

Effect of Chlorine Dioxide on Freshness of 'Maehyang' Strawberries during Export

Hye Min Kim¹ and Seung Jae Hwang^{1,2,3*}

¹Department of Horticulture, Division of Applied Life Science, Graduate School of Gyeongsang National University, Jinju 52828, Korea

²Department of Horticulture, College of Agriculture & Life Sciences, Gyeongsang National University, Jinju 52828, Korea

³Institute of Agriculture & Life Sciences, Gyeongsang National University, Jinju 52828, Korea

*Corresponding author: hsj@gnu.ac.kr

Abstract

The objective of this study was to assess the effect of precooling and application of gaseous ClO₂ on the retention of freshness and quality of 'Maehyang' strawberry fruits intended for export. 'Maehyang' strawberry fruits (*Fragaria × ananassa* Duch.) were grown in commercial greenhouses and then harvested. Fruits of uniform and medium size at 60% ripeness were selected and assigned to one of four treatment groups: non-treatment (control), precooling only (PO), gaseous ClO₂ only (GCO) or precooling combined with gaseous ClO₂ (P + C). Weight loss was lowest in the PO treatment and greatest in the GCO treatment after export. Compared to the control and PO treatment groups, strawberry fruits in the GCO treatment group maintained high brightness and high chroma. Six days after shipping, fruits in the P + C treatment group had the highest soluble solids content, even as high as 10.05 °Brix; the lowest value was observed in the PO treatment. The incidence rate of gray mold in strawberry fruits was 20% and 17% in the control and the PO treatment, respectively; in the GCO treatment, the incidence rate of gray mold amounted to 10%. No gray mold was observed in the P + C treatment group. These results indicate that gaseous ClO₂ treatment combined with precooling (P + C) was effective in maintaining the freshness of 'Maehyang' strawberry fruits intended for export from South Korea to Hong Kong.

Additional key words: color, gray mold rot, soluble solids content, storage temperature, weight loss

Introduction

Strawberry fruits are known for their plentiful vitamins and inorganic nutrients, as well as their visual appeal and desirable taste (Yang et al., 2010). In this regard, strawberry is notable as a particularly healthy fruit, especially in the winter season in South Korea. Strawberry also takes center stage as an export crop, with around 2.3 million tons exported from Korea to other countries each year (KREI, 2014). Since 2004, 'Maehyang' (*Fragaria × ananassa* Duch.) has been the most popular strawberry cultivar for commercial export to Southeast Asian countries such as Hong Kong, Singapore, and Malaysia.

 OPEN ACCESS



Korean J. Hortic. Sci. Technol. 34(4):626-633, 2016
<http://dx.doi.org/10.12972/kjhst.20160064>

pISSN : 1226-8763
 eISSN : 2465-8588

Received: January 19, 2016

Revised: March 15, 2016

Accepted: June 22, 2016

Copyright©2016 Korean Society for Horticultural Science.

This is an Open-Access article distributed under the terms of the [Creative Commons Attribution NonCommercial License](https://creativecommons.org/licenses/by-nc/4.0/) which permits unrestricted non-commercial use, distribution, and reproduction in any medium, provided the original work is properly cited.

We would like to thank Gyeongnam Trading Inc., Changwon, Korea, for providing the 'Maehyang' strawberry fruits, and Mr. Vincent Wong, Operations Manager, Good View Fruits Co. Ltd., Hong Kong, for permitting us to conduct the necessary experiments on the imported 'Maehyang' strawberry fruits in Hong Kong. This research was supported by the Technology Development Program for Agriculture and Forestry, Ministry for Food, Agriculture, Forestry and Fisheries, Republic of Korea (Project No. 315004-05 and 314063-01).

However, strawberry fruits have high metabolic activity and suffer from a high possibility of microbial contamination. This can result in a short shelf life, fungal decay, color change, and an off-flavor (Van der Steen et al., 2002; Kim et al., 2010). It is therefore important to employ an appropriate preservation method to delay respiration, prevent physical damage, dryness, and maturity, and to restrict pathogen attack in order to extend shelf life. Preservation methods such as precooling, storage at low temperature, carbon dioxide (CO₂) and chlorine dioxide (ClO₂) treatment or ethylene removal (Jeong et al., 1990; Kim et al., 1999a; Ahn et al., 2000; Jin et al., 2007) can be used for this purpose.

Recently, aqueous ClO₂, a well-known bactericidal, viricidal, and fungicidal agent, has been recognized for its use in commercial industries to maintain freshness of fruits, seafood, and poultry. Studies have also revealed that aqueous ClO₂ is effective in improving the microbial safety and quality of strawberry fruits during storage (Jin et al., 2007). There have been reported uses of aqueous chloride to preserve edible fruits, vegetables, and seafood in America, Japan, and European countries. However, possible health concerns have been raised because of the presence of trihalomethanes that are generated in the presence of organic materials (Beuchat et al., 1998; Kim et al., 1999b). Moreover, a recent FAO/WHO expert committee meeting suggested an allowed daily intake of 0-30 mg·L⁻¹ ClO₂.

The fact that strawberry fruits are soft makes it difficult to administer aqueous ClO₂ treatment, since the pressure exerted causes them physical damage. Therefore, it might be appropriate to use a gaseous ClO₂ treatment for strawberry fruits. Gaseous ClO₂ is usually used in hospitals to remove pathogenic organisms, but has not yet been applied to dietary fruits. If successful, gaseous treatment of strawberries might result in better quality control, which would ensure a more stable supply and pricing – important factors for export.

Compared to air transportation, export by ship is cheaper and can move higher volumes, but it takes 3–10 days longer to transport goods. Transport by ship, therefore, would seem unsuitable for strawberries, a fruit that can easily over ripen, become soft or rot. To deal with this problem, a new processing technology has been developed using gaseous ClO₂ either alone or in combination with precooling to retain the freshness and quality of fruits intended for export.

The aim of this study was to assess the effect of precooling and application of gaseous ClO₂ on the retention of freshness and quality of 'Maehyang' strawberry fruits intended for export, and to investigate the advantages of these treatments in the 'Maehyang' strawberry export industry.

Materials and Methods

'Maehyang' strawberry fruits were grown and harvested from commercial greenhouses in Jinju (Gyeongnam province, South Korea). Fruits of uniform and medium size and 60% ripeness were selected for use in this study.

A randomized complete block design was used. Strawberry fruits were assigned to one of four treatment groups, with 15 fruits per group, and 3 replicates of each experiment: non-treatment (control), precooling only (PO), gaseous ClO₂ only (GCO) or precooling combined with gaseous ClO₂ (P+C). Strawberry fruits in the control treatment group were put outside at 15°C (outside air temperature). In the PO treatment group, strawberry fruits were precooled using a forced air cooling storage system set at 2°C to decrease the material temperature of the fruits, as recommended by previous studies (Park et al., 2012; Kim and Hwang, 2013). The average material temperature of the strawberry fruits was 15°C before storage, and 3°C after precooling (1/5 cooling time). Strawberry fruits in the GCO group were treated with gaseous ClO₂ (1.0 mg·L⁻¹), generated using a ClO₂ gas generating system (Bactericide, Sunseal Co. Ltd., Busan, Korea) at 15°C (outside air temperature)

for 1 hour. To ensure the effectiveness of gaseous ClO₂ treatment, a high concentration of gaseous ClO₂ was used, and the treatment time was long. The amount of gaseous ClO₂ applied was measured using a ClO₂ gas detector (C16 PortaSens II, Analytical Technology Co. Ltd., PA, USA). In the treatment involving P+C, the strawberry fruits were treated with gaseous ClO₂ (1.0 mg·L⁻¹) for 1 hour at the precooling temperature of 2°C. After receiving these treatments, the strawberry fruits were hygienically packed into plastic boxes, put inside cardboard boxes, and wrapped cleanly and completely with plastic film to ensure the boxes were securely packed. The boxes were then put into a climate-controlled container set at 2°C and immediately exported to Hong Kong by ship. Temperature and relative humidity (RH) were recorded inside the container during shipping, and in the laboratory, using an iButton recorder (iButton DS1923L-F5, Maxim Integrated Co. Ltd., San Jose, USA).

To determine the weight loss of strawberry fruits caused by transpiration and respiration, fruits were weighed using a digital balance scale (MW-330, CAS, Yangju Co. Ltd., Korea) just before treatment in South Korea, and again upon their arrival in Hong Kong.

To measure the skin color of strawberry fruits, a color reader (CR-11, Minolta Co. Ltd., Tokyo, Japan) was used at the side of the fruits' central zone and compared with the Munsell hue circle to determine brightness and chroma.

The soluble solids content of strawberry fruit juice was measured using a digital refractometer (PR-201a, Atago Co. Ltd., Tokyo, Japan) and was expressed as °Brix.

The incidence of gray mold rot affecting the fruit was analyzed by eye and then quantified as a percentage by counting the number of decayed fruits, divided by the total number of fruits in a single plastic box, and multiplying by 100. There were 24 strawberries in each plastic box weighing approximately 250 g.

Analysis of variance and Duncan's multiple range tests were performed using the SAS program (Statistical Analysis System Co. Ltd., V. 9.1, Cary, NC, USA).

Results and Discussion

The temperature and RH inside the containers during export from South Korea to Hong Kong by ship are shown in Fig. 1 (time points A-G). The temperature inside the container was controlled at 2°C. From the point of departure in South Korea (E) to the time of port entry in Hong Kong (F), the ranges of temperature and RH were 2-6°C and 87-97%, respectively; the little fluctuation shows that environmental conditions were stable. However, from the entry in Hong Kong (F) to the point of opening the container (G), the temperature rose suddenly by a factor of 5 from 2 to 10°C and the RH decreased. Fluctuating temperatures during fruit shipping may result in increased loss of quality in terms of weight loss, lower ascorbic acid content, a darker color, evident dryness of the skin, and an unsalable condition (Nunes et al., 2003).

The incidence of gray mold in strawberry fruits before departure and after export is presented in Fig. 2. The sudden rise in temperature may have induced gray mold in strawberry fruits. Park and Hwang (2010) reported that storage temperature is vital for preserving strawberry fruits, and a temperature of less than 4°C is most effective for keeping strawberries fresh. It is well known that environmental conditions, particularly temperature and RH, have a major impact on the appearance, texture, composition and eating quality of strawberry fruits.

The observed quality of strawberry fruits under each experimental condition is shown in Fig. 3. Harvested fruits continue

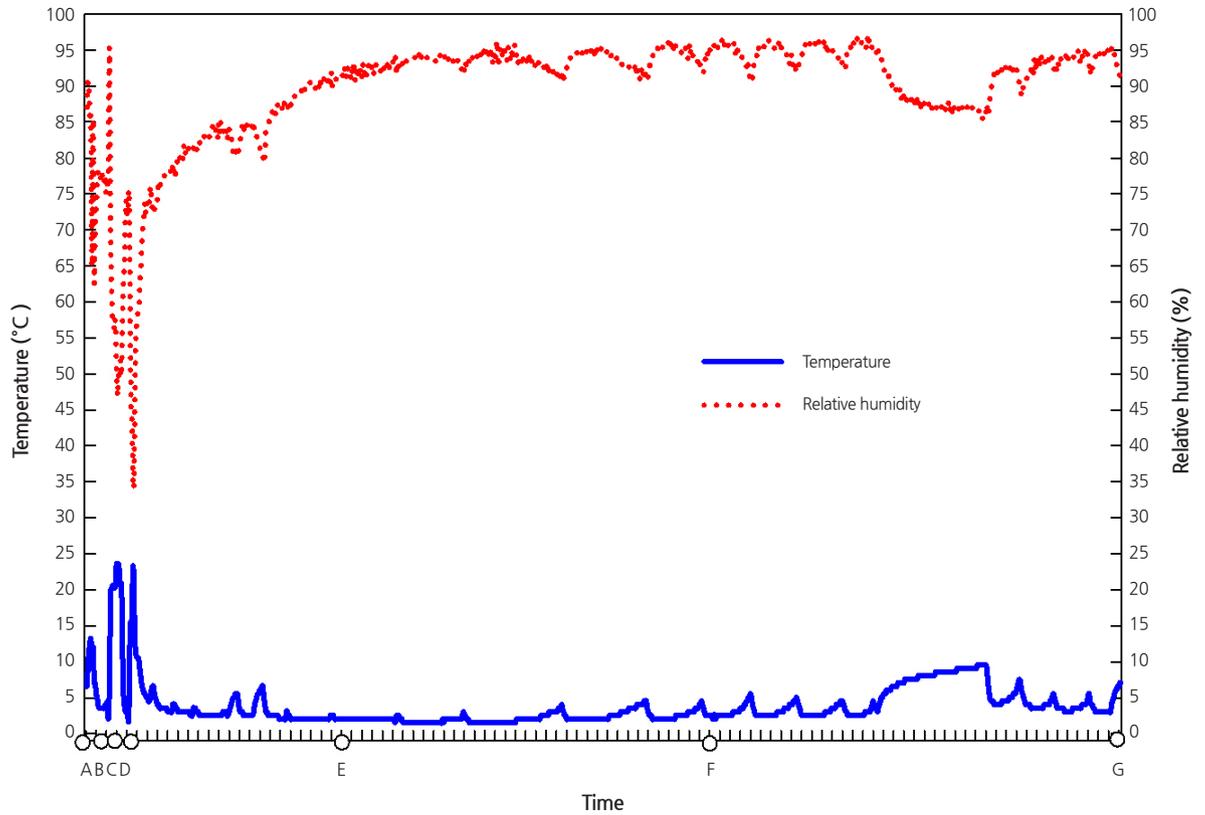


Fig. 1. Changes in temperature and relative humidity experienced by 'Maehyang' strawberry fruits during export by ship from South Korea to Hong Kong between 18th and 25th April 2013. (A) harvest at 07:30 on April 18th 2013, (B) storage at 08:30 on April 18th 2013, (C) selection at 13:00 on April 18th 2013, (D) transfer to container vessel at 17:48 on April 18th 2013, (E) ship departure at 19:00 on April 19th 2013, (F) port entry at 18:00 on April 22th 2013, and (G) opening the container at 10:00 on April 25th 2013.



Fig. 2. Photograph showing 'Maehyang' strawberry fruits intended for export. (A) strawberry fruits at the point of export in South Korea, (B) strawberry fruits with some gray mold rot, weight loss, and change in color at the point of import in Hong Kong.

to respire and lose water to the environment, which cannot be replaced, thus weight loss occurs (Thompson, 2003). In all treatment groups, fruits decreased in weight after export (Fig. 3A). Weight loss was significantly lower with the PO treatment compared to the other treatments, and was highest in the GCO treatment group after export. As previously reported by

Robinson et al. (1975), to maintain good fruit quality, the acceptable limit of strawberry weight loss is not more than 6%. Fruits in the PO treatment group remained below this 6% threshold of weight loss, while fruits in the control, GCO and P + C treatment groups lost more than 6% of their weight. It is notable that weight loss is increased by treatment with gaseous ClO_2 alone. According to Szczesniak and Smit (1969), the epidermis of strawberry fruits consists of polygonal cells with larger stomata, and strawberry pith consists of thin-walled cells that are often separated during growth, leaving large cavities. The large and thin cell walls in strawberry fruits contribute to their high susceptibility to weight loss. In the present study, gaseous ClO_2 might have some direct or indirect effect and/or contribute to opening of the stomatal pores, resulting in weight loss.

The chroma, or 'colorfulness' of strawberry fruits is one of the most important visible factors for consumers when selecting for strawberry quality. The higher the chroma, the better the visible quality, so it is important for strawberry fruits to have a vivid red color. In this study, strawberry fruits were 60% ripe, so initially had a high brightness value and low chroma value. The strawberry fruits had a lower chroma value (9.4–11.5) than those in a previous study (25–45) reported by Nunes et al. (2006). In that study, a different strawberry cultivar was used, and the strawberry fruits for export were early harvested. Compared to the fruits before export, post-export fruits had decreased brightness in all treatments (Fig. 3B), and chroma was increased in all groups except for the control (Fig. 3C). Previous research has reported that a controlled atmosphere may affect the color of stored strawberry fruits (Holcroft and Kader, 1999); whereas fresh strawberry fruits have a brilliant red color, processed fruits are characterized by rapid loss and degradation of pigment (Espin et al., 2000).

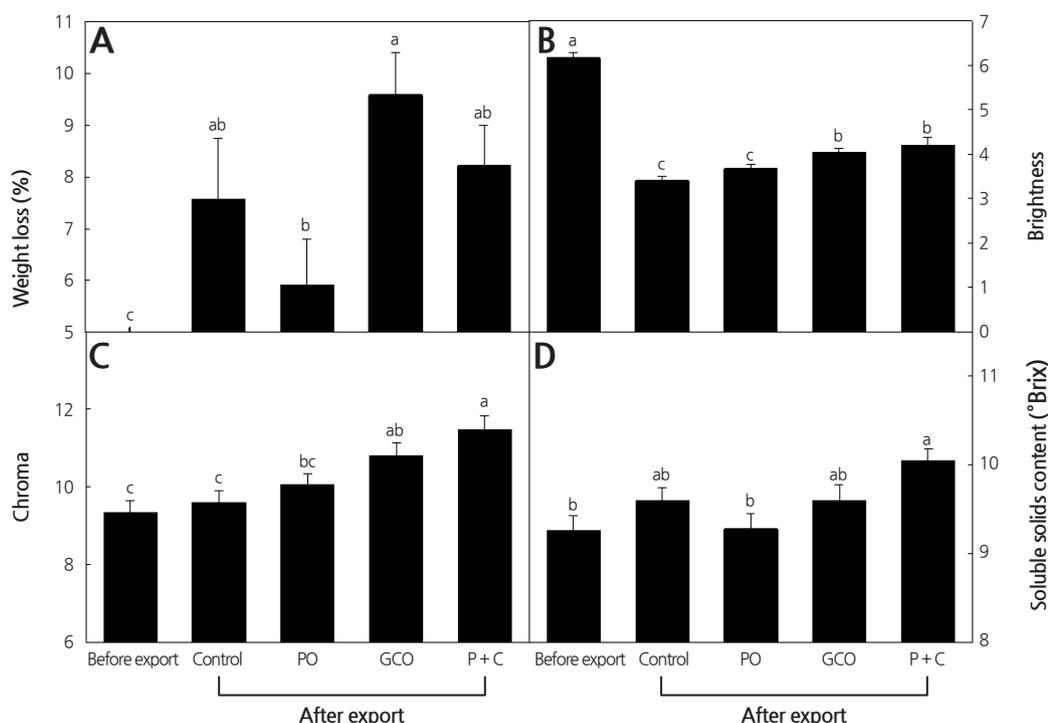


Fig. 3. Effects of precooling and chlorine dioxide treatment on weight loss (A), brightness (B), chroma (C), and soluble solids content (D) of 'Maehyang' strawberries. Before export and immediately after harvest, 'Maehyang' strawberry fruits were assigned to one of four treatment groups; control, non-treatment; PO, precooling at 2°C only; GCO, treatment with gaseous ClO_2 (1.0 mg·L⁻¹) only; and P + C, precooling at 2°C combined with 1.0 mg·L⁻¹ gaseous ClO_2 . Treatment was given before and after export. Vertical bars indicate ± standard errors (n = 15 fruits). Lower-case letters above each bar indicate statistically significant means according to Duncan's multiple range test ($p \leq 0.05$).

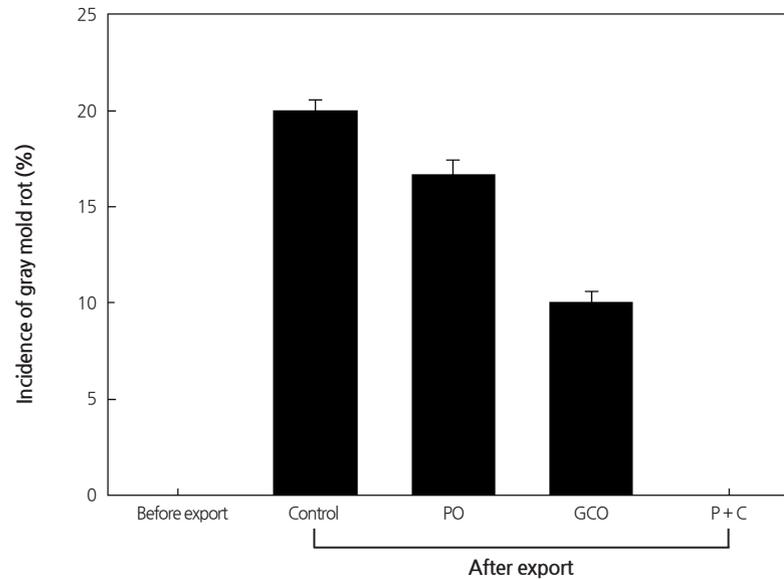


Fig. 4. Incidence of gray mold rot of 'Maehyang' strawberry fruits before and after export. Before export, immediately after the harvest; Control, non-treatment; PO, precooling at 2°C only; GCO, treatment with 1.0 mg·L⁻¹ gaseous ClO₂ only; and P + C, precooling at 2°C combined with treatment with 1.0 mg·L⁻¹ gaseous ClO₂. Vertical bars indicate ± standard errors (n = 24 fruits).

Lee et al. (2010) found that 'Sulhyang' strawberry fruits treated with 0.2 mg·L⁻¹ gaseous ClO₂ at 25°C for 20 minutes showed decolorization in the fruit flesh. The concentration of gaseous ClO₂ in our experiment was 5 times higher and applied for 3 times longer than in the Lee study, yet we found no decolorization or damage. We considered that the 'Maehyang' strawberry fruits used in our experiment, which were treated with gaseous ClO₂ at a lower temperature (2 or 15°C), and had lower maturity (60%) and harder fruit flesh than 'Sulhyang', were not damaged because the 'Maehyang' cultivar was bred for export. In our experiment, strawberry fruits maintained higher brightness and chroma when treated with gaseous ClO₂ compared to the control and PO treatment groups. Thus, gaseous ClO₂ has a good effect on strawberry fruit color, and is suitable for use in the storage of strawberry fruits.

The soluble solids content of strawberry fruits increased after export (Fig. 3D). Before export, the mean soluble solids content of fruits was 9.27 °Brix. Six days after shipping, the lowest soluble solids content value was observed in the PO treatment group. This might be attributable to the effect of precooling in delaying the breakdown of cell wall polysaccharides (Damodaran, 2007). However, despite also being subjected to precooling, fruits in the P + C group had the highest soluble solids content, with a value as high as 10.05 °Brix. This result suggests that the soluble solids content of fruits is more affected by gaseous ClO₂ than by precooling, and as such, P + C treatment seems suitable for ensuring a high soluble solids content in strawberry fruits to maintain good taste quality after export.

Gray mold may have occurred because of a sudden increase in temperature during the export process; a favourable condition for gray mold growth (Fig. 1). The incidence rate of gray mold of strawberry fruits was 20% and 17% in the control and the PO treatment groups, respectively. Fruits in the GCO treatment group had a gray mold incidence of 10%, and there was no incidence of gray mold in P + C treatment group (Fig. 4). Thus, the results demonstrate that P + C treatment profoundly decreases the incidence of gray mold. Wu and Kim (2007) showed that aqueous ClO₂ treatment, a novel sanitization procedure for enhancing food safety, could be used to control foodborne pathogens as well as yeasts and molds

on blueberries. Previous studies have also shown that treatment with $10 \text{ mg}\cdot\text{L}^{-1}$ gaseous ClO_2 for 3 minutes reduced the number of microorganisms on the surface of tomatoes, cantaloupes, and strawberries (Trinetta et al., 2013). Barakat et al. (2007) reported that gaseous ClO_2 reduced the initial microflora (mesophilic and psychrotrophic bacteria, yeasts, and molds) on strawberry. The reduction of gray mold observed in our study shows that gaseous ClO_2 is viable for use in fruit export and can be used to prevent gray mold in edible fruits.

The results of our study indicate that gaseous ClO_2 treatment combined with precooling (P+C) is effective in maintaining the freshness of 'Maehyang' strawberries except for water loss intended for export from South Korea to Hong Kong. This information could be beneficial for importers to obtain good quality and disease-free strawberries. However, further studies should be carried out, specifically with regard to the biochemical and molecular aspects that may identify the enzymes and genes involved in changes in physicochemical parameters and strawberry fruit quality. These results would be useful to integrate into proper handling and postharvest storage techniques for strawberry fruits intended for export from South Korea to other countries.

Literature Cited

- Ahn GH, Ha YL, Shon GM, Song WD, Seo KK, Choi SJ (2000) The effects of ethylene absorbent on the quality of 'Fuyu' persimmon fruits in MA package. *Korean J Food Sci Technol* 32:1278-1284
- Barakat SM, Bhagat AR, Linton RH (2007) Inactivation kinetics of inoculated *Escherichia coli* O157:H7, *Listeria monocytogenes* and *Salmonella enteric* on strawberries by chlorine dioxide gas. *Food Micro* 24:736-744
- Beuchat LR, Nail BV, Adler BB, Clavero MRS (1998) Efficacy of spray application of chlorinated water in killing pathogenic bacteria on raw apples, tomatoes, and lettuce. *J Food Protect* 61:1305-1311
- Damodaran S, Parkin KL, Fennema OR (2007) Fennema's food chemistry. Ed 4, CRC Press, p 1022
- Espin JC, Soler-Rivas C, Wichers HJ, Garcia-Vigueria C (2000) Anthocyanin based natural colorants: a new source of antiradial activity for foodstuff. *J Agric Food Chem* 48:1588-1592
- Holcroft DM, Kader AA (1999) Controlled atmosphere-induced changes in pH and organic acid metabolism may affect color of stored strawberry fruit. *Postharvest Biol Technol* 17:19-32
- Jeong JW, Jo JH, Kwon DJ, Kim YB (1990) Studies on the low temperature storage of strawberry pulp and red pepper paste by cryoprotectants. *Korean J Food Sci Technol* 22:434-438
- Jin YY, Kim YJ, Chung K, Won M, Song KB (2007) Effect of aqueous chlorine dioxide treatment on the microbial growth and qualities of strawberries during storage. *Food Sci Biotechnol* 16:1018-1022
- Kim JM, Huang TS, Marshall MR, Wei CI (1999a) Chlorine dioxide treatment of seafoods to reduce bacterial loads. *Food Microbiol Safety* 64:1089-1093. doi:10.1111/j.1365-2621.1999.tb12288.x
- Kim JM, Maurice R, Marshall MR, Du WX, Otwell WS, Wei CI (1999b) Determination of chlorate and chlorite and mutagenicity of seafood treated with aqueous chlorine dioxide. *J Agric Food Chem* 47:3589-3591. doi:10.1021/jf981397h
- Kim HM, Hwang SJ (2013) Qualitative changes in maturity, precooling temperatures and light illumination on the post-harvest management of the fruits in 'Maehyang' strawberry for export. *Protected horticult plant fac* 22:432-438. doi:10.12791/KSBEC.2013.22.4.432
- Kim JY, Kim JY, Lim GO, Jang SA, Song KB (2010) The effects of aqueous chlorine dioxide or fumaric acid treatment combined with UV-C on postharvest quality of 'Maehyang' strawberries. *Postharvest Biol Technol* 56:254-256. doi:10.1016/j.postharvbio.2010.01.013
- Korea Rural Economic Institute (KREI) (2014) Agricultural outlook 2014. p 140
- Lee HE, Choi JW, Kim JG (2010) Determination of chlorine dioxide gas treatment in strawberry. *Korean J Hortic Sci Technol* 28:64. (Abstr.)
- Nunes MCN, Emond JP, Brecht JK (2003) Quality of strawberries as affected by temperature abuse during ground, in-flight and retail handling operations. *Acta Hort* 604:239-246. doi:10.17660/ActaHortic.2003.604.24
- Nunes MCN, Brecht JK, Morais AM, Sargent SA (2006) Physicochemical changes during strawberry development in the field compared with those that occur in harvested fruit during storage. *J Sci Food Agric* 86:180-190. doi:10.1002/jsfa.2314
- Park JE, Hwang SJ (2010) Effect of precooling and storage temperatures on the post-harvest management of the fruits in 'Maehyang' and 'Soogyong' strawberry for export. *J Bio-Environ Con* 19:366-371
- Park JE, Kim HM, Hwang SJ (2012) Effect of harvest time, precooling, and storage temperature for keeping the freshness of 'Maehyang' strawberry for export. *J Bio-Environ Con* 21:404-410. doi:10.12791/KSBEC.2012.21.4.404
- Robinson JE, Browne KM, Burton WG (1975) Storage characteristics of some vegetables and soft fruits. *Ann Appl Biol* 36:355-360.

doi:10.1111/j.1744-7348.1975.tb01656.x

- Szczesniak AS, Smith BJ** (1969) Observation on strawberry texture, a three-pronged approach. *J Textural Stud* 1:65-89. doi:10.1111/j.1745-4603.1969.tb00957.x
- Thompson AK** (2003) *Fruit and vegetables-harvesting, handling and storage*. Blackwell Publisher. pp 100-460
- Trinetta V, Linton RH, Morgan MT** (2013) The application of high-concentration short-time chlorine dioxide treatment for selected specialty crops including Roma tomatoes (*Lycopersicon esculentum*), cantaloupes (*Cucumis melo* ssp. *melo* var. *cantaloupensis*) and strawberries (*Fragaria x ananassa*). *Food Microbiol* 34:296-302. doi:10.1016/j.fm.2012.12.010
- Van der Steen C, Jacxsens L, Develieghere F, Devereve J** (2002) Combining high oxygen atmosphere packaging to improve the keeping quality of strawberries and raspberries. *Postharvest Biol Technol* 26:49-58. doi:10.1016/S0925-5214(02)00005-4
- Wu VC, Kim B** (2007) Effect of a simple chlorine dioxide method for controlling five foodborne pathogens, yeasts and molds on blueberries. *Food Microbiol* 24:794-800. doi:10.1016/j.fm.2007.03.010
- Yang FM, Li HM, Li F, Xin ZH, Zhao YH, Hu QH** (2010) Effect of nano-packing on preservation quality of fresh strawberry (*Fragaria ananassa* Duch. cv Fengxiang) during storage at 4°C. *J Food Sci* 75:C236-C240. doi:10.1111/j.1750-3841.2010.01520.x