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Effect of 1-methylcyclopropene on Postharvest Quality in 'Formosa' Plums (*Prunus salicina* L.) Harvested at Various Stages of Maturity

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Abstract. 'Formosa' plums were picked at three maturity stages according to skin redness, treated with 1 $\mu L \cdot L^{-1}$ 1-MCP at 10℃ for 24 h and then stored for 21 days at 10℃. Ethylene production, respiration rate, firmness, color, TSS, TA, and ethanol concentration were determined. Total phenolic content, total flavonoid content, and antioxidant capacity were determined periodically by separating the flesh from the peel. Ethylene production and respiration rate were strongly inhibited in all stages of the 1-MCP-treated fruit, while ethylene production dramatically increased in all stages of non-treated fruit until 11 days after harvest, after which it decreased until the end of the experiment. The respiration rate of the stored fruit increased for 11 days in stages 1 and 2 and for 7 days in stage 3 and decreased after. 1-MCP-treated fruit in all stages showed delay in fruit quality changes such as firmness, TA, skin color, and ethanol concentration, but non-treated fruit did not. Total phenolic contents, total flavonoid contents and antioxidant capacity of 'Formosa' plums were not affected by 1-MCP treatment or maturity stage. However, those values were higher in the peel than in the flesh.

***Additional key words*:** antioxidant activity, ethylene, respiration, total flavonoids, total phenolics

Introduction

Plums are highly perishable and soften quickly after harvest, these characteristics are related to high ethylene production (Abdi et al., 1998). Softening is a serious problem for plum storage and transportation. Thus early harvest before skin color change is common in Korea to increase the shelf life. Historically, plums were harvested during the pre-climacteric stage, stored at 0℃ and then transferred to room temperature. Cold storage is effective for reducing ethylene production but causes chilling injury when the plums are stored for a long period of time (Crisosto et al., 1999). Therefore, methods to decrease ethylene production without negative side effects would be useful to delay plum softening and postharvest ripening. 1-methylcyclopropene (1-MCP) is known to suppress ethylene production and delay postharvest ripening of fruit; thus, it has positive effects on the shelf life, shipping, and storage of horticultural crops. 1-MCP is a gaseous compound that binds irreversibly to the ethylene receptors and thereby prevents ethylene-dependent responses (Serek et al., 1995; Sisler and Serek, 1997). There is ample evidence that suggests that 1-MCP application suppresses ethylene biosynthesis and maintains postharvest quality in plums (Khan and Singh, 2007; Martinez-Romero et al., 2003; Oh et al., 2007), as well as many other fruits including apple, avocado, banana, mango, papaya, persimmon and many kinds of flowers and vegetables (Baritelle et al., 2001; Blankenship and Dole, 2003; Feng et al., 2004; Hofman et al., 2001; Nakano et al., 2001; Pelayo et al., 2003; Watkins et al., 2006). Another notable finding is that no side effects have been detected from 1-MCP application.

There have been many studies on postharvest technology to prolong storage-life in plums due to their fast ripening rate. Fruit softening greatly affects the quality and causes many problems in shipping and storage. Fruit softening involves compositional and structural changes in cell wall carbohydrates due to the action of cell wall enzymes (Fischer and Bennett, 1991) and is related to ethylene production (Abdi et al., 1998). Because of rapid ripening, plums are often harvested before color change in the fruit skin. However, fruits harvested when they are immature have inferior quality when ripened compared to that of fruits harvested when they are mature (Guerra and Casquero,

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2008). In order to increase the postharvest storage life of fruits, techniques of cold storage (Robertson et al., 1991), preharvest calcium application, postharvest heat treatment, pre- or postharvest application of polyamines (Serrano et al., 2003) and 1-MCP (Khan and Singh, 2007), and edible coatings have been studied. However, the techniques that are actually used are very limited. Also, there is a danger of reducing the quality of plums when treatments are conducted prior to harvest in the immature stage.

The present study was carried out to investigate the postharvest aspect of 'Formosa' plums treated with 1-MCP harvested at various stages of maturity. Furthermore, the effects of fruit maturity stage, functional compounds like phenolics and flavonoids, and antioxidant capacity were investigated according to maturity stage of 1-MCP application.

Materials and Methods

Plant Material

'Formosa' plums were harvested in mid-July 2007 from a commercial orchard in Gimchoen, Korea. Fruit that was unblemished, uniform in size and free from symptoms of disease was harvested during the commercial harvest period and immediately transferred to the laboratory. Plums were classified according to maturity stage based on skin color. The three maturity stages were as follows. Stage 1: less than 5% of the plum peel was red; stage 2: more than 5% but less than 30% of the plum peel was red; stage 3: more than 30% of the plum peel was red. The plums were placed in a ventilated plastic tray (525 × 375 × 370 mm) and stored at 10℃ in a temperature-controlled room after 1-MCP treatment. There would be rapid induced decay before the 1-MCP effect if the plums were stored above 10℃ as the chilling injury temperature was reported to be at 2-8℃ in plums (Crisosto et al., 1999). Three replicate trays were prepared for each condition, and 50 plums were placed in each tray. To assess quality, three replicate samples were removed from each tray on the specified days of storage. All samples were prepared with three replicates, and results are shown as the mean with standard error.

1-MCP Treatment

The fruit was harvested and stored for 12 h at 10℃ until 1-MCP was applied. 1-MCP-releasing agent (Smart Fresh™ in powder form, 3.3% active ingredient, Rohm and Hass, USA) was weighed to produce a 1 $\mu L \cdot L^{-1}$ concentration, and warm water was added to the desired volume. 1-MCP was applied to the plums at 10℃ for 24 h in 0.2 m^3 hermetically sealed containers.

Ethylene and Respiration Rate Determinations

The fruit was weighed and sealed in 1.6 L plastic jars for 1 h. Ethylene production was determined by injecting 1 mL of headspace gas into a gas chromatograph (Model 5890, Hewlett-Packard Corp., Boston, MA, USA) equipped with a 2 m × 1/8 inch alumina F1 column (Supelco Corp., St. Louis, MO, USA) and a flame ionization detector (FID). Helium was used as the carrier gas, and the injector, oven and detector temperatures were 150℃, 70℃, and 200℃, respectively. CO_2 production was measured by injecting 1 mL of headspace gas into the same gas chromatograph equipped with a 2 m × 1/8 inch stainless steel column packed with activated carbon and a thermal conductivity detector (TCD). For this step, the detector temperature was changed to 150℃. Ethylene and CO_2 productions were expressed as $\mu L \cdot kg^{-1} \cdot h^{-1}$ and $mL \cdot kg^{-1} \cdot h^{-1}$, respectively.

Fruit Quality Assessments

Skin color was determined using the Hunter L, a, b colorimeter system (CR300, Minolta Corp., Tokyo, Japan), and color change was investigated using 'a' values. Fruit firmness was assessed using a 5 mm diameter probe coupled with a texture analyzer (TA plus, Lloyd Instruments™, Hants, UK). A small piece of fruit skin was removed, and the firmnesses of two sides of an individual plum fruit were recorded in Newtons (N). To determine the total acidity (TA), fruit juice was titrated with 0.1 N NaOH to a pH of 8.2, which is the end point of titration. The TA was calculated by the amount of 0.1 N NaOH, and was expressed as a percentage (%). The samples that experienced decay symptoms on their surfaces were removed from the storage room, and the amount of decay was expressed as a percentage of the total plum unit.

Ethanol Content

A 10 g sample was weighed in a Falcon tube and was then filled to 30 mL with distilled water. The samples were homogenized, and then 5 mL of the distilled sample was collected using distilling equipment. A 1-μL distilled sample was injected into a gas chromatograph (3900, Varian Corp., Palo Alto, CA, USA) equipped with an FID and a 30 m × 25 mm Supelcowax capillary column (Supelco Corp., St. Louis, MO, USA).

Total Phenolic and Total Flavonoid Content Determination

For the analysis of phenolic and flavonoid compounds in plums, an extract was prepared from 1 g of ground freeze-dried plum powder using 80% aqueous methanol in a 50 mL falcon tube. The mixture of plum powder and

aqueous methanol was sonicated for 20 min and filtered through Whatman No. 2 filter paper (Whatman Intl. Ltd., Kent, UK). The final extract solution was stored at -70℃ until analysis. Total phenolic content was determined by the Folin–Ciocalteu's method, which was adapted from Swain and Hillis (1959). The 150 mL extract, 2,400 mL of nanopure water, and 150 mL of 0.25 N Folin–Ciocalteu's reagent were combined in a plastic vial and mixed well using a Vortex. The mixture was allowed to react for 3 min, then 300 mL of 1N Na_2CO_3 solution was added and mixed well. The solution was incubated at room temperature (23℃) in the dark for 2 h. The absorbance was measured at 725 nm using a spectrophotometer (Hewlett Packard 8452A, Diode Array, USA), and the results were expressed in gallic acid equivalents (GAE; mg·100 g^{-1} fresh mass) using a gallic acid (0–0.1 mg·mL^{-1}) standard curve. Additional dilution was performed if the measured absorbance value was greater than the linear range of the standard curve.

Total flavonoid content was measured using the colorimetric assay developed by Zhishen et al. (1999). Two mL of diluted extract was added to a 10 mL volumetric flask filled with 2 mL of distilled water. After 5 min, 0.3 mL of 5% $NaNO_2$ was added to the flask, followed by the addition of 0.3 mL of 10% $AlCl_3$. After 6 min, 2 mL of 1 M NaOH was added and diluted to 10 mL with distilled water before being thoroughly mixed. A blank was prepared with distilled water. The absorbance of the pink mixture was measured at 510 nm versus that of the prepared blank. The total flavonoid content of each plum was expressed on a dry weight basis as mg of catechin equivalent (CAE) 100 g.

Total Antioxidant Capacity Determination

Total antioxidant capacity was determined by the method developed by Kim et al. (2002). For the test, 1 mM 2, 2′-azino (2-amidino-propane) dihydrochloride was mixed with 2.5 mM 2, 2′-azino-bis (3-ethylbenzothiazoline-6sulfonic acid) (ABTS) as diammonium salt in phosphate buffered saline (PBS) solution (100 mM potassium phosphate buffer (pH 7.4) containing 150 mM NaCl). After the mixture was heated in a water bath at 68℃ for 13 min, the blue-green ABTS solution was adjusted with fresh PBS solution to an absorbance of 0.65 ± 0.02 at 734 nm. The sample solution of 40 μL was added to 1,960 μL of the ABTS radical solution and incubated in a water bath at 37℃ for 10 min. The decrease in absorbance at 734 nm was measured. The reference solution consisted of 40 μL of 50% methanol and 1960 μL of ABTS solution. The ABTS radical scavenging capacities of plum extracts were expressed on a dry weight basis as mg of vitamin C equivalent (ascorbic acid equivalent: AAE) 100 g.

Results and Discussion

Ethylene Production and Respiration Rate

Ethylene production increased in the non-treated fruit harvested at various maturity stages until 11 days of storage and then decreased until the end of the experiment (Fig. 1). The amount of ethylene in non-treated plums increased from approximately 0 nL·g^{-1}·h^{-1} to a maximum of 20-24 nL·g^{-1}·h^{-1} at all maturity stages (Fig. 1). 1-MCP-treated fruit of all maturity stages displayed very low ethylene production until the end of storage. There was no difference in ethylene production among maturity stages in either non-treated or 1-MCP-treated fruit. This result demonstrates that 1-MCP effectively suppressed ethylene production. Reductions in ethylene production and respiration rate after the postharvest application of 1-MCP have been reported in plums and other fruit including apples, bananas and avocados (Feng et al., 2004.; Khan and Singh, 2007; Martinez-Romero et al., 2003b; Oh et al., 2007; Pelayo et al., 2003; Watkins et al., 2000). 1-MCP is thought to interact with ethylene receptors to prevent ethylene-dependent responses (Sisler and Serek, 1997). Sensory evaluation studies in plums recommended that, in order to increase fruit flavor, and therefore consumption, plums should be harvested at more advanced maturity, when higher quality characteristics have been developed (Crisosto et al., 2004). Therefore, reduction in rapid softening should be avoided during postharvest handling to protect fruit quality and increase shelf life of delayed harvested fruit. In this study, the effect of 1-MCP on plum quality was similar throughout the maturity stages. Although there is a relationship between

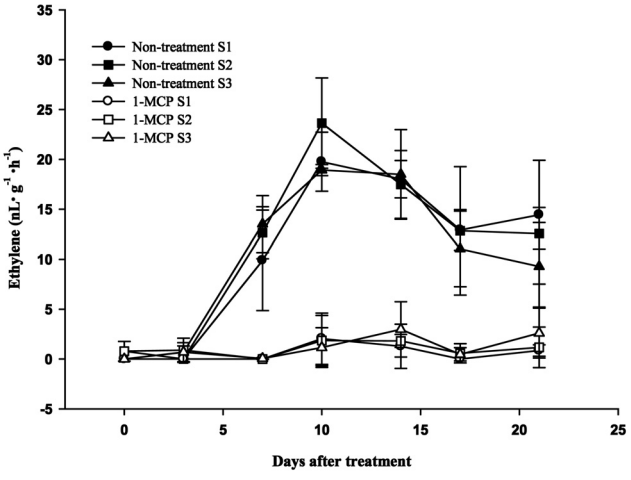

Fig. 1. Changes in ethylene production in 'Formosa' plums stored at 10℃. 1-MCP was treated with 1 μL·L^{-1} content at 10℃ for 24 h after harvest. Bars represent SE of the mean from three replicates. S1, maturity level in which less than 5% of the peel red; S2, maturity level in which more than 5% but less than 30% of the peel was red; S3, maturity level in which more than 30% of the peel was red.

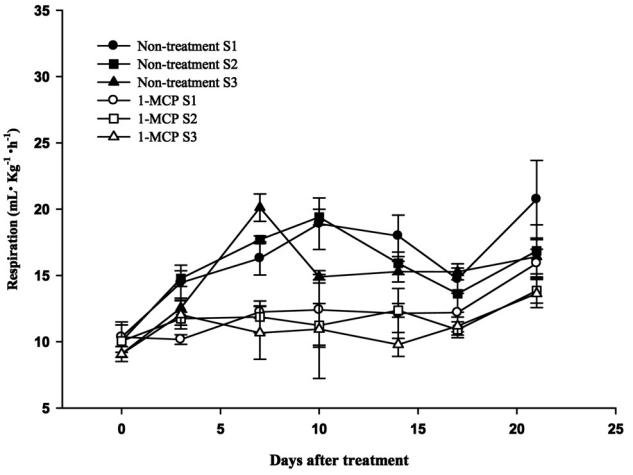

Fig. 2. Changes in respiration in 'Formosa' plums stored at 10℃. 1-MCP was treated with 1 μL·L^{-1} content at 10℃ for 24 h after harvest. Bars represent SE of the mean from three replicates. S1, maturity level in which less than 5% of the peel red; S2, maturity level in which more than 5% but less than 30% of the peel was red; S3, maturity level in which more than 30% of the peel was red.

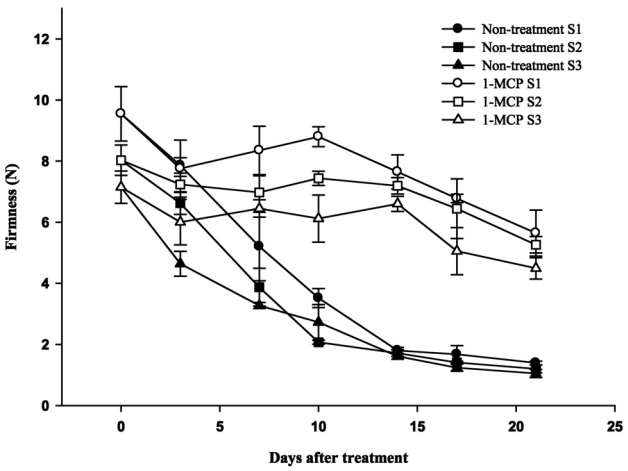

Fig. 3. Changes in firmness in 'Formosa' plums stored at 10℃. 1-MCP was treated with 1 μL·L^{-1} content at 10℃ for 24 h after harvest. Bars represent SE of the mean from three replicates. S1, maturity level in which less than 5% of the peel red; S2, maturity level in which more than 5% but less than 30% of the peel was red; S3, maturity level in which more than 30% of the peel was red.

1-MCP and ethylene receptors, the effect of 1-MCP on ethylene synthesis is not clear.

Respiration rate gradually increased in both stages 1 and 2, but the respiration rate of 1-MCP non-treated fruit in stage 3 increased more rapidly until 7 days and then decreased (Fig. 2). Measurements of CO_2 evolution from 'Formosa' plums of stage 3 showed a climacteric respiration pattern, as described by Sekse (1998) for 'Victoria' plums. The amount of CO_2 in stage 3 'Formosa' plums increased from approximately 10 mL CO_2 kg·h^{-1} to a maximum of 20 mL CO_2 kg·h^{-1} (Fig. 2). Maturity stages 1 and 2 displayed an increasing respiration pattern, but the slope was not as steep as that of maturity stage 3.

Respiration of 1-MCP-treated fruit in every stage was inhibited until the end of storage. There was also no difference in ethylene production among the different maturity stages in 1-MCP treated fruits. Inhibition of ethylene production and respiration rate through postharvest 1-MCP application was similar in effect in 'Formosa' plums regardless of maturity stage, similar to the results in 'Ooishiwase' plums (Oh et al., 2007).

Fruit Quality

Fruit firmness in non-treated fruit of every stage gradually decreased until 14 days after storage, reaching the lowest value after 22 days of storage (Fig. 3). Fruit firmness in 1-MCP treated fruit of every stage maintained values similar to that of the initial value until 14 days of storage and then gradually decreased until the end of the experiment. The firmness values were different among maturity stages in the decreasing order of stage 1, stage 2, and stage 3 in both 1-MCP treated and non-treated fruit. However, firmness was better maintained in 1-MCP treated plums than in non-treated plums. 1-MCP is an effective compound that binds irreversibly to ethylene receptors. Therefore, it prevents fruit softening, an ethylene-dependent response (Serek et al., 1995; Sisler and Serek, 1997). There is much evidence that proves 1-MCP application suppresses ethylene biosynthesis and maintains fruit softening, one of the postharvest quality in plums (Khan and Singh, 2007; Martinez-Romero et al., 2003a; Oh et al., 2007). Thus, 1-MCP treatment resulted in more effective maintenance of firmness when the plums were harvested at an earlier maturity stage. The TA values of stage 1, stage 2, and stage 3 were reduced during the postharvest storage in both non-treated and 1-MCP-treated plums (Fig. 4). In particular, TA values were highest in 1-MCP-treated fruit at stage 1 and were lowest in non-treated fruit at stage 3. Stages 1 and 2 of 1-MCP-treated fruit preserved their initial values until 10 days of storage and then slowly decreased until the end of storage. Ethanol production dramatically increased after 17 days of storage in all treatments, displaying lower values in 1-MCP-treated fruits than in non-treated fruit (Fig. 5). High level of ethanol is usually related to off-flavors development (Ke and Kader, 1992). Therefore, postharvest application of 1-MCP in all three stages was a way to prevent plum's flavor loss during storage. There was a report that color changes in fruit were ethylene-independent and not affected by 1-MCP (Dong et al., 2004). In this study the plums were harvested according to color development stages. However, there was not much difference in ethylene production

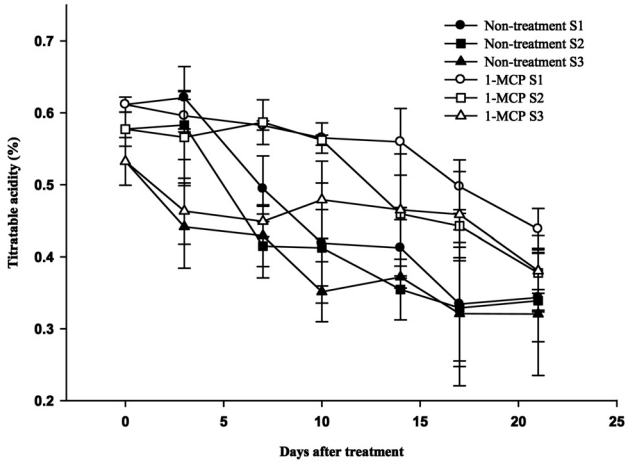

Fig. 4. Changes in titratable acidity in 'Formosa' plums stored at 10℃. 1-MCP was treated with 1 μL·L^{-1} content at 10℃ for 24 h after harvest. Bars represent SE of the mean from three replicates. S1, maturity level in which less than 5% of the peel red; S2, maturity level in which more than 5% but less than 30% of the peel was red; S3, maturity level in which more than 30% of the peel was red.

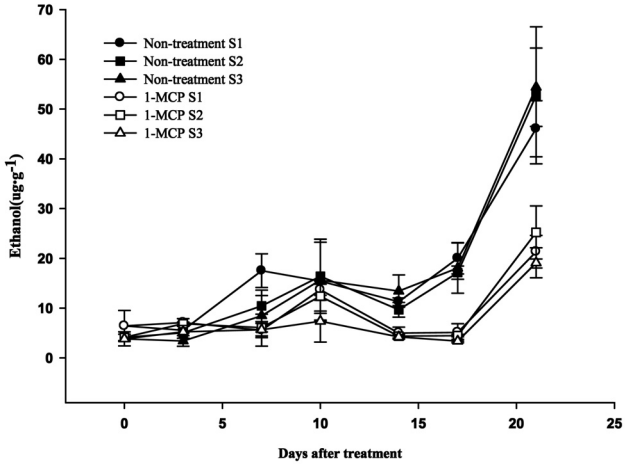

Fig. 5. Changes in ethanol content in 'Formosa' plums stored at 10℃. 1-MCP was treated with 1 μL·L^{-1} content at 10℃ for 24 h after harvest. Bars represent SE of the mean from three replicates. S1, maturity level in which less than 5% of the peel red; S2, maturity level in which more than 5% but less than 30% of the peel was red; S3, maturity level in which more than 30% of the peel was red.

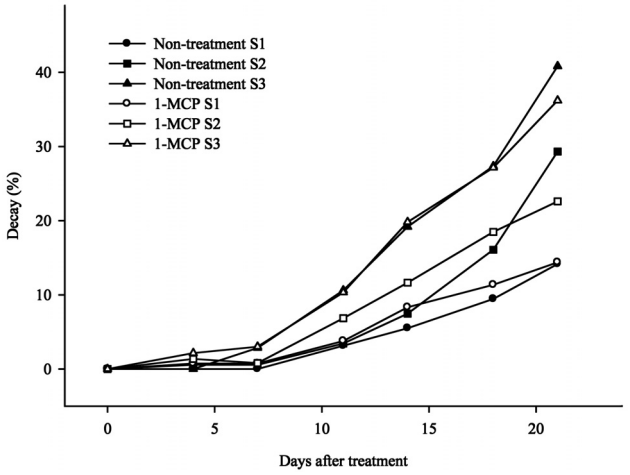

Fig. 6. Decay incidence in 'Formosa' plums stored at 10℃. 1-MCP was treated with 1 μL·L^{-1} content at 10℃ for 24 h after harvest. S1, maturity level in which less than 5% of the peel red; S2, maturity level in which more than 5% but less than 30% of the peel was red; S3, maturity level in which more than 30% of the peel was red.

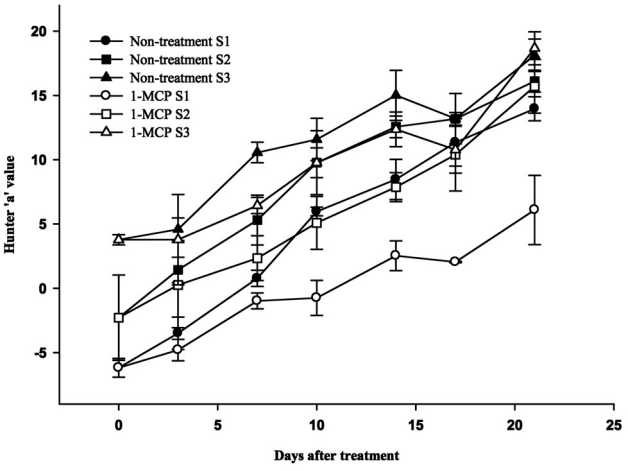

Fig. 7. Changes in Hunter 'a' value in 'Formosa' plums stored at 10℃. 1-MCP was treated with 1 μL·L^{-1} content at 10℃ for 24 h after harvest. Bars represent SE of the mean from three replicates. S1, maturity level in which less than 5% of the peel red; S2, maturity level in which more than 5% but less than 30% of the peel was red; S3, maturity level in which more than 30% of the peel was red.

and respiration rate (Figs. 1 and 2), and there was no difference in ethanol production among harvest stages of fruit either (Fig. 5).

Decay incidence in both non-treated and 1-MCP-treated fruit was lowest in harvest stage 1 and highest in stage 3 (Fig. 6). However, there were no significant differences in decay incidence between non-treated and 1-MCP-treated fruits within the same harvest stages. Hunter 'a' values gradually increased in all treatments (Fig. 7). However, non-treated fruit in all harvest stages demonstrated a more rapid change than 1-MCP-treated fruit. In harvest stage 1, 1-MCP-treated plums changed color slowly and did not reach full redness by the end of the experiment, and the highest Hunter 'a' values occurred in harvest stage 3 without 1-MCP treatment. Postharvest application of 1-MCP was beneficial for maintaining fruit quality at every maturity stage of harvest and was related to inhibition of ethylene production. Similar results have been reported in President and 'Ooishiwase' plums with various maturity stages (Oh et al., 2007; Valero et al., 2003).

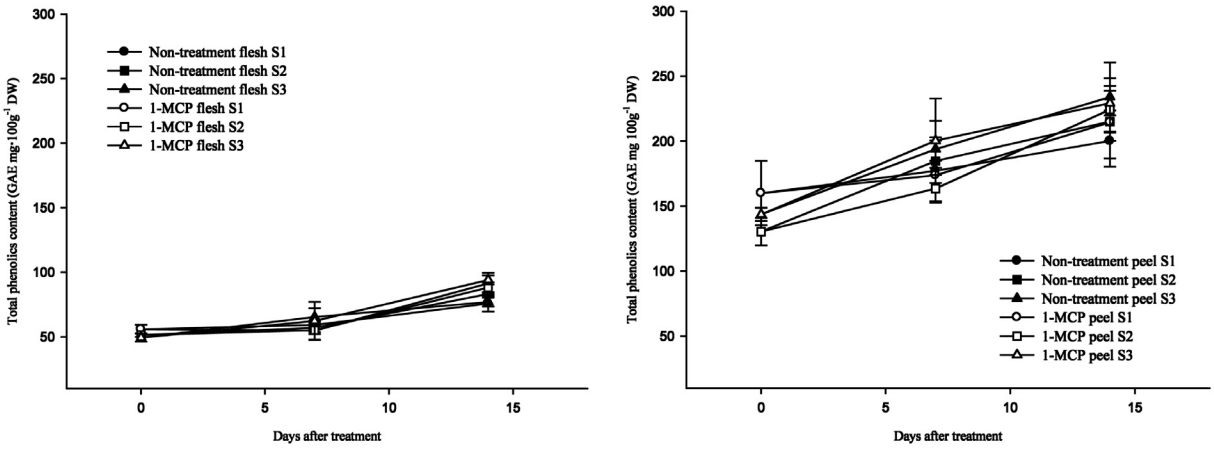

Fig. 8. Changes in total phenolic content in 'Formosa' plums stored at 10℃. 1-MCP was treated with 1 μL·L^{-1} content at 10℃ for 24 h after harvest. The left is total phenolics content of flesh, and the right is that of peel. Bars represent SE of the mean from three replicates. S1, maturity level in which less than 5% of the peel red; S2, maturity level in which more than 5% but less than 30% of the peel was red; S3, maturity level in which more than 30% of the peel was red.

Total Phenolic Content, Total Flavonoid Content, and Total Antioxidant Capacity

Phenolic compounds frequently occur in foods such as fruits and vegetables and are routinely consumed in our diet. They contribute to the sensory qualities (color, flavor, and taste) of fresh fruits, vegetables and their products. In addition, many phenolic phytochemicals have antioxidative, anticarcinogenic, antimicrobial, antiallergenic, antimutagenic and antiinflammatory activities (Cao and Cao, 1999; Eberhardt et al., 2000; Ito et al., 1998; Kawaii et al., 1999; Kim et al., 2000). Plums contain copious amounts of natural phytochemicals, such as flavonoids and phenolic acids, which may function as effective natural antioxidants in our daily diet. Wang et al. (1996) demonstrated that plums had a 4.4 times greater total antioxidant capacity than apples, the latter being one of the most commonly consumed fruits in our diet. The distribution and composition of phenolic phytochemicals are affected by maturity, cultivars, horticultural practices, geographic origin, growing season, postharvest storage conditions and processing procedures (Burda et al., 1990; Donovan et al., 1998; Kalt et al., 1999; Lee and Jaworski, 1987; Spanos and Wrolstad, 1990). Plums contain copious amounts of natural phytochemicals, such as flavonoids and phenolic acids, which may function as effective natural antioxidants in our daily diet. Wang et al. (1996) demonstrated that plums had a 4.4 times greater total antioxidant capacity than apples.

Total phenolic content, total flavonoid content, and total antioxidant capacity were assessed according to treatment of 1-MCP, harvest stage, and fruit part. Plums contain many functional compounds such as phenolic compounds (Gil et al., 2002), which have a close relationship with antioxidant capacity in plums (Kim et al., 2003). Several major phenolic compounds have been found in plums, such as chlorogenic acid, cyanidine 3-rutinoside, and quercetin 3-rutinoside (Chun et al., 2003b). These phenolic compounds are reported to be found in fruit flesh and skin of dark colored plums (Chun et al., 2003a; Gil et al., 2002). Thus plums were separated as flesh and peel, and then the amount of total phenolics was assessed. Total phenolic content increased in both the peel and the flesh (Fig. 8), but the change was more rapid in the peel. The total phenolic content of the fresh plums per 100 g ranged from 48.44 ± 3.2 mg GAE·100 g to 93.76 ± 3.0 mg GAE·100 g in the flesh and from 130.36 ± 10.6 mg GAE·100 g to 255.05 ± 34.0 mg GAE·100 g in the peel. The peel had 2-3 times more phenolics than the flesh. The amount increased gradually after harvest with or without 1-MCP treatment in both the flesh and the peel. However, 1-MCP treatment had no effect on the preservation of total phenolics, as there was no difference in the amount of total phenolics between non-treated and 1-MCP-treated fruit in either the peel or the flesh of the plums. The total phenolic amount in this study was similar to that in a previous report, which ranged from 174 ± 1.5 mg GAE·100 g to 375 ± 3.8 mg GAE·100 g in the peel according to the cultivar (Chun et al., 2003; Marinova et al., 2005). The reason that total phenolic content was higher in the peel than in the flesh is because of the red anthocyanin in the peel. The main anthocyanin of plum, cyaniding-3-glucoside, is also a type of phenolic compound and flavonoid (Gross, 1987).

The total flavonoid content increased until 7 days of storage in each treatment (Fig. 9). After that, the values decreased until 14 days of storage in most of the treatments except in the 1-MCP-treated peel when the plums were harvested at stages 2 or 3. The flavonoid content of the fresh plums per 100 g ranged from 19.92 ± 2.13 mg CAE·100 g to 39.52 ± 2.55 mg CAE·100 g in flesh and from 84.36

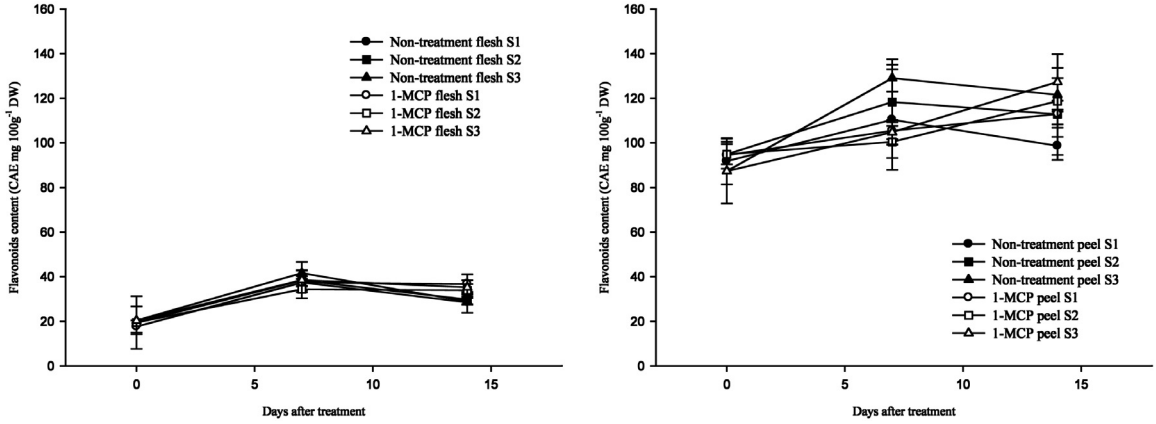

Fig. 9. Changes in flavonoid content in 'Formosa' plums stored at 10°C. 1-MCP was treated with 1 μL·L^{-1} content at 10°C for 24 h after harvest. The left is total flavonoid content of flesh, and the right is that of peel. S1, maturity level in which less than 5% of the peel red; S2, maturity level in which more than 5% but less than 30% of the peel was red; S3, maturity level in which more than 30% of the peel was red.

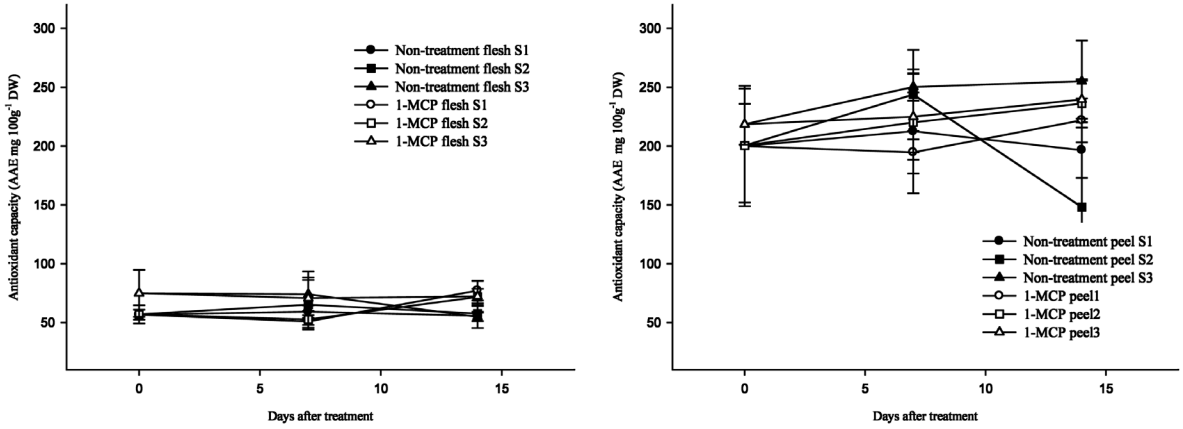

Fig. 10. Changes in antioxidant capacity in 'Formosa' plums stored at 10℃. 1-MCP was treated with 1 μL·L^{-1} content at 10℃ for 24 h after harvest. The left is total antioxidant capacity of flesh, and the right is that of peel. Bars represent SE of the mean from three replicates. S1, maturity level in which less than 5% of the peel red; S2, maturity level in which more than 5% but less than 30% of the peel was red; S3, maturity level in which more than 30% of the peel was red.

± 10.6 mg CAE·100 g to 125.55 ± 24.0 mg CAE·100 g in peel. Fruit peel had a 3-4 times higher total flavonoid content than fruit flesh. Similar results have been reported in other plum cultivars (Gil et al., 2002).

Antioxidants are compounds that can delay or inhibit the oxidation of lipids or other molecules by inhibiting oxidizing chain reactions, playing an important role in health protection (Velioglu et al., 1998). The antioxidant activity in the peel was about 3-5 folds higher than that of the flesh in non-treated or 1-MCP-treated fruit (Fig. 10). However, the antioxidant values were not much different between non-treated and 1-MCP-treated fruit or among harvest periods. The color was more intense in the peel than in the flesh because of the presence of anthocyanin, a known antioxidant. Thus, antioxidant activity was higher in the peel than in the flesh (Rice-Evans et al., 1996). There was not much difference in total phenolic content, total flavonoid content, or total antioxidant capacity between non-treated and 1-MCP-treated fruit or among the three different harvest maturity stages (Figs. 8, 9, and 10). However, the values were different between the flesh and the peel, exhibiting higher values in the peel than in the flesh. It has been reported that dark-colored plums have a higher total phenolic content, total flavonoid content, and antioxidant capacity than light-colored plums because of the presence of anthocyanin (Chun et al., 2003). Therefore, these measures are not related to the color change following postharvest storage but are closely related to plum cultivar according to fruit peel and flesh color (Chun et al., 2003; Gil et al., 2002).

There was a report about 1-MCP treatment to plums and then the plums were stored at 20℃ (Jung et al., 2010). Fruit were treated with 1 μL·L^{-1} 1-MCP 1 day after being harvest and stored at ambient temperature (20℃). 1-MCP treatment delayed fruit softening, weight loss, changes in skin color,

and TA during the shelf life period at ambient temperature (20℃). Although the results indicate that 1-MCP can be used to maintain the quality of non-refrigerated plums, these quality values of plums decreased more rapidly in 20℃ storage than in 10℃ storage in this study. Therefore, it would be better if plums were treated with 1-MCP and stored at low temperature (above chilling injury temperature) to maintain quality.

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