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Effects of Carbon Dioxide Treatment and Modified Atmosphere Packaging on the Quality of Long Distance Transporting "Maehyang" Strawberry

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Abstract

This study was conducted to investigate the effects of carbon dioxide (CO_2) and modified atmosphere (MA) packaging on the quality of strawberry during long distance transportation. "Maehyang" strawberries (*Fragaria* x *ananassa* Duch.) with red color on 70% of the fruit surface were harvested in Gyeongnam province, Korea. The samples were placed in gas-tight chamber with 30% CO_2 concentration for 3 hours at 3˚C. Strawberry samples were then packaged with modified atmosphere-modified humidity (MA/MH) packaging film. Samples treated with CO_2 alone and combined CO_2 with MA packaging were stored for one day at 1˚C, transported for 10 days at 1˚C, and distributed for 3 days at 4˚C. Carbon dioxide alone or combination with MA packaging was effective in maintaining quality of "Maehyang" strawberries. Carbon dioxide treatment significantly increased firmness and reduced softening index and decay rate during 14 day transportation and distribution. Samples treated with CO_2 + MA had higher overall score with low softening index and weight loss after 14 days of transportation and low temperature distribution compared to CO_2 treatment only. The results indicated that a short term application of CO_2 or combination treatment of CO_2 and MA could be good postharvest handling for maintaining freshness of "Maehyang" strawberries during long distance vessel export.

Keywords

Carbon Dioxide, Firmness, Modified Atmosphere, Quality, Strawberry

1. Introduction

Strawberry is highly perishable fruit and requires careful handling in order to maintain quality after harvest. Strawberry is considered as winter fruit in Korea because con-

sumption of the fruit is high in winter season. Though the domestic market of strawberry has been increased in Korea, the strawberry industry tries to expand the export market. Total strawberry export has been increasing and the trend is expected to remain strong, mainly due to the increased shipments to South East Asian countries such as Singapore and Hong Kong of China [1]. However, strawberry has a limited shelf-life due to rapid softening and decay during postharvest handling such as transportation, storage and marketing. The main characteristics related to the market quality of strawberry fruits are texture (firmness), flavor and decay rate. Generally, fungal decay is caused to loss of quality on strawberry for storage time [2]. It is therefore important to apply an appropriate postharvest treatment to delay respiration, prevent physical damage, dryness and to restrict fungal decay in order to extend shelf-life. Postharvest treatment such as precooling [3], storage at low temperature [4], carbon dioxide [2] [5] [6] and chlorine dioxide [7] can be used for this purpose. For example, Lee H.J. *et al.* reported that a short term application of CO_2 during cooling has a benefit for keeping freshness of strawberries during export and local marketing [5]. Harker F.R. *et al.* reported that mechanism for CO_2-induced firmness enhancement in strawberry is due to changes in the pH of the apoplast. Such changes in pH may promote the precipitation of soluble pectins and thus enhance cell-to-cell bonding in strawberry fruit [6].

Controlled atmosphere or modified atmosphere (CA or MA) has been used successfully on maintaining the quality of strawberries. Modified atmosphere packaging can be considered as a self-contained form of controlled atmosphere designed to maintain the internal gas composition of the packaging during transportation and storage. A modified atmosphere extends the shelf-life of the fruits, whereas the sealed container protects them from exposure to diseases and other environmental contaminants [8]. Controlling the relative humidity and storage temperature were important factors for keeping the freshness of fruits.

To increase the export of fruit, such as strawberries, it is necessary to develop the postharvest management of fruit during retail marketing after transportation. Compared to air transportation, vessel export is cheaper and can move higher volumes, but it takes 3 - 10 days longer to transport goods. Vessel export would seem unsuitable for strawberries, a fruit that can over ripen easily and become soft or rot [7]. In this study, to extend the shelf-life of strawberry, we examined the CO_2 treatment alone and combined CO_2 with MA. We investigate the quality of "Maehyang" strawberry during different storage conditions in the retail marketing after vessel export.

2. Material and Methods

2.1. Plant Materials and Treatment

Fresh "Maehyang" strawberry fruits were grown and harvested from commercial greenhouses in Jinju, Gyeongsangnam-do, Korea. Strawberry fruits were harvested in the early morning and immediately precooled in storage room at 1˚C for 2 hour. Fruits of uniform medium size with red color on 70% of the fruit surface were used for this study. Postharvest treatment was 30% concentration of carbon dioxide gas with 3 hour

and using strawberry modified atmosphere packaging film (Xtend, Stepac, Israel).

2.2. Storage, Transportation and Retail Marketing Conditions

"Maehyang" samples treated with 30% concentration of CO_2 alone and combined CO_2 with MA packaging were stored for one day at 1˚C, transported for 10 days at 1˚C by vessel container, and distribution condition; cold storage for 3 days at 4˚C, retail market (10˚C - 15˚C) and room temperature.

2.3. Quality Evaluations

Quality evaluations included weight loss, firmness, total soluble solid (TSS) and sensory analysis.

Weight loss was evaluated by measuring the weight of eight randomly chosen boxes. Fruits were weighed using a digital balance scale (HH320, OHAUS, NJ, USA) just before treatment in South Korea, again upon their arrival in Singapore and retail marketing duration.

All texture measurements were undertaken potable firmness testing machine (FHM-5, Takemura, Japan) and 10 individual fruit per treatment were selected for each of them.

Total soluble solids (TSS) were measured according to the AOAC procedures [9]. On each evaluation day, 5 fruit from each replicate was wrapped with 2 layer of cotton cloth and squeezed with a hand pressed juice maker. TSS of the resultant juice was measured in terms of brix using a refractometer (PAL-1, Atago Co. Ltd, Tokyo, Japan).

The sensory analysis of strawberry sample was carried out by expert panel. The member of the panel were trained to recognize and overall visual quality of strawberry sample prior to the test. These sensory qualities were evaluated by using 9-point scale (9 = excellent, 7 = good, 5 = moderate, 3 = poor, and 1 = unusable). A score of 6 was considered as the limit of marketability. To incidence of decay 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 20 - 24 strawberries in each plastic box weighing approximately 280 g. Softening score of individual fruit in a box was carried out on 5-scale (0 = 0% surface softened, 1 = up to 10% surface softened, 2 = 10 to 25% surface softened, 3 = 25 to 50% surface softened, and 4 = >50% surface softened) [2].

2.4. Statistical Analysis

The experiment was conducted with three replications per treatment. Statistical analyses of the data were carried out using SAS software (SAS Institute, Cary, NC, USA). The level of significance was calculated from the F value of ANOVA. Mean comparison was achieved by Duncan's multiple range test.

3. Results and Discussion

3.1. Weight Loss

Weight loss during storage due to transpiration was observed for all treatments. Com-

bination of CO_2 and MA treatments showed significantly lower values than the control and CO_2 treatment. Modified atmosphere such as box in bag, it maintained moisture and freshness. By Robinson *et al.*, losses of 6% of the initial value of fresh weight of a soft fruit should be considered the limit for marketability [10]. In this study, after 14 days of storage, control had loss 2% and CO_2 treatment had loss 3% due to stress of gas injection in acrylic chamber. However treated with combination of CO_2 and MA was shown that loss of fresh weight was 1% in 14 days of storage at under 4˚C. Comparing all treatments, combination of CO_2 and MA treatments had a significant effect on weight loss, presenting the lowest values (**Figure 1**).

3.2. Firmness

One of the main factors used to determine fruit quality and postharvest shelf life is the amount of loss of firmness during the storage of soft fruit such as strawberries [11]. By Manning [12], fruit softening is attributed to the degradation of cell wall components, mainly pectin, due to the action of specific enzymes such as polygalacturonase. The firmness of strawberries increased as the 30% concentration of carbon dioxide treatment within 3 hour. After vessel export at 1˚C, firmness was maintained higher than control in all storage condition (**Figure 2**). Although increases in fruit firmness were reported in other studies by the application of high level of carbon dioxide [5] [6], in addition to the firmness enhancement observed when strawberry fruit are held at low temperatures [13]. The firmness of strawberries after vessel export remained higher than harvest firmness values throughout the 15 day period of continuous cold storage at under 4˚C. By F.R. Harker *et al.*, strawberries from all treatments softened rapidly and no residual effect of CO_2-enhanced firming was detectable within 3 days at 20˚C (data not shown) [6]. However, "Maehyang" strawberries treated with CO_2 and CO_2 + MA maintained firmness until 3 days at room temperature (over 26˚C), unlike that of

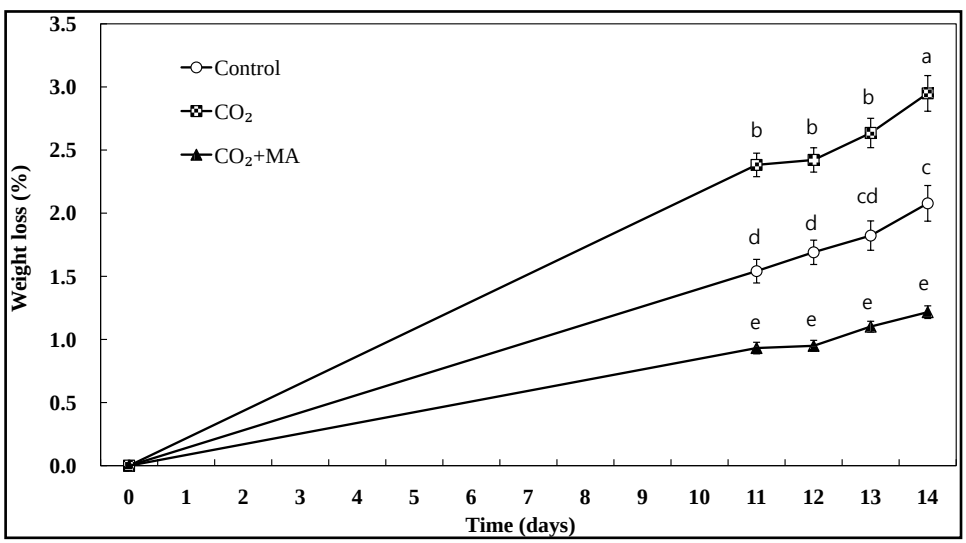


Figure 1. Changes in weight loss of "Maehyang" strawberries treated with CO_2 alone or combination of CO_2 and MA packaging after 10 days of transportation. Vertical lines represent S.E.

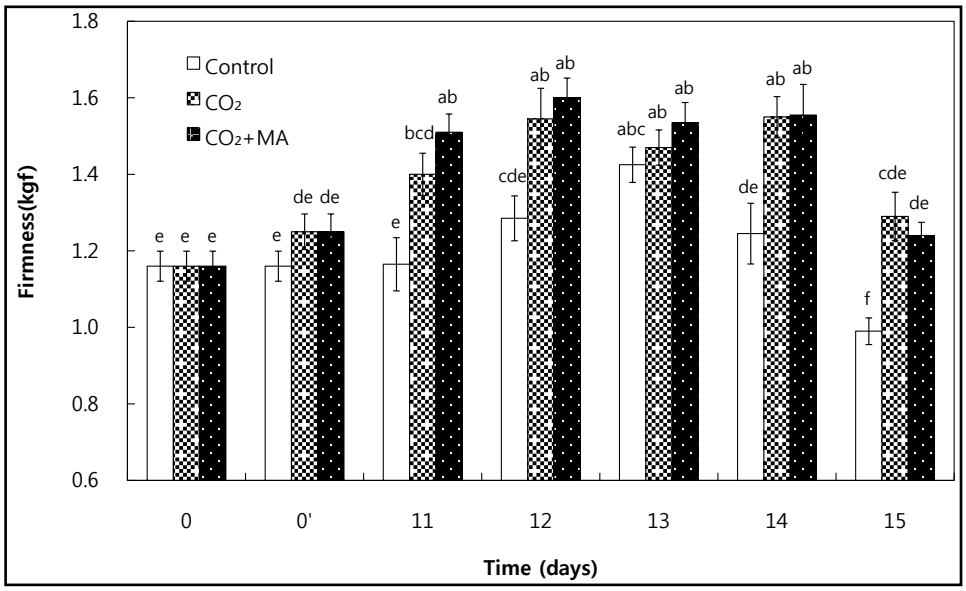


Figure 2. Changes in firmness of "Maehyang" strawberries treated with CO_2 alone or combination of CO_2 and MA packaging after 10 days of transportation during storage days at 4˚C. 0 means at harvest before treatment. 0' means after treatment of CO_2 for 3hr before storage. Vertical lines represent S.E. Different letters indicate significant differences at $p \leq 0.05$.

untreated control.

3.3. Total Soluble Solids

Total soluble solids are a critical factor for determining fruit quality and consumer acceptability. Sugars are the main soluble metabolites, and include glucose, fructose and sucrose comprising 99% of total sugar content [14]. The TSS of cv. "Maehyang" strawberries at harvest was 10.88˚ Brix and all treatments showed increases in the values during the storage time (**Table 1**). TSS was remained with low temperature storage, whereas TSS of "Maehyang" strawberries stored in retail market at 10˚C - 15˚C were shown 9.72˚ Brix at the end of marketing (after harvest 14 days).

3.4. Sensory Quality

Sensory quality is related to the characteristics of the food and how consumers perceive them [15]. With increasing storage time, deterioration starts with decay, fermentation and bruising [16]. Visual quality of "Maehyang" strawberries after vessel transportation was evaluated. Carbon dioxide alone and combination of CO_2 and MA treatment were effective in delaying dark red coloration on fruit surface.

Softening index of "Maehyang" strawberries was the highest in the control group at 11 days of storage (<4˚C) (**Figure 3**). After 15 days of storage (<4˚C), control showed higher score than those of CO_2 and combined CO_2 with MA treated strawberry. However, in low temperature storage under 4˚C, it restrained to occur softening on the surface of strawberry. Comparing all treatments, CO_2 and combination of CO_2 and MA treatments had a significant effect ($p < 0.05$) on softening index, presenting lower

Table 1. Changes in total soluble solids of "Maehyang" strawberry treated with carbon dioxide or MAP at different storage conditions after vessel export.

Storage condition	Treatment	Time (days)						
		0	0'	11	12	13	14	15
4˚C	Control	10.88 ± 0.18	10.88 ± 0.18	10.00 ± 0.20	11.18 ± 0.37	11.34 ± 0.61	13.76 ± 0.15	10.24 ± 0.06
	CO_2	10.88 ± 0.18	12.44 ± 0.35	10.20 ± 0.11	11.58 ± 0.57	11.00 ± 0.34	11.04 ± 0.28	10.70 ± 0.27
	CO_2 + MA	10.88 ± 0.18	12.44 ± 0.35	11.00 ± 0.36	11.60 ± 0.30	11.48 ± 0.20	10.70 ± 0.31	10.18 ± 0.20
Retail marketing (10-15°C)	CO_2	–	–	–	9.88 ± 0.20	10.66 ± 0.17	9.72 ± 0.20	–

0 means at harvest before treatment. 0' means after treatment of CO_2 for 3 hr before storage. Data are means ± S.E.

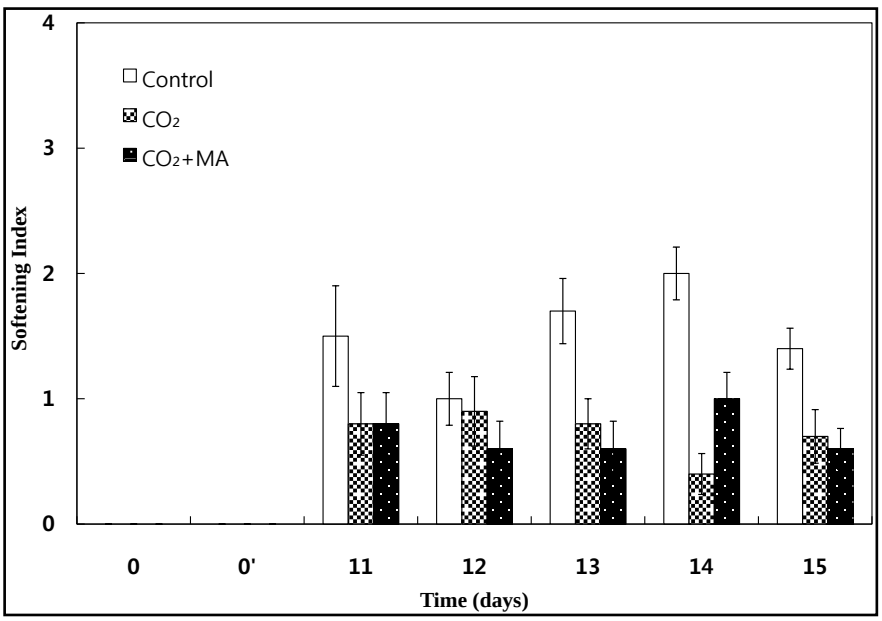
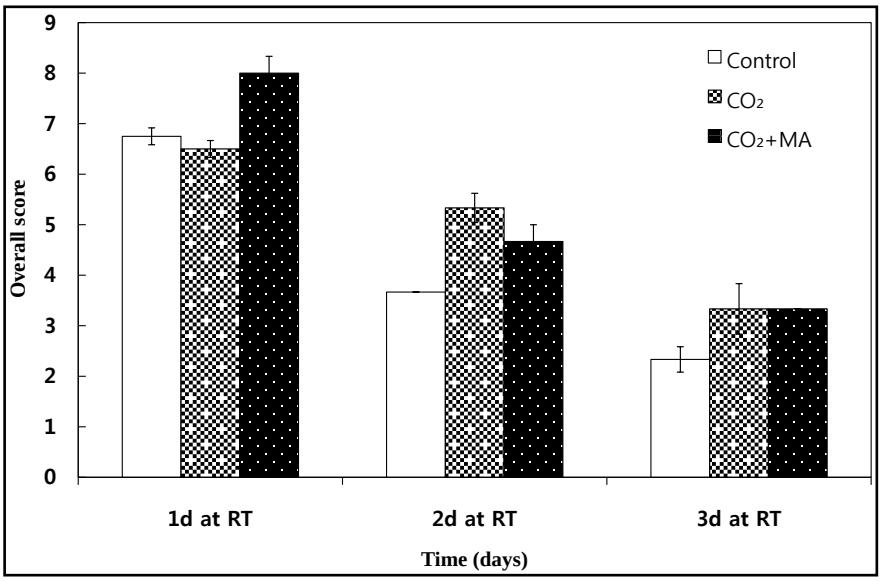


Figure 3. Softening index of "Maehyang" strawberries treated with CO_2 alone or combination of CO_2 and MA packaging after 10 days of transportation during storage days at 4˚C. 0 means at harvest before treatment. 0' means after treatment of CO_2 for 3 hr before storage. Vertical lines represent S.E. Softening index was scored using five-point scale based on the degree of softening area of the fruit surface where 0 = normal (0% surface softened), 1 = trace (up to 10% surface softened), 2 = slight (10 to 25% surface softened), 3 = moderate (25% - 50% surface softened), and 4 = severe (>50% surface softened).

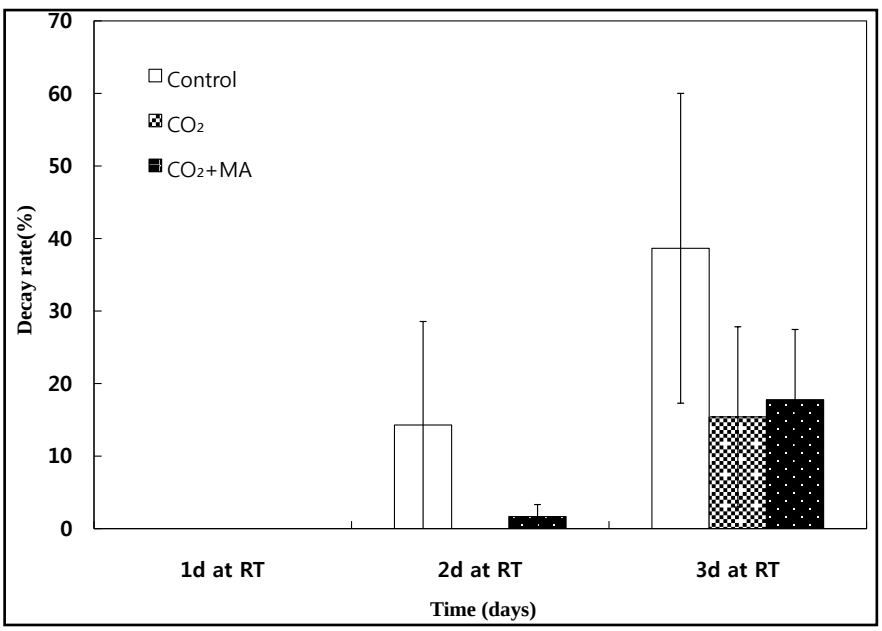
values than control.

Overall score of "Maehyang" strawberries decreased gradually in storage time in all treatments at room temperature after vessel export (**Figure 4**). Although samples of different treatments received marketable scores until 12 days of storage (cold storage following 10 days transportation). After 2 days at room temperature after cold storage following 10 days transportation, strawberries lost marketability in all the treatment representing severely softening. Non-treated control showed lower score than those of CO_2 and CO_2 + MA treated strawberry.

Decay development is one of the main causes for postharvest losses of horticultural



(a)



(b)

Figure 4. Overall quality score and decay rate of "Maehyang" strawberries treated with CO_2 alone or combination of CO_2 and MA packaging during storage period at room temperature (1d, 2d and 3d) after cold storage following 10 day transportation was scored by three trained panelists using a 1 - 9 hedonic scale where 1 = dislike extremely; 2 = dislike very much; 3 = dislike moderately; 4 = dislike slightly; 5 = neither like nor dislike; 6 = like slightly; 7 = like moderately; 8 = like very much; and 9 = like extremely.

produce. In particularly, strawberries are highly susceptible to microbial infection and have a short shelf-life caused by *Botrytis cinerea* [17]. Fruit decay was not shown by cold temperature storage (<4˚C) for up to 15 days after harvest. However, the decay rate was the highest in the control group at 3 days room temperature storage cold sto-

rage following 10 days transportation (**Figure 4**). High carbon dioxide levels may have inhibited decay by Nielsen and Leufven [18]. At the point of 2 days in room temperature, it occurred fungal decay on control and CO_2 + MA. And after 3 days in room temperature, all treatments were shown that fungal decay on surface. In summary, worth notice is that we did not detect any decay at all when strawberry were sent immediately after vessel export and retail marketing, but only after storage at room temperature (simulation in wholesale market) high levels of fungal decay were shown after 2 days of storage on control and CO_2 + MA, and after 3 days, all treatments were shown high percentage of fungal decay on fruit surface.

4. Conclusion

Maintaining the quality of highly perishable fruits, such as strawberries, associated with the cold, retail market, local chain systems after long term transporting, is a difficult subject. Atmosphere containing 30% CO_2 was effective in reducing decay rate and fruit softening and maintaining bright red color of "Mayhyang" strawberries during long term transportation and distribution. Samples treated with combination of 30% CO_2 and MA had higher overall score with low softening index and weight loss after 14 days of transportation and low temperature distribution. Thus, CO_2 treatment alone or combination of CO_2 and MA could be a practical postharvest technology to extend shelf-life of "Maehyang" strawberry. Therefore, "Maehyang" strawberry can be exported through vessel transportation.

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