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Effect of Aqueous Chlorine Dioxide Treatment on the Microbial Growth and Qualities of Strawberries During Storage

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Abstract Effect of aqueous chlorine dioxide treatment on the microbial growth and quality changes of strawberries during storage was examined. Strawberries were treated with 5, 10, and 50 ppm of chlorine dioxide solution, and stored at 4±1°C. Total aerobic bacteria in strawberries treated at 50 ppm of chlorine dioxide were increased from 1.40 to 2.10 log CFU/g after 7 days, while increasing in the control from 2.75 to 4.32 log CFU/g. Yeasts and molds in strawberries treated at 50 ppm of chlorine dioxide were increased from 1.10 to 1.97 log CFU/g after 7 days, while the control was increased from 2.55 to 4.50 log CFU/g. The pH and titratable acidity of strawberries were not significantly different among treatments. Sensory evaluation results showed that chlorine dioxide-treated strawberries had better sensory scores than the control. These results indicate that chlorine dioxide treatment could be useful in improving the microbial safety and qualities of strawberries during storage.

Keywords: strawberry, aqueous chlorine dioxide, microbial growth, storage

Introduction

Strawberries are good sources of many natural antioxidants as well as vitamins and minerals (1, 2). However, strawberry fruits have a very short postharvest life due to high metabolic activity and rots from microbial growth (3-5), and quality loss during transport and handling may be significant (6). Therefore, they require appropriate preservation techniques needed for extending shelf life of strawberries. There have been many attempts to decrease the microbial spoilage of fresh vegetable and fruits (7, 8). Among them, there are chemical disinfectants such as chlorine compounds.

Many raw fruit and vegetable products are washed or sprayed with chlorinated water to reduce microorganisms (9). However, regarding the use of chlorine, there have been some health concerns due to the presence of trihalomethanes generated in the presence of organic materials (10, 11). Therefore, aqueous chlorine dioxide has been suggested as an effective alternative to chlorine (11, 12).

Chlorine dioxide is a strong oxidizing and sanitizing agent that has broad and high biocidal effect. In particular, aqueous chlorine dioxide has been shown to be an effective surface disinfectant (13). Application of aqueous chlorine dioxide has received much attention since Food and Drug Administration has allowed the use of aqueous chlorine dioxidein washing fruits and vegetables (14). Thus, aqueous chlorine dioxide has been used for vegetables and fruits processing (15, 16), meat processing (17), and fish processing (18) to reduce microbial counts without any health concern (19).

Therefore, in this study, to further apply the aqueous chlorine dioxide treatment in food preservation, we examined the effect of aqueous chlorine dioxide on the microbial growth and qualities of strawberries to improve the microbial safety and qualities of strawberries during storage.

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Materials and Methods

Materials Strawberries 'Seolhyang Nonsan 3' were purchased at a specific local market in Daejeon, Korea.

Chlorine dioxide preparation and treatment Chlorine dioxide was prepared using chlorine dioxide generating system (CH_2O Inc., Olympia, WA, USA) as described previously (20). Samples were treated by dipping in a solution of 0, 5, 10, and 50 ppm chlorine dioxide solution for 2 min, respectively, which was determined according to the method of APHA (21). After chlorine dioxide treatment, samples were individually packaged in polyethylene bags and stored at 4±1°C.

Microbial analysis After chlorine dioxide treatment, samples (10 strawberries) were removed using a sterile scalpel. Samples were then homogenized using a Stomacher (MIX 2; AES Laboratoire, Paris, France) for 3 min, filtered through a sterile cheese cloth, and diluted with peptone water (0.1% sterile peptone, w/v) for microbial count. Serial dilutions were performed in triplicate on each selective agar plate. Total bacterial counts were determined by plating appropriately diluted samples onto plate count agar (PCA, Difco Co., Detroit, MI, USA). Samples were evenly spread on the surface of the plates with a sterile glass rod. Yeasts and molds were plated on potato dextrose agar (PDA, Difco Co.). Both plates were incubated at 37°C for 48 hr. Each microbial count was the mean of three determinations. Microbial counts were expressed as log CFU/g.

pH and titratable acidity Strawberries were ground, filtered, and the pH value of filtered strawberry juice was measured using a pH meter (MCH600SI; Tong Magic Co., Seoul, Korea). Titratable acidity of the filtered strawberry solution was also determined. The amount of NaOH consumed for titration was determined and expressed as the amount of citric acid.

Measurement of weight loss The weight loss of strawberries due to transpiration and respiration was determined by weighing the sample during storage. Weight loss was expressed as a percentage of the original weight of the sample

Sensory evaluation Samples were analyzed for their freshness, texture, odor, color, and overall acceptability by 7 trained panels. Sensory qualities of samples were evaluated using 5 point scoring method.

Statistical analysis Analysis of variance and Duncan's multiple range tests were performed to analyze the results using a SAS program (SAS Institute, Inc., Cary, NC, USA).

Results and Discussion

Microbiological changes Strawberry fruits are usually rotten by softening and growth of mold or pathogenic bacteria. Initial populations of total bacteria, yeast, and mold of strawberries were 2.75 and 2.55 log CFU/g, respectively. Chlorine dioxide treatment decreased significantly populations in total aerobic bacteria in strawberries, compared to the control (Fig. 1). After chlorine dioxide treatment, populations of bacteria in strawberries were 2.75, 2.54, 1.89, and 1.40 log CFU/g for 0, 5, 10, and 50 ppm of chlorine dioxide, respectively. After 7 days of storage, the control had 4.32 log CFU/g, while samples treated with 5, 10, and 50 ppm of chlorine dioxide had the populations of total aerobic bacteria of 3.52, 2.64, and 2.10 log CFU/g, respectively (Fig. 1). Populations of total aerobic bacteria in strawberries treated at 50 ppm chlorine dioxide were reduced by 2.22 log CFU/g, compared to the control. Thus, microbial growth was inhibited with increasing

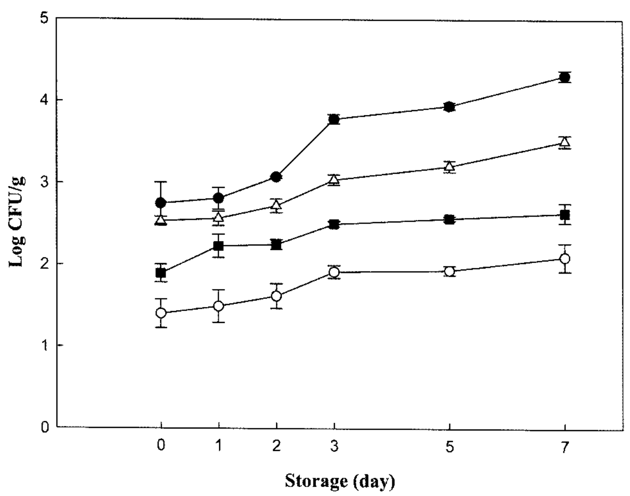

Fig. 1. Change in total aerobic bacteria of chlorine dioxide treated strawberries during storage.
●, control; △, 5 ppm; ■, 10 ppm; ○, 50 ppm.

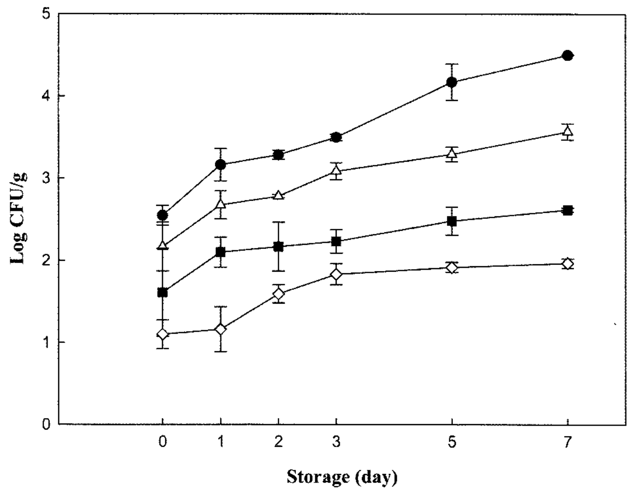

Fig. 2. Change in yeasts and molds of chlorine dioxide treated strawberries during storage.
●, control; △, 5 ppm; ■, 10 ppm; ○, 50 ppm.

concentration of chlorine dioxide.

Yeasts and molds had a similar pattern as total aerobic bacteria (Fig. 2). After treatment, populations of yeasts and molds for samples treated with 0, 5, 10, and 50 ppm of chlorine dioxide were 2.55, 2.17, 1.61, and 1.10 log CFU/g, respectively. After 7 days of storage, the populations of yeasts and molds of the control sample reached 4.50 log CFU/g, while treated samples with 5, 10, and 50 ppm of chlorine dioxide had 3.57, 2.62, and 1.97 log CFU/g, respectively. Populations of yeasts and molds in strawberries treated at 50 ppm chlorine dioxide were reduced by 2.53 log CFU/g, compared to the control. Similar to our results, Wu and Kim (22) have reported that treatment of 15 ppm chlorine dioxide on blueberries decreases yeasts and molds by 2.86 log cycle. In this study, populations of total aerobic bacteria and yeasts and molds of strawberries treated with chlorine dioxide were significantly reduced by more than 2 log cycles, compared to the control. Therefore, these results indicate that chlorine dioxide treatment can retard the microbial growth of strawberries, and extend the shelf life.

Chlorine dioxide has been known to generate protein denaturation and to cause the death of microorganism by damage of cell membrane and inactivation of mRNA (11, 23). Taormina and Beuchat (24) have reported that 500 ppm chlorine dioxide treatment causes reduction of 2 log CFU/g of *Escherichia coli* O157:H7 in alfalfa seeds. Lee *et al.* (25) also have reported that 40 ppm treatment of chlorine dioxide on apple decreases *Alicyclobaillus acidoterrestris* spores by 4 log CFU/g. The effect of chlorine dioxide treatment obtained in this study was in good agreement with the results reported by Wu and Kim (22). These results showed that chlorine dioxide treatment inhibited the increase in populations of total bacteria as well as yeasts and molds on strawberries during storage.

Change in pH and titratable acidity Figure 3 showed that the pH of strawberries treated with chlorine dioxide was increased during storage. However, there was no significant difference among the treatments during storage.

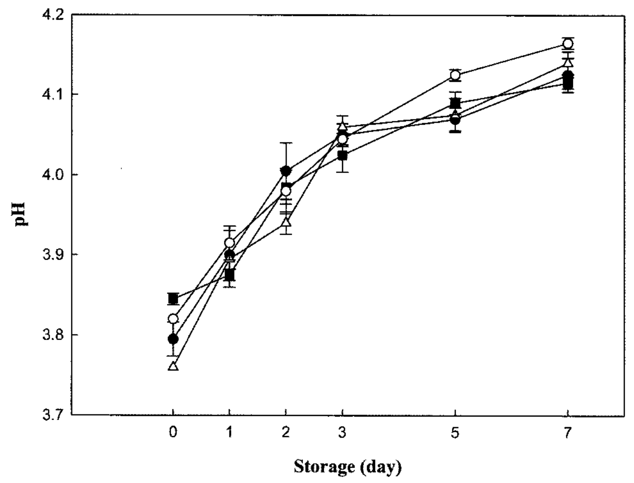

Fig. 3. Change in pH of chlorine dioxide treated strawberries during storage.
●, control; △, 5 ppm; ■, 10 ppm; ○, 50 ppm.

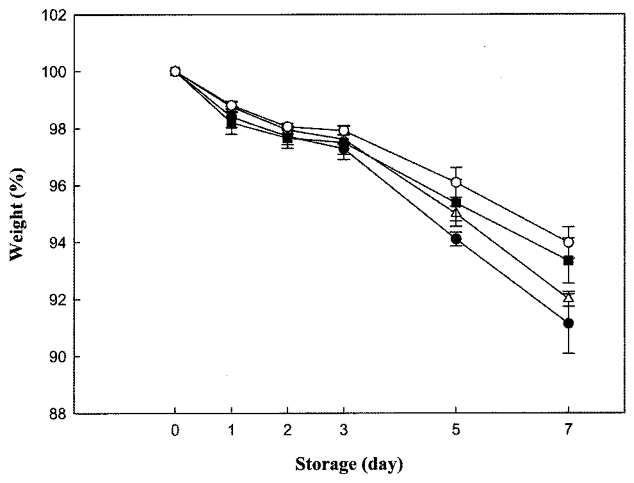

Fig. 5. Change in weight loss of chlorine dioxide treated strawberries during storage.
●, control; △, 5 ppm; ■, 10 ppm; ○, 50 ppm.

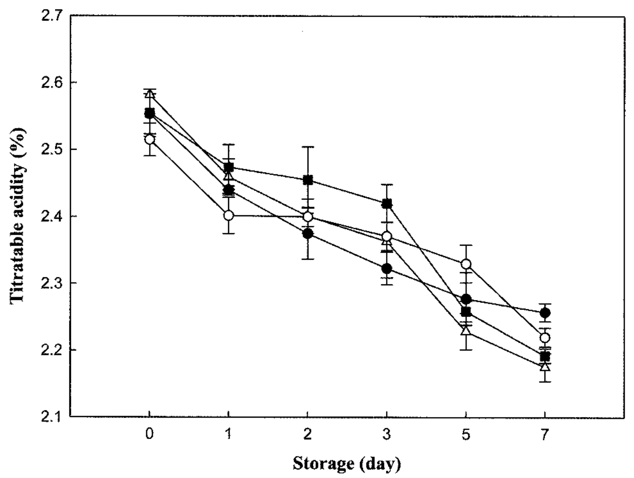

Fig. 4. Change in titratable acidity of chlorine dioxide treated strawberries during storage.
●, control; △, 5 ppm; ■, 10 ppm; ○, 50 ppm.

Initial pH values after treatment of strawberries with chlorine dioxide at 0, 5, 10, and 50 ppm were 3.80, 3.76, 3.85, and 3.82, respectively, showing that there was no significant change among treatments. Strawberries treated with chlorine dioxide solution showed similar increases in pH value during storage. These results are in good agreement with that of Chung and Cho (26).

Titratable acidity of strawberries was decreased during storage (Fig. 4). Initial titratable acidity values after treatment of strawberry with chlorine dioxide at 0, 5, 10, and 50 ppm were 2.55, 2.58, 2.56, and 2.52, respectively, indicating that there was no significant change among treatments. During storage, titratable acidity was decreased because of decrease of organic acids content. These results are in good agreement with those of Cha *et al.* (27). In addition, it should be noted that our results were higher than those of Cho *et al.* (28), where they reported 1.62% as titratable acidity. This difference can be attributed to the different variety of the fruit.

Change in weight loss Besides change in color and softening of the fruit, weight loss during storage is one of the reasons for poor quality of the fruit (29). Weight loss of strawberries treated with chlorine dioxide during storage was shown in Fig. 5. Weight of samples treated with 5 ppm of chlorine dioxide decreased in a similar pattern as the control, while those with 10 and 50 ppm chlorine dioxide treatments were decreased slowly. After 7 day of storage, weight losses of strawberry treated with chlorine dioxide at 10 and 50 ppm were 5.93 and 5.47%, respectively, compared to 8.53% for the control. These results are in good agreement with those of Robinson *et al.* (30). They reported that the loss of weight over 6% was the limit of quality of the strawberry fruit. Therefore, strawberries treated with 50 ppm chlorine dioxide had the desirable quality after 7 day of storage in terms of weight loss, since the loss of weight was less than 6%.

Sensory evaluation Strawberry fruits are usually harvested at full maturity, which is ready for consumption, to provide desirable flavor and color (31). During storage, their sensory qualities become deteriorated mainly due to metabolism and microbial growth. The postharvest life of fruits and vegetables is characterized in terms of visual appearance and texture (1). Sensory evaluations of strawberries during storage are shown in Table 1. Sensory qualities such as freshness, texture, color, odor, and overall acceptability were examined during storage. After 7 day of storage, strawberries treated with chlorine dioxide had better sensory scores than the control. The control maintained the quality for 5 days, while strawberries treated at 50 ppm maintained the quality by day 7 of storage. These results indicate that chlorine dioxide treatment could improve sensory qualities and extend the shelf life.

In conclusion, this study clearly indicated that chlorine dioxide treatment significantly decreased populations of microorganisms of strawberries during storage. In addition, chlorine dioxide treatment was effective in maintaining the quality of strawberries. Therefore, chlorine dioxide treatment

Table 1. Sensory evaluation of chlorine dioxide treated strawberries during storage

Organoleptic parameter	ClO_2 concentration (ppm)	Storage period (day)					
		0	1	2	3	5	7
Freshness	0	5.00±0.00[a1)]	5.00±0.00[a]	3.86±0.58[a]	2.86±0.69[b]	2.00±0.58[c]	1.14±0.38[b]
	5	5.00±0.00[a]	5.00±0.00[a]	3.71±0.44[a]	3.43±0.53[a]	2.57±0.53[b]	1.29±0.49[b]
	10	5.00±0.00[a]	5.00±0.00[a]	4.00±0.53[a]	3.86±0.44[a]	3.14±0.38[a]	2.43±0.53[a]
	50	5.00±0.00[a]	5.00±0.00[a]	4.00±0.60[a]	4.00±0.49[a]	3.29±0.49[a]	2.71±0.49[a]
Texture	0	5.00±0.00[a]	4.00±0.60[a]	3.43±0.53[a]	3.29±0.49[a]	1.86±0.69[b]	1.17±0.41[b]
	5	5.00±0.00[a]	4.00±0.49[a]	3.71±0.49[a]	3.57±0.79[a]	2.14±0.69[ba]	1.29±0.49[b]
	10	5.00±0.00[a]	4.00±0.58[a]	3.86±0.83[a]	3.71±0.49[a]	2.71±0.76[a]	2.00±0.58[a]
	50	5.00±0.00[a]	4.00±0.60	4.00±0.58[a]	3.86±0.67[a]	2.86±0.69[a]	2.14±0.38[b]
Color	0	5.00±0.00[a]	5.00±0.00[a]	3.71±0.76[a]	3.43±0.53[a]	2.00±0.58[b]	2.43±0.53[a]
	5	5.00±0.00[a]	5.00±0.00[a]	3.86±0.76[a]	3.57±0.53[a]	3.00±0.00[a]	2.00±0.58[a]
	10	5.00±0.00[a]	5.00±0.00[a]	3.86±0.83[a]	3.43±0.53[a]	2.57±0.53[a]	2.43±0.53[b]
	50	5.00±0.00[a]	5.00±0.00[a]	4.00±0.76[a]	3.71±0.76[a]	3.00±0.00[a]	2.43±0.53[a]
Odor	0	5.00±0.00[a]	5.00±0.00[a]	3.86±0.55[a]	3.43±0.79[a]	2.43±0.79[a]	1.71±0.76[b]
	5	5.00±0.00[a]	5.00±0.00[a]	4.00±0.58[a]	3.00±0.79[a]	2.57±0.79[a]	1.57±0.53[b]
	10	5.00±0.00[a]	5.00±0.00[a]	4.29±0.50[a]	4.00±0.76[a]	2.57±0.53[a]	2.43±0.53[a]
	50	5.00±0.00[a]	5.00±0.00[a]	4.43±0.53[a]	4.00±0.49[a]	2.57±0.53[a]	2.71±0.49[a]
Overall	0	5.00±0.00[a]	5.00±0.00[a]	3.43±0.53[b]	3.00±0.58[b]	1.86±0.38[c]	1.14±0.38[b]
	5	5.00±0.00[a]	5.00±0.00[a]	3.71±0.49[ba]	3.29±0.49[b]	2.43±0.53[b]	1.43±0.53[b]
	10	5.00±0.00[a]	5.00±0.00[a]	4.14±0.33[a]	3.86±0.38[a]	2.86±0.38[ba]	2.29±0.49[a]
	50	5.00±0.00[a]	5.00±0.00[a]	4.14±0.71[a]	4.00±0.58[a]	3.14±0.38[a]	2.71±0.49[a]

[1)]Mean±SD. Any figures in the same column with different letters are significantly different at $p<0.05$ level by Duncan's multiple range test.

can extend the shelf life and improve the microbial safety of strawberries during storage.

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