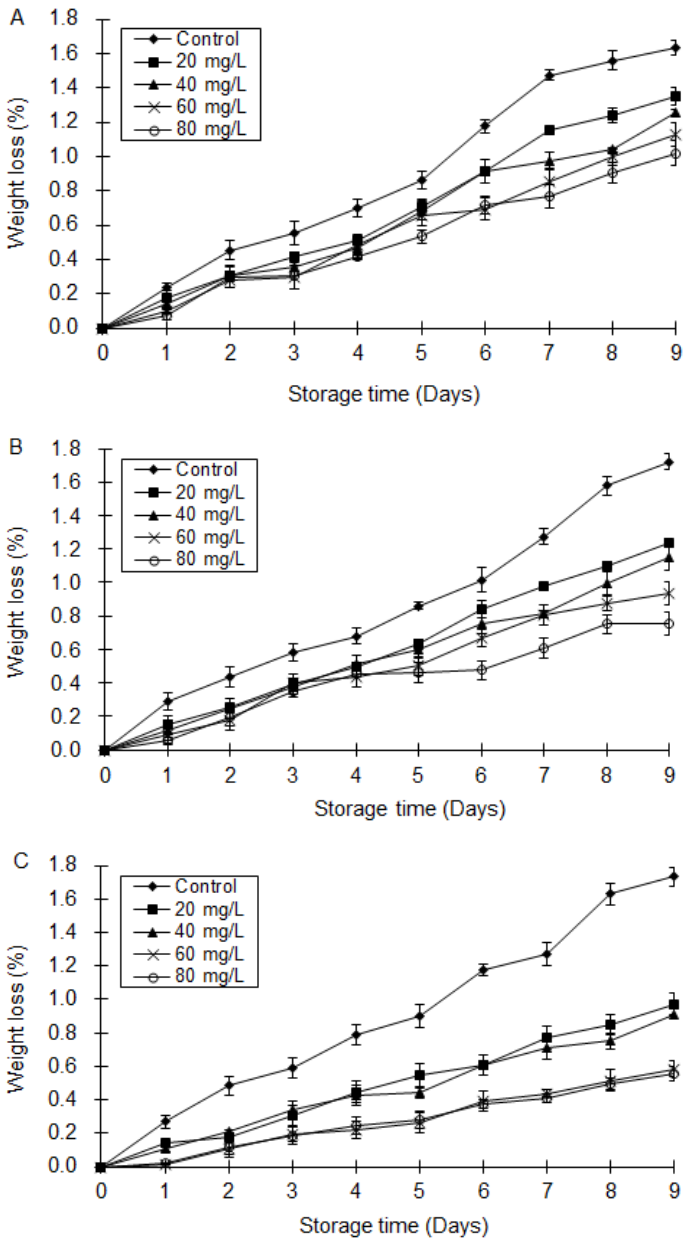

Figure 2 Effects of ClO_2 treatment on weight loss of strawberry fruit. The samples were treated by different concentrations of ClO_2 (20, 40, 60, and 80 mg/L) for 5 min (A), 10 min (B), and 15 min (C). Vertical bars indicate standard deviation.

Weight loss was determined to evaluate the effects of ClO_2 treatment on maintaining the weight of strawberry fruit. All samples displayed weight loss with respect to the initial weight (Fig. 2). At the end of storage, the untreated control lost more than 1.60% of the initial weight. The ClO_2 treated samples presented a significantly lower weight loss than the control during storage ($P<0.05$). Compared to 5 and 10 min treatments, the samples treated by 60 and 80 mg/L ClO_2 for 15 min generated significantly lower weight losses ($P<0.05$). When treatment time was extended to 15 min, weight losses of samples treated by 60 and 80 mg/L ClO_2 were significantly lower when compared with 20 and 40 mg/L ClO_2 treatments ($P<0.05$). The differences between treatments with 60 and 80 mg/L ClO_2 for 15 min were not significant ($P>0.05$).

Decay rate

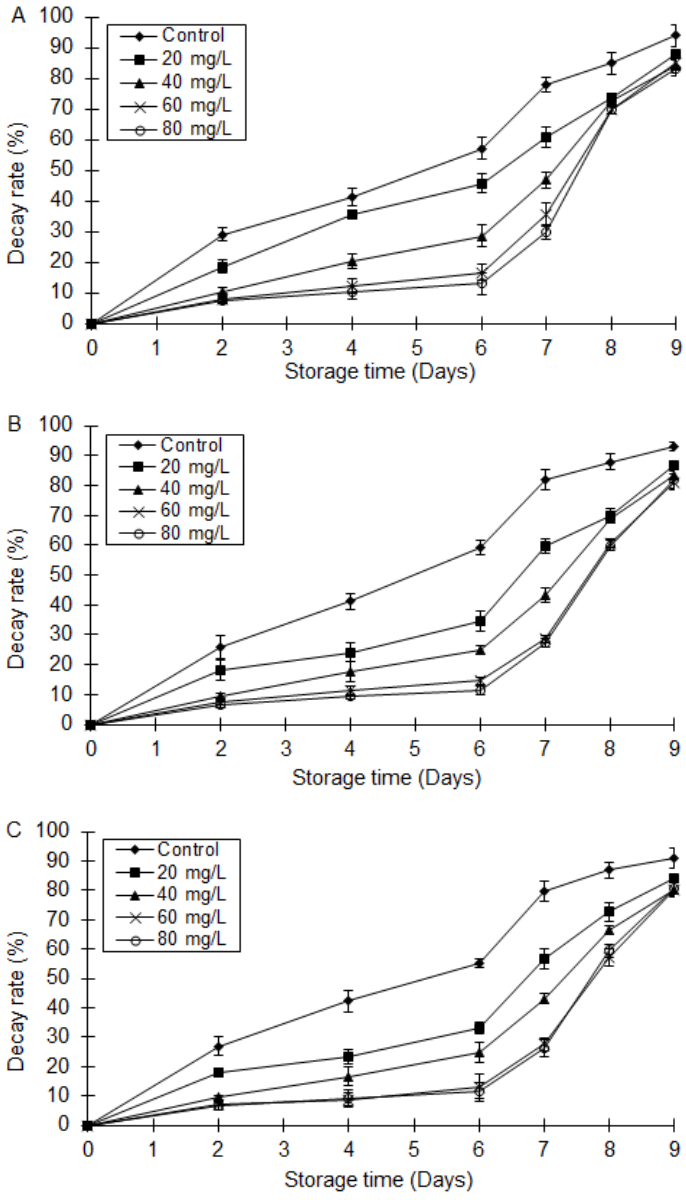

Figure 3 Effects of ClO_2 treatment on decay rate of strawberry fruit. The samples were treated by different concentrations of ClO_2 (20, 40, 60, and 80 mg/L) for 5 min (A), 10 min (B), and 15 min (C). Vertical bars indicate standard deviation.

As shown in Fig. 3, decay rates for all the samples increased with storage time. Compared to the untreated control, decay rates in ClO_2 treated samples were significantly lower ($P<0.05$). Decay rate became lower as ClO_2 concentration was increased and treatment time was prolonged. Within 8 days of storage, compared to 20 and 40 mg/L ClO_2 treatments, samples treated by 60 and 80 mg/L ClO_2 showed much lower decay rates ($P<0.05$). At the end of storage, no significant differences were observed among 40, 60, and 80 mg/L ClO_2 ($P>0.05$). For 60 and 80 mg/L ClO_2 treatments, decay rates for samples treated for 10 and 15 min were similar ($P>0.05$).

Contents of ascorbic acid, reducing sugar and titratable acid

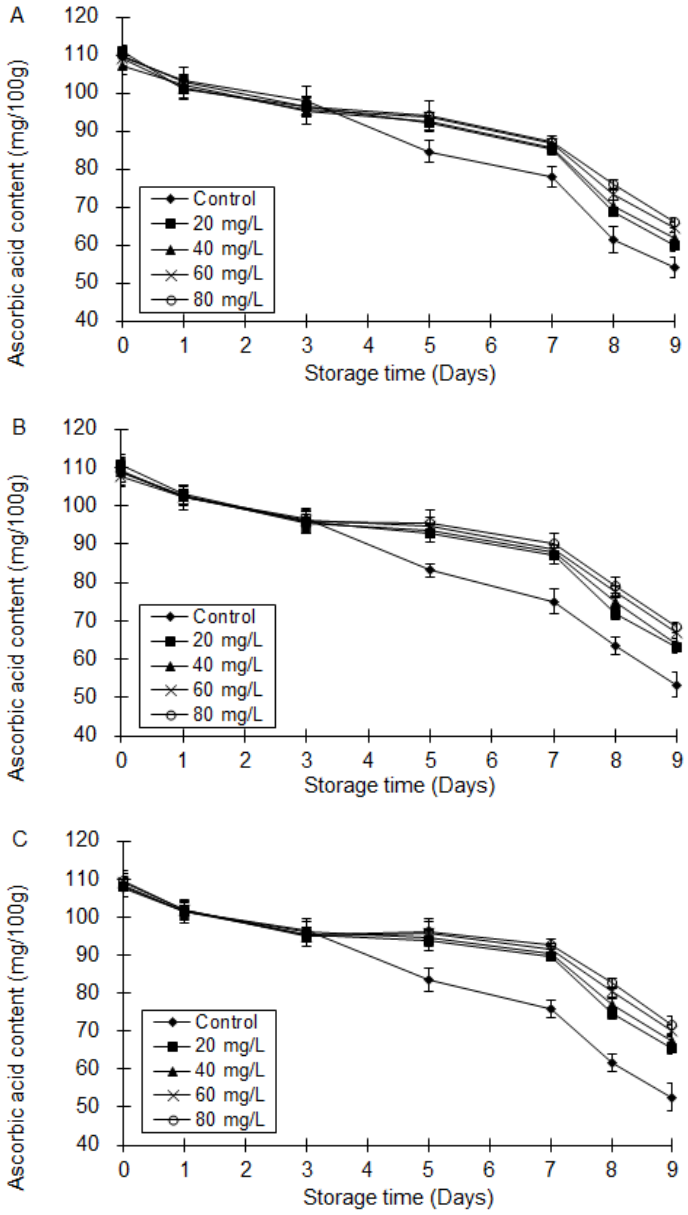

Figure 4 Effects of ClO_2 treatment on ascorbic acid content of strawberry fruit. The samples were treated by different concentrations of ClO_2 (20, 40, 60, and 80 mg/L) for 5 min (A), 10 min (B), and 15 min (C). Vertical bars indicate standard deviation.

In view of strawberry as a source of ascorbic acid, the ascorbic acid content of strawberry fruit during storage was determined. Initial contents of ascorbic acid in the control and ClO_2 treated samples were similar ($P>0.05$). As shown in Fig. 4, a remarkable decrease was detected in all samples. Ascorbic acid contents of the ClO_2 treated samples were lower than those of the control in the first 3 days of storage; however, the differences between them were not significant ($P>0.05$). From day 5, the contents of ClO_2 treated samples became higher comparing with the control ($P<0.05$). The 60 and 80 mg/L ClO_2 treatments were more effective than the 20 and 40 mg/L ClO_2 treatments in retaining ascorbic acid. For 60 and 80 mg/L ClO_2 treatments, compared to 5 and 10 min ClO_2 treated samples, the contents of 15 min ClO_2 treated samples were significantly higher ($P<0.05$). Samples treated by 60 and 80 mg/L ClO_2 for 15 min exhibited more than 70 mg/100g ascorbic acid contents at the end of storage ($P>0.05$).

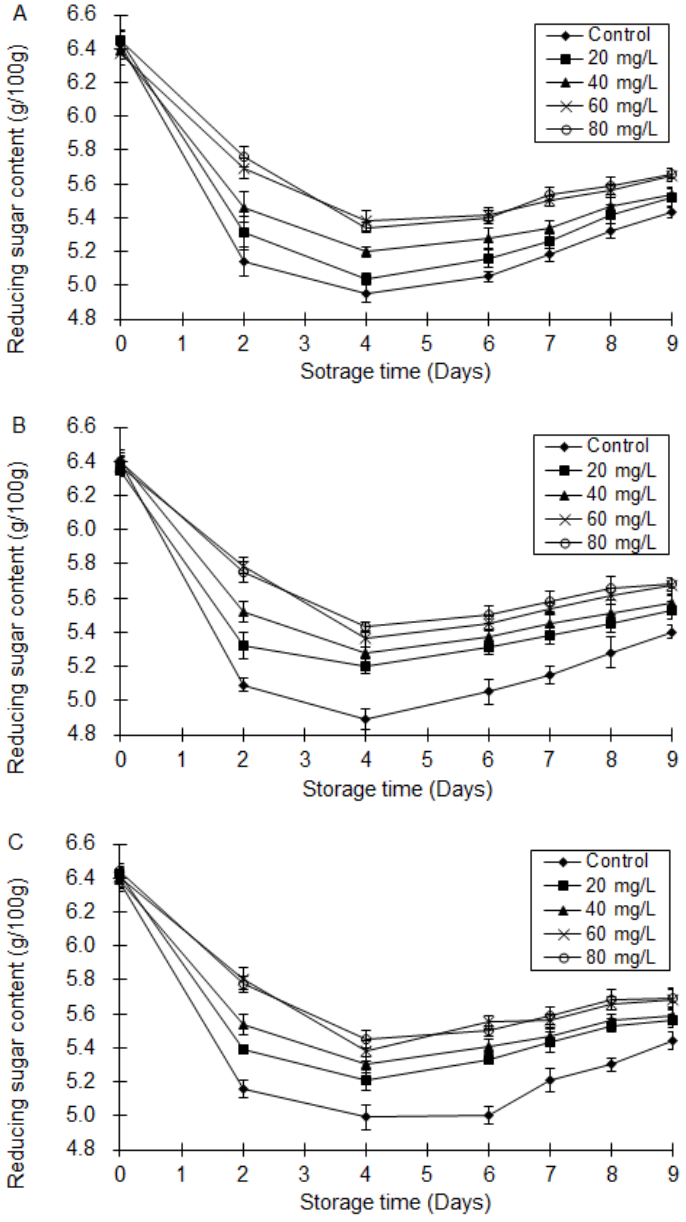

Figure 5 Effects of ClO_2 treatment on reducing sugar content of strawberry fruit. The samples were treated by different concentrations of ClO_2 (20, 40, 60, and 80 mg/L) for 5 min (A), 10 min (B), and 15 min (C). Vertical bars indicate standard deviation.

The effects of ClO_2 treatment on reducing sugar content in strawberry fruit are shown in Fig. 5. There were no significant differences in initial reducing sugar contents among all samples ($P>0.05$). Reducing sugar contents of the control and ClO_2 treated samples decreased in the first 4 days, then increased gradually throughout the remaining time. Though contents of all samples showed the same changing trends over storage period, contents of the ClO_2 treated samples were higher than those of the control ($P<0.05$). The most effective treatment for retention of reducing sugar was achieved at higher ClO_2 concentrations and longer treatment times. Compared to 20 and 40 mg/L ClO_2 treatments, reducing sugar contents of 60 and 80 mg/L ClO_2 treated samples were higher during storage ($P<0.05$). The 60 mg/L ClO_2 treatments were similar with the 80 mg/L ClO_2 treatments ($P>0.05$). Considering treatment time, reducing sugar contents of samples treated by ClO_2 for 10 and 15 min were similar ($P>0.05$).

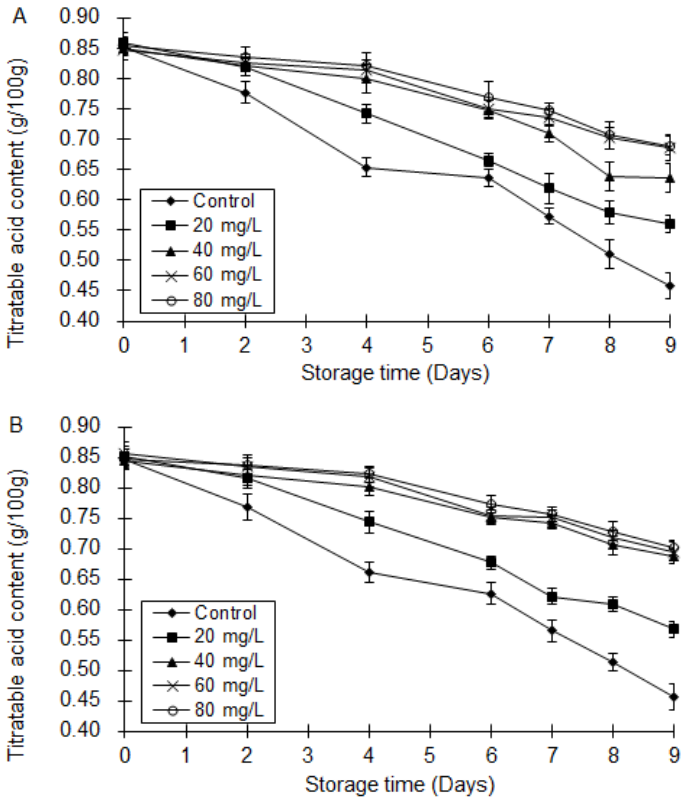

Figure 6 Effects of ClO_2 treatment on titratable acid content of strawberry fruit. The samples were treated by different concentrations of ClO_2 (20, 40, 60, and 80 mg/L) for 5 min (A), 10 min (B), and 15 min (C). Vertical bars indicate standard deviation.

The effects of ClO_2 treatment on titratable acid content are presented in Fig. 6. Initial titratable acid contents in all samples were similar ($P>0.05$). Titratable acid contents of the control and ClO_2 treated samples decreased during storage. The titratable acid content of the control dropped drastically to about 0.45 g/100g on the last storage day. However, the contents of the ClO_2 treated samples remained higher than those of the control during storage ($P<0.05$). All the ClO_2 treatments were similar in the first 2 days ($P>0.05$). From day 4, compared to the 20 mg/L ClO_2 treatment, titratable acid contents of samples treated by 40, 60 and 80 mg/L ClO_2 were higher ($P<0.05$). For 10 and 15 min ClO_2 treatments, the 40, 60 and 80 mg/L ClO_2 treatments were similar throughout entire storage period ($P>0.05$). The titratable acid contents of the 5, 10 and 15 min ClO_2 treated samples were not significantly different in the first 4 days ($P>0.05$). From day 6, the contents of the 15 min ClO_2 treated samples became higher comparing with 5 and 10 min ClO_2 treatments ($P<0.05$).

The differences between the effects of 60 and 80 mg/L ClO_2 treatments on above storage quality parameters were not significant ($P>0.05$). Therefore, the treatment with 60 mg/L ClO_2 for 15 min was selected as the ideal ClO_2 treatment condition to investigate the effect of ClO_2 treatment on shelf-life from microbiological and sensory quality perspectives.

Shelf-life

Table 1 Effect of 60 mg/L ClO_2 treatment for 15 min on microbial counts (log cfu/g) of strawberry fruit

Microbial group	Treatment	Storage time (days)				
		0	3	5	7	9
Aerobic mesophilic bacteria	Control	4.3±0.2*a**	5.9±0.6a	6.9±0.2a	8.3±0.4a	-***
	ClO_2 treatment	2.1±0.4b	3.3±0.3b	4.5±0.4b	5.7±0.5b	6.6±0.3
Aerobic psychrotrophic bacteria	Control	4.1±0.2a	5.6±0.3a	6.8±0.4a	8.1±0.4a	-
	ClO_2 treatment	2.0±0.3b	3.1±0.2b	4.2±0.3b	5.5±0.3b	6.4±0.4
Lactic acid bacteria	Control	1.5±0.5a	2.3±0.4a	3.3±0.2a	4.5±0.3a	5.9±0.5a
	ClO_2 treatment	0.7±0.1b	1.4±0.3b	2.0±0.3b	2.9±0.4b	3.3±0.2b
Yeasts and moulds	Control	3.0±0.3a	3.9±0.3a	4.7±0.3a	5.6±0.4a	-
	ClO_2 treatment	1.6±0.4b	2.2±0.2b	2.9±0.2b	3.6±0.3b	4.5±0.3

Legend: *Data are expressed as means±SD of triplicate assays. Numbers with underlines are counts above the acceptability limit.
**Within the same microbial group, means with different letters for the same storage time are significantly different ($P<0.05$) according to the LSD test.
***-, not detected.

Changes in the microflora of strawberry fruit during storage were evaluated with changes in microbial counts for aerobic mesophilic bacteria, aerobic psychrotrophic bacteria, lactic acid bacteria, and yeast and mold immediately after ClO_2 treatments and during storage (Table 1). High loads of aerobic mesophilic bacteria (4.4±0.4 log cfu/g) and aerobic psychrotrophic bacteria (4.2±0.2 log cfu/g) were observed in raw fruit. Lactic acid bacteria (1.7±0.3 log cfu/g), yeasts and moulds (3.2±0.2 log cfu/g) were present in relatively lower counts. Microbial populations decreased in the control and ClO_2 treated samples after washing, whereas the ClO_2 treatments significantly decreased the microflora in strawberry fruit compared to the control ($P<0.05$). Microbial populations showed a gradual increase during storage in all samples; However, the populations in the ClO_2 treated samples were maintained at significantly lower levels than those in the control ($P<0.05$). The counts of aerobic mesophilic bacteria and aerobic psychrotrophic bacteria reached more than 8 log cfu/g in control on day 7 while maintained acceptable in ClO_2 treated samples throughout the 9-day storage. The count of yeasts and molds in the control reached more than 5 log cfu/g in control on day 7, whereas the count of ClO_2 treated samples remained acceptable throughout the 9-day storage. Populations of lactic acid bacteria in the control and ClO_2 treated samples also increased during storage; however, the counts did not reach unacceptable levels. Therefore, lactic acid bacteria could not be considered as a determinant in the shelf-life study. When analyzed together with the populations of aerobic mesophilic bacteria, aerobic psychrotrophic bacteria, and yeasts and molds, it can be concluded that, from the microbiological point of view, 4 extra days in shelf-life was achieved by the 60 mg/L ClO_2 treatment for 15 min.

Table 2 Effect of 60 mg/L ClO_2 treatment for 15 min on sensory quality of strawberry fruit

Sensory quality attribute	Treatment	Storage time (days)				
		0	3	5	7	9
OVQ	Control	9.0±0.0[*]a[**]	7.3±0.3b	6.1±0.4b	4.6±0.3b	-[***]
	ClO_2 treatment	9.0±0.0a	8.5±0.4a	7.9±0.3a	7.3±0.3a	6.8±0.5
Off-odor	Control	1.0±0.0a	2.1±0.4a	2.6±0.4a	3.7±0.2a	-
	ClO_2 treatment	1.0±0.0a	1.5±0.2b	1.7±0.3b	2.0±0.2b	2.5±0.3
Flavor	Control	1.0±0.0a	2.2±0.2a	2.8±0.3a	3.4±0.3a	-
	ClO_2 treatment	1.0±0.0a	1.2±0.3b	1.5±0.2b	1.8±0.2b	2.4±0.4
Texture	Control	1.0±0.0a	2.5±0.4a	2.6±0.3a	3.3±0.4a	-
	ClO_2 treatment	1.0±0.0a	1.2±0.1b	1.4±0.2b	1.6±0.3b	2.2±0.2

Legend: [*]Data are expressed as means±SD of triplicate assays. Numbers with underlines are scores above the acceptability limit.
[**]Within the same sensory quality attribute, means with different letters for the same storage time are significantly different (P<0.05) according to the LSD test.
[***]-, not detected.

As shown in Table 2, immediately after washing, there were no significant differences in the same sensory quality attribute between the control and ClO_2 treated samples (P>0.05). Sensory quality declined in all samples as storage time prolonged. Overall visual quality, off-odor, flavor, and texture of the control were all above the acceptability limit after 7 days; however, the samples treated by 60 mg/L ClO_2 for 15 min maintained higher sensory quality as compared to the control during storage (P<0.05). And sensory quality of the ClO_2 treated samples remained acceptable throughout the entire storage. From the sensory quality point of view, a shelf-life prolongation of 4 days was achieved by the 60 mg/L ClO_2 treatment for 15 min, which was consistent with the microbial growth assay. Therefore, the shelf-life of strawberry fruit treated by 60 mg/L ClO_2 for 15 min was prolonged to 9 days compared to 5 days for the untreated control.

DISCUSSION

Aqueous ClO_2 has been proved to be effective in preserving postharvest fruits and vegetables. Du *et al.* **(2009)** found that higher aqueous ClO_2 concentration and longer treatment time provided better inhibitory effects on enzymatic browning of fresh-cut lotus root. In our previous studies, ClO_2 concentration and treatment time have also been found to be two critical factors affecting the effects of ClO_2 treatment on fresh produce **(Chen *et al.*, 2010; Chen *et al.*, 2011; Chen and Zhu, 2011a; Chen and Zhu, 2011b)**. In the present study, with increased ClO_2 concentration and treatment time, postharvest storage quality of strawberry fruit was more effectively maintained, which are consistent with published data.

ClO_2 as a powerful oxidant may lead to the oxidation of ascorbic acid during treatment **(Du *et al.*, 2007)**. ClO_2 may also oxidize some components including pigments on produce surfaces and suppress color formation **(Fu *et al.*, 2007)**. Du *et al.* **(2007)** reported that though the loss of ascorbic acid in ClO2 treated green bell peppers was drastic in the first 10 d, it was retarded after 20 d, resulting in higher contents of ascorbic acid after 40 d. Similarly, our previous study also showed that flavonoid and ascorbic acid contents of the ClO_2 treated mulberry fruits were lower than those of the control in the early storage days; however, as storage time extended, ClO_2 treatments showed the ability to slow down the loss of nutritional components **(Chen *et al.*, 2011)**. In this study, ascorbic acid contents of ClO_2 treated strawberry fruits were slightly lower than those of the control during the early days but tended to be higher as storage time prolonged. Therefore, ClO_2 showed the ability to retard the loss of ascorbic acid. Further research is warranted to investigate the mechanism of ClO_2 treatment on nutritional components of fresh fruits and vegetables.

Our previous studies have showed that there was no detectable ClO_2 residue in ClO_2 treated plum or mulberry fruits **(Chen *et al.*, 2011; Chen and Zhu, 2011a)**. These results may attribute to the potable tap water rinse after ClO_2 treatment according to the USFDA information **(2014)**, which is designed to remove any ClO_2 residue on fruit and vegetable surfaces. In consideration of the significance of food safety to consumers, it is strongly recommended that ClO_2 treatments of fruits and vegetables should be followed by a potable water rinse.

CONCLUSION

ClO_2 treatment effectively maintained postharvest storage quality and extended shelf-life of strawberry fruit. ClO_2 concentration and treatment time were two critical factors affecting ClO_2 treatment. The treatment with 60 mg/L for 15 min was the ideal condition for preserving strawberry fruit. ClO_2 was therefore demonstrated to be a promising approach to preserve postharvest strawberry fruit.

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