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Effect of 1-Methylcyclopropene Treatment on Ripening and Quality of European Plum (*Prunus domestica* L.)

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ETHYLENE action inhibition by 1-methylcyclopropene (1-MCP) extends postharvest life of many climacteric fruits. This work evaluates the effect of 1-MCP (0.625 ppm) treatment on the physiological behavior and quality during postharvest life of 'Katinka' and 'Haganta' European plum (*Prunus domestica* L.) in 2012 and 2013. 1-MCP treatment of the fruits reduced ethylene production more than 30 % and delayed the climacteric peak in 'Haganta' and 'Katinka'. In addition, 1-MCP obviously reduced respiration rate for 'Katinka'. 1-MCP delayed fruit ripening, as shown by lower soluble solids content (SSC) in treated fruits at the beginning of storage and by a significant higher SSC at the end of storage. Moreover, it significantly decreased weight loss and delayed fruit softening for the cultivars under study but no stable trend with titratable acidity (TA) was found. Based on the results 1-MCP may be a treatment for delaying ripening of European plum.

Keywords: 1-MCP, Ripening, Plum, Ethylene, Fruit quality, Respiration.

Fruit ripening is a sequence of biochemical processes, which change a physiologically mature but inedible fruit into an edible one. Plums are very perishable fruits with a short postharvest life compared to other climacteric temperate fruits such as apples and pears (Kader, 1992).Thus, the storage life can be extended if the biochemical processes are decreased. Generally, it is accepted that ethylene plays a key role in inducing ripening processes especially in climacteric fruits (Streif *et al.*, 2010). Inhibition of ethylene biosynthesis or its action offers a good way to retard fruit ripening (Larrigaudiere *et al.*, 2009). The exogenous application of products as 1-methylcyclopropene (1-MCP), aminoethoxyvinylglycine (AVG), polyamines (PAs), and nitric oxide (NO), have been found to be effective in delaying fruit ripening in many fruits (Khan & Singh, 2008 and Khan *et al.*, 2009).

The (1-MCP) has been found to be the most effective as ethylene inhibitor. It is a gas with molecular weight of 54, discovered by Edward Sisler and Sylvia

Blankenship (Blankenship and Dole 2003). It is an inhibitor of ethylene action and has been widely used to improve shelf life and quality of plant products. The effect of 1-MCP on physiological behavior has been studied in many fruits. 1-MCP applications have been shown to reduce respiration and ethylene production rate in a number of climacteric fruits such as Japanese plum (Abdi *et al.*, 1998 and Khan & Singh, 2007), apple (Fan *et al.*, 1999), apricot (Fan *et al.*, 2000 and Dong *et al.*, 2002), pears (Trinchero *et al.*, 2004) and European plum (Valero *et al.*, 2003).

The effect of 1-MCP application on postharvest quality has been studied in many fruits. Plum fruit softening is significantly retarded in 'Angeleno' Japanese plum by 1-MCP treatment after storage at low temperature. Moreover, 1-MCP application could extend fruit shelf life and replace CA (Controlled atmosphere) storage for short or medium storage period (Menniti *et al.*, 2006). Similar results have been obtained by other studies, which examined the effect of 1-MCP application on softening of plum fruit (Salvador *et al.*, 2003, Valero *et al.*, 2003, 2004 and Khan & Singh, 2007, 2009). Suppression of the enzymes involved in fruit softening by the 1-MCP treatments has been proved in plum fruit (Menniti *et al.*, 2004, Khan and Singh, 2007, 2009).

The influence of 1-MCP application on soluble solids contents (SSC) and total acidity (TA) has been studied in many fruits. There are some studies pointing out an increase in soluble solids content by applying 1-MCP in plums (Valero *et al.*, 2004) and some apple cultivars such as 'Delicious' and 'Empire' (Watkins *et al.*, 2000). But the 1-MCP treatments have no effect on SSC in some other fruits such as apricot (Dong *et al.*, 2002), orange (Porat *et al.*, 1999), some apple cultivars (DeEll *et al.*, 2002) and banana (Jiang *et al.*, 2004). On the other hand, the loss of TA has been delayed by using 1-MCP application in many fruits, plums (Valero *et al.*, 2003, Salvador *et al.*, 2003 and Khan & Singh, 2007), pineapples (Selvarajah *et al.*, 2001), peaches (Liu *et al.*, 2005) and some apple cultivars (Fan *et al.*, 1999). However, the 1-MCP application has no effect on TA in some other species such as apricot (Dong *et al.*, 2002) and orange (Porat *et al.*, 1999) and are inconstant with some other apple cultivars (Watkins *et al.*, 2000).

The objective of this work was to study the effect of 1-MCP on ripening and quality attributes of the European plums 'Katinka' (early ripening) and 'Haganta' (late ripening) in cold storage and held at 20 °C to ripe (shelf life).

Material and Methods

Fruit, 1-MCP treatment, and storage conditions

Fruits of the European plum (*Prunus domestica* L.), cultivars 'Katinka' and 'Haganta' were harvested at the experimental orchard of Technische Universität München at Freising-Weihnstephan during 2012 for 'Haganta' and 2013 for 'Katinka' and 'Haganta'. Fruits were manually harvested at commercial ripening stage and transported to the laboratory where they were sorted in order to remove mechanically damaged fruit and fruits without stems. Fruits were pre-cooled at 2°C for at least 12 h before treatments. SmartFresh™ Technology (1-MCP

0.14%, Dow AgroSciences) was applied at Bayerisches Obstzentrum. The powder was weighed and warm water was added to obtain a dosage of 0.625 ppm 1-MCP. Treatments were performed in hermetically sealed plastic boxes (0,015 m^3). Duration of treatment was 24 h at 1 °C. Control fruits were treated in the same way but without 1-MCP as described by Fan *et al.* (2002). Following treatment, fruits were packaged in plastic boxes (5-7kg) and stored at 2 °C (80±5% RH) for 20 to 50 days. Fruit samples were removed from cold storage after 10-15 days intervals and allowed to ripen at 20 °C for 3-7 days.

Ethylene production and Respiration Rate

To study ethylene production rate of the plum fruits during ripening, three replicates from each of the cultivars for each analysis time were chosen, about 1 kg for each replicate. Each replicate was placed in a sealed 3 L glass jar for 2 hours at 20°C. Ethylene production was calculated by ethylene concentration in the gas phase of the headspace of the jars (Wang *et al.*, 2010). From the headspace of every jar 1 ml gas was withdrawn by syringe over a rubber septum and injected into a Carlo Erba 4200 Gas chromatograph (Carlo Erba, Spa, Milano, Italy) equipped with aluminum column 80/100 mesh, and a Flame Ionization Detector (FID). The temperatures of injector, oven and detector were 175, 100 and 120°C, respectively. The gas flow was 235 ml/min for air, 20 ml/min for hydrogen and 30 ml/min for nitrogen (carrier gas). Measurements were repeated for three or four times for every replicate. Ethylene production rate was calculated as ppm/kg/h.

Respiration rate was measured as a function of CO_2 concentration by using OXYBABY®(WITTGAS Co. Ltd., Germany) a mobile hand held gas analyzer after calibration with standard gases (Wang *et al.*, 2010). Three replicates of each cultivar, each treatment, and each sampling time were used. For each replicate, 1 kg of fruit was placed in a 3 L airtight glass jar contained air as initial gas atmosphere for 2 h. The gas was sampled through an airtight septum, and repeated three times for each replicate. Respiration rates of plum fruits were calculated as ml/kg/h CO_2. Respiration rate measurements were carried out only on 'Katinka' cultivar in 2013.

Fruit quality analysis

Fruit samples were analyzed for soluble solids concentration (SSC) and titratable acidity (TA) before and after cold storage, as well as before and after shelf life for every batch/cultivar. Soluble solids content (SSC) and titratable acidity (TA) were assayed for each freshly prepared juice sample. The SSC was measured using a digital refractometer and TA was determined by titrating 5 mL of juice with 0.1 N NaOH to pH 8.2 using an autotitrator according to an AOAC method (AOAC, 1980). The SSC/TA ratio was calculated as well. Plum fruit firmness was measured with a tool for the rapid non-destructive evaluation of firmness of soft fruit (FirmTech 2), which gently squeezes the fruits to specified force to determine the fruit firmness. For plum, FirmTech has a turntable with 12 oval shaped indentures to hold the fruits. The FirmTech was calibrated for force and fruit size by manufacturer's tools. Firmness was measured by mg/mm. Measurements were performed in 2013 for 'Katinka', 'Haroma' and 'Haganta'. Weight loss was determined for fruits at cold storage and after held on 20 °C for ripening according to the following equation

$$Weight\ loss\ \% = \frac{\text{Initialweight} - \text{Weightsampling date}}{\text{Initial weight}} * 100$$

The statistical analysis was carried out by SPSS (version 16). The collected data were subjected to ANOVA analysis. Mean comparisons were performed using the Least Significant Differences (LSD) and Duncan tests to compare means at 5% probability level. The other processing of data, graphical display and standard deviation (SD) of the results were performed by Microsoft office excel (Pivotable).

Results and Discussion

Ethylene production and respiration rate

Postharvest application of 1-MCP significantly reduced ethylene production both in the early cultivar ‘Katinka’ (Fig. 1 A, B, C) and in the late cultivar ‘Haganta’ (Fig. 2 and 3). In general, ethylene production of untreated fruits was significantly higher (at least 1.5 fold) as compared to treated fruits. Moreover, the climacteric rise was delayed with a lower peak of ethylene in ‘Katinka’ treated fruits at 2^{nd} analyzing time (after 20 days in cold storage, Fig. 1C). The ethylene production rate was slightly higher in treated fruits at the 2^{nd} day at 20 °C after 10 days cold storage (Fig. 1 B). Ethylene was detected neither in treated nor in control fruits of ‘Haganta’ 2012 during the first three days of ripening at 20 °C in the first batch (without cold storage, Fig. 2A) and at the 1^{st} day in the 2^{nd} batch (after 15 days in cold storage, Fig. 2B). Ethylene production rate reached the climacteric peak after 12, 8 and 7 days at 20 °C for ‘Haganta’ 2012 in the first batch (without cold storage), the 2^{nd} batch (after 15 days of cold storage) and last batch (after 30 days of cold storage), respectively (Fig. 2). The same trend as for ‘Katinka’ was found for ‘Haganta’ in the 2^{nd} season (2013, Fig. 3). Respiration rate (CO_2/kg/h) was noticeably higher in control fruits compared to 1-MCP treated fruits (Fig. 1 a, b and c). In the 1^{st} batch (without cold storage) of ‘Katinka’ fruits, CO_2 level has two peaks at 2^{nd} and 4^{th} day at 20 °C. Moreover, CO_2 reached a maximum in later batches earlier than in the first ones: the respiration rate reached the peak at 3^{rd} and 4^{th} day for 3^{rd} and 1^{st} batches, respectively. In general, ‘Katinka’ and ‘Haganta’ fruits exhibited a climacteric-like behavior in ethylene production and respiration rate (Fig. 1, 2 and 3). Ethylene plays a key role as a plant hormone responsible for coordinating and initiating ripening events in climacteric fruit (Abdi *et al.*, 1998, Bapat *et al.*, 2010). It triggers the processes of ripening and senescence. Ethylene inhibitors can delay the ripening of climacteric fruit (Liu, *et al.*, 2005). The application of 1-MCP in some of Japanese and European plum cultivars showed beneficial effects such as: reduction of ethylene production, respiration rate and losses of fruit weight. In addition, fruit quality could be maintained and then, storability and shelf life could be extended (Abdi *et al.*, 1998, Salvador *et al.*, 2003, Valero *et al.*, 2003). The reduction of ethylene production during shelf life, following or not cold storage, of European plum may be due to 1-MCP interaction with ethylene receptors (Blankenship and Dole 2003). Other possible causes could be the suppression of the enzymes 1-aminocyclopropene-1-carboxylic acid synthase (ACS, EC 4.4.1.14) and 1-aminocyclopropene-1-carboxylic acid oxidase (ACO, EC

4.4.17.4), and of 1-aminocyclopropene-1-carboxcylic acid content (Khan and Singh, 2007, 2009). It seems that some new receptors are being regenerated since ethylene production slightly started increasing. However, 1-MCP significantly decreased respiration rate in 'Katinka' and 'Haganta' (Fig. 4-39). These results are in accordance with findings by Dong *et al.* (2002), Salvador *et al.*, (2003) and Valero *et al.* (2003, 2004). 'Katinka' showed a biphasic pattern in respiration rate during ripening at room temperature in treated and untreated fruits. This behavior was reported in previous study on banana (*Musa accuminata* L. cv. Cavendish) and Japanese plum by Khan *et al.*, (2009). On the other hand, they found that treating 'Tegan Blue' Japanese plum fruits with high MCP doses (2.0 ppm) prevented any respiratory raise. However, the effect of MCP on respiration rate was not as pronounced as that found on ethylene production rate.

Fruit quality attributes

The effect of 1-MCP on fruit quality is presented in Fig. 4 to 8. The 1-MCP had significant effect on fruit soluble solids content (SSC) especially after shelf life. SSC increased during cold storage and after shelf life in treated 'Haganta' plum fruits in seasons 2012 (Fig. 4 A) and 2013 (Fig. 5 A) but it decreased markedly in untreated fruits. The same trend was found in 'Katinka' (Fig. 6 A) except in the last batch (after 15 days in cold storage) either before or after shelf life without remarkable differences. These results confirm that 1-MCP delayed ripening in 'Haganta' and 'Katinka' fruits (Valero *et al.*, 2004, Khan & Singh, 2007 and Khan *et al.*, 2009). However, other reports pointed out that 1-MCP had no effect on SSC of Japanese plum, apricot (Dong *et al.*, 2002, Salvador *et al.*, 2003) and orange (Porat *et al.*, 1999).

Regarding acidity (TA), it decreased after shelf life in both treatments, seasons and for cultivars 'Katinka' (Fig. 5 B) and 'Haganta' (Fig. 4B) except 'Haganta' at the 3^{rd} analyzing time in control treatment showing slightly increased TA values (Fig. 5 B). Applying 1-MCP treatment, there were no pronounced changes of TA. The 1-MCP treatment in 2012 season gave slightly higher TA at the beginning of cold storage of 'Haganta', while no marked effect was found in the same cultivar as well as in 'Katinka' in 2013. These results are in accordance with results obtained by Dong *et al.* (2002) on apricot and Porat *et al.* (1999) on orange. However, there are contradicting reports for some apple cultivars (Watkins *et al.*, 2000). In other observations 1-MCP could delay the loss of TA in European plum (Valero *et al.*, 2003), peaches (Liu *et al.*, 2005) and in some apple cultivars (Fan *et al.*, 1999). The ripening index (SSC/TA ratio) increased during shelf life at 20 °C in both treatments but it was higher in treated fruits in both seasons and for both cultivars (Fig. 4 C, 5 C, 6 C). Exceptions were 'Katinka' fruits in the last batch (15 days of cold storage + 3 days shelf life at 20 °C) and 'Haganta' fruits in the first batches in both seasons where SSC/TA ratio was higher in control than in treated fruits. Generally, SSC/TA decreased during the whole storage period in 'Haganta' but not 'Katinka', where the SSC/TA was increasing during the storage period .

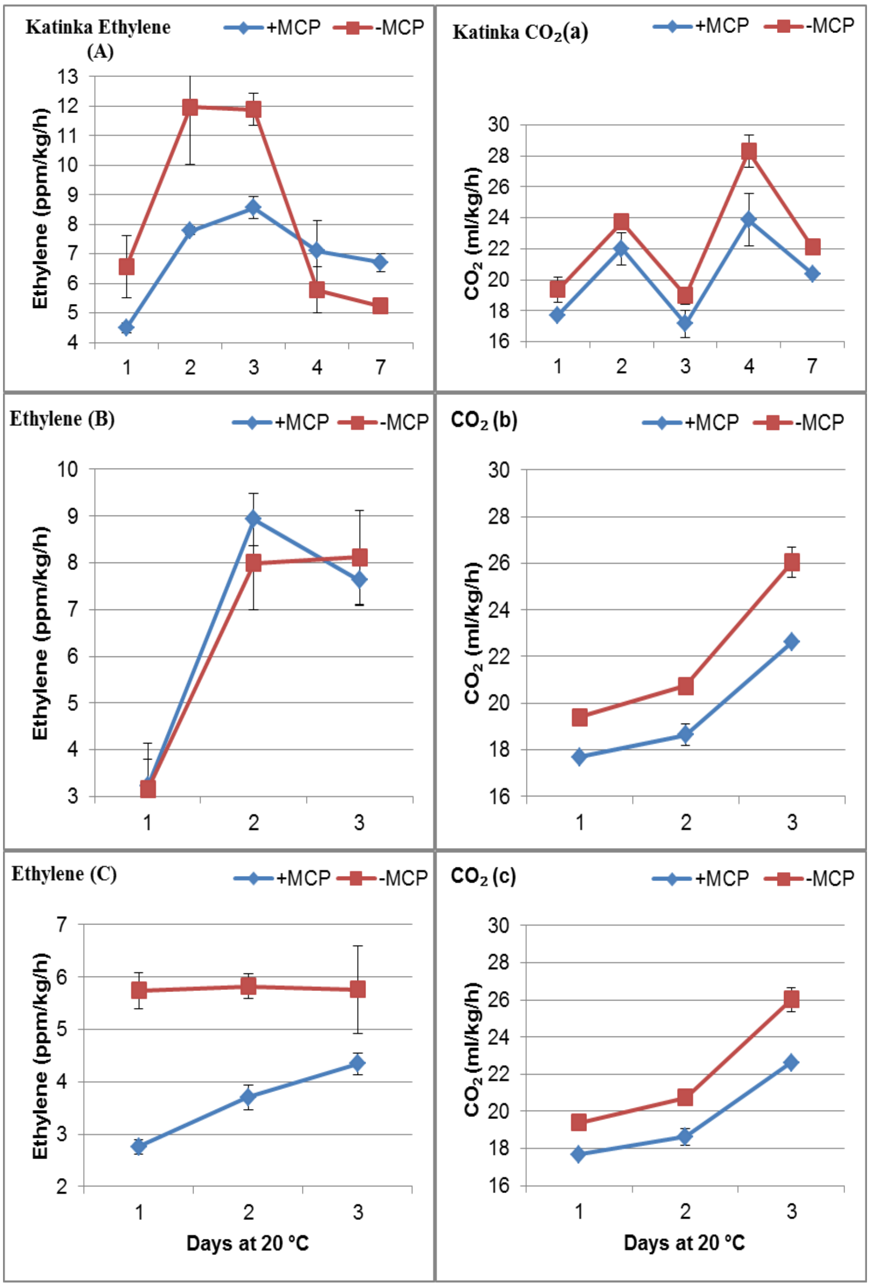

Fig.1. Effect of 1-MCP in ethylene production and respiration rate of 'Katinka' plum in 2013 during ripening at 20 °C, after treating without cold storage (A), 10 days (B) and 20 days stored in cold storage (C). Values are mean of three replicates and vertical bars represent standard deviation (SD).

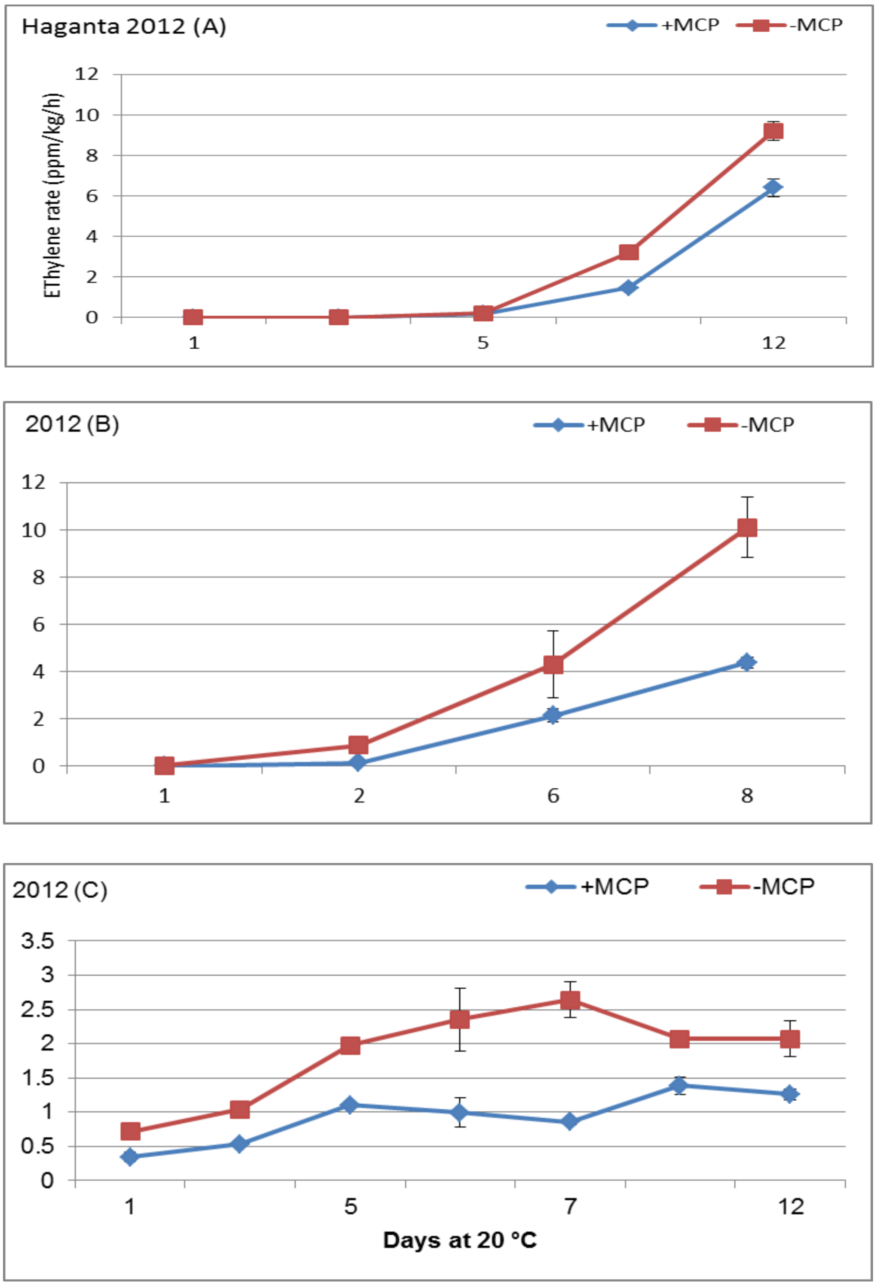

Fig. 2. Effect of 1-MCP on ethylene production rate of 'Haganta' plum in 2012 during shelf life at 20 °C, after treating without cold storage (A), 15 days (B) and 30 days stored in cold storage (C). Values are means of three replicates and vertical bars represent standard deviation (SD).

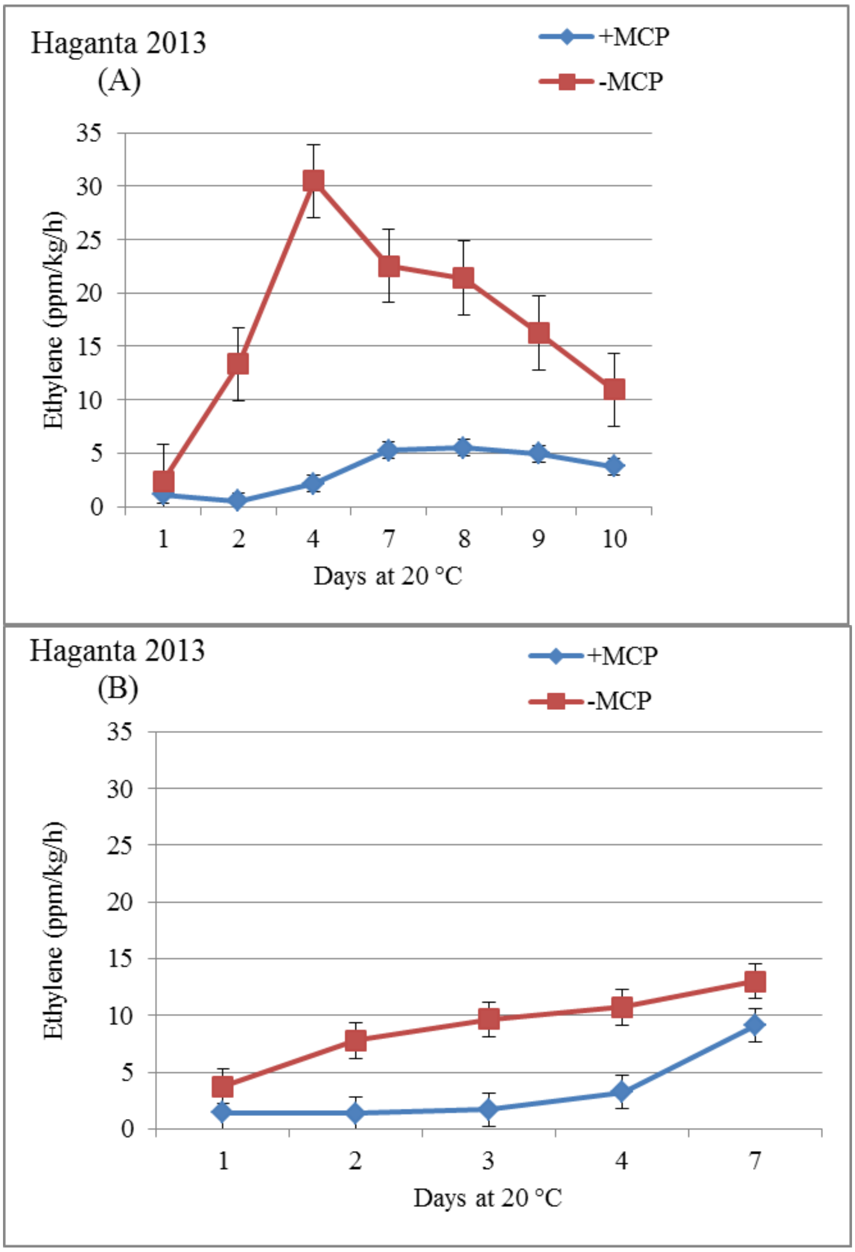

Fig. 3. Effect of 1-MCP on ethylene production rate of 'Haganta' plum in 2013 during shelf life at 20 °C, after treating without cold storage (A) and 15 days stored in cold storage (B). Values are means of three replicates and vertical bars represent standard deviation (SD).

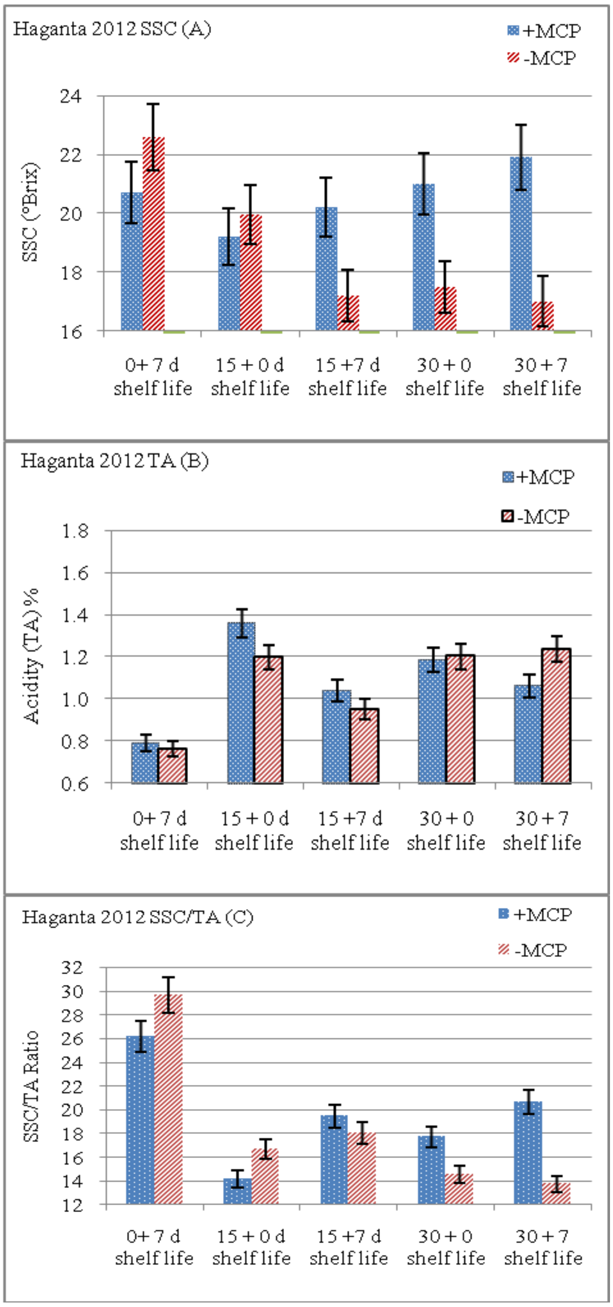

Fig. 4. Effect of 1-MCP on 'Haganta' plum fruit soluble solids content (SSC in °Brix (A)), titratable acidity (TA in g/100 ml (B)) and SSC/TA ratio (C) in 2012 season, after treatment 0, 15, 30 days of cold storage followed by 0 and 7 days in shelf life (at 20 °C).

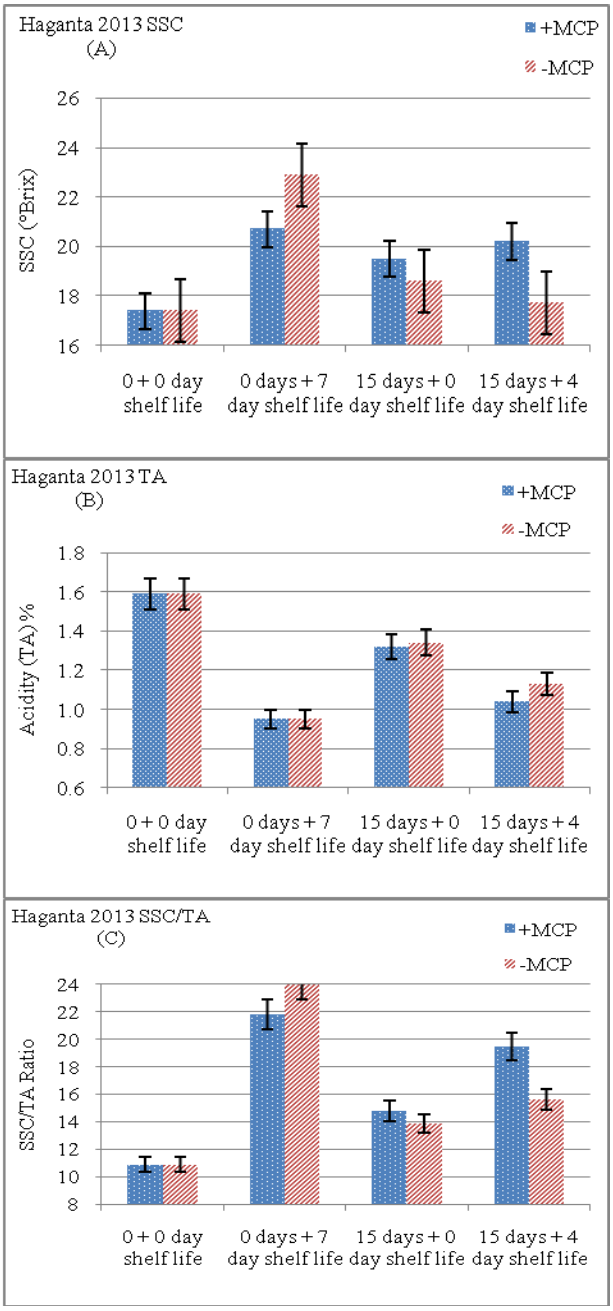

Fig. 5. Effect of 1-MCP on 'Haganta' plum fruit soluble solids content (SSC in °Brix (A)), titratable acidity (TA in g/100 ml (B)) and SSC/TA ratio (C) in 2012 season, after treatment 0, 15, 30 days of cold storage followed by 0 and 7 days in shelf life (at 20 °C).

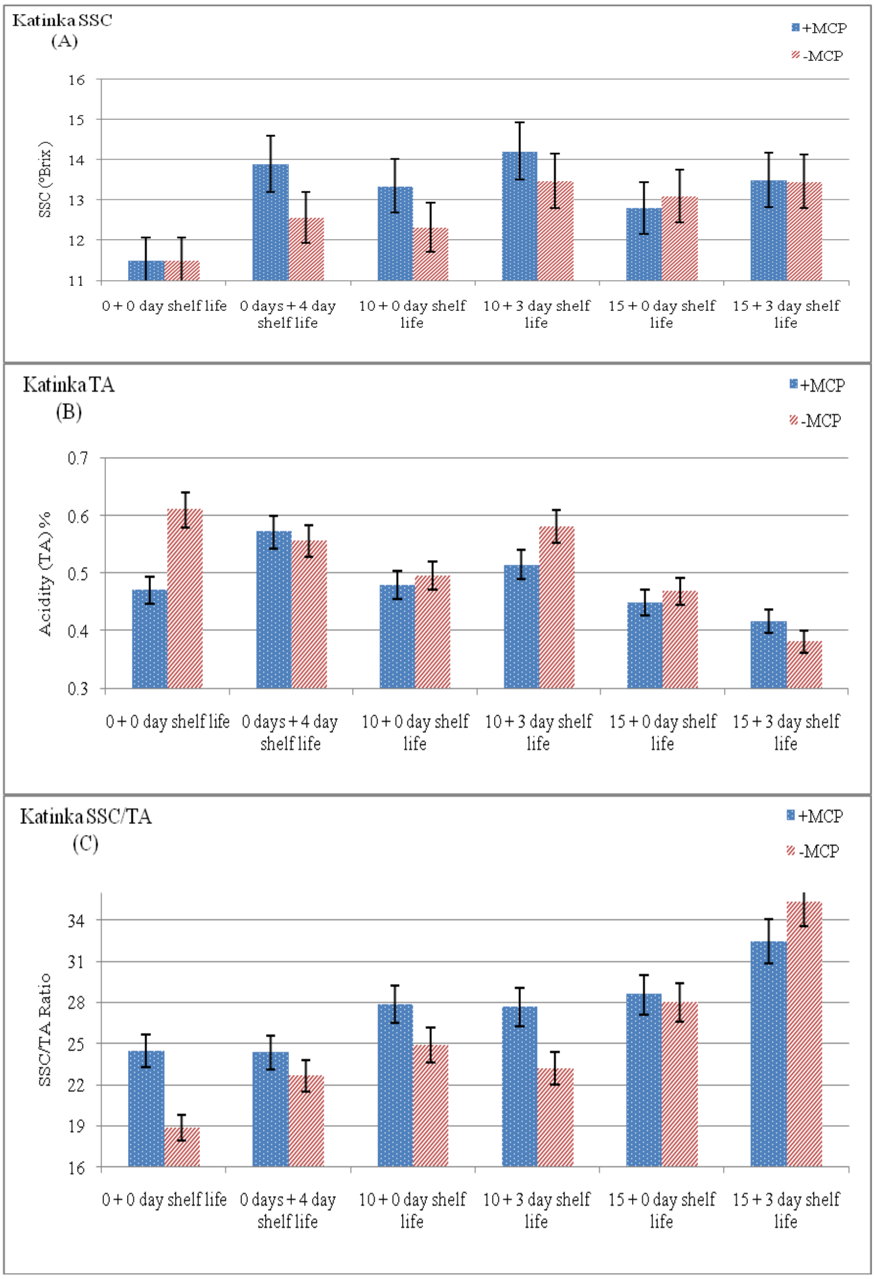

Fig. 6. Effect of 1-MCP on ‘Katinka’ plum fruit soluble solids content (SSC in °Brix (A)), titratable acidity (TA in g/100 ml (B)) and SSC/TA ratio (C), after treatment 0, 10, 15 days of cold storage followed by 0 and 4 or 3 days in shelf life (at 20 °C) .

Fruit weight loss

Fruit weight loss was slightly affected by the 1-MCP treatments. The untreated control exhibited higher weight loss than 1-MCP treatment during cold storage and followed shelf life at 20 °C. An exception was 'Haganta', 2nd batch (15 days of cold storage + 5 days at room temperature), with a decreased weight loss percentage due to the 1-MCP treatment (Fig. 7). However, the effect of MCP on reducing weight loss was noticed by many authors, in plum (Valero *et al.*, 2003) and avocado (Joeng *et al.*, 2002). On the other hand, in apricot and orange no effect has been detected (Fan *et al.*, 2000 and Porat *et al.*, 1999). Loss of weight is one of the most important causes responsible for fruit quality deterioration.

Fruit firmness

The effect of 1-MCP application on fruit firmness before and after shelf life at 20 °C is shown in Fig 8. 1-MCP had marked effect on fruit firmness, since control plum exhibited less firmness than 1-MCP treated fruit. However, the differences were only significant in case of 'Haganta'. Generally, fruit firmness significantly decreased during shelf life in both treatments. The early ripening cultivar 'Katinka' has less firmness compared with the late ripening 'Haganta'. These results are in accordance with many authors for Japanese and European plum (Salvador *et al.*, 2003, Valero *et al.*, 2003, 2004, Khan and Singh, 2007, 2009).

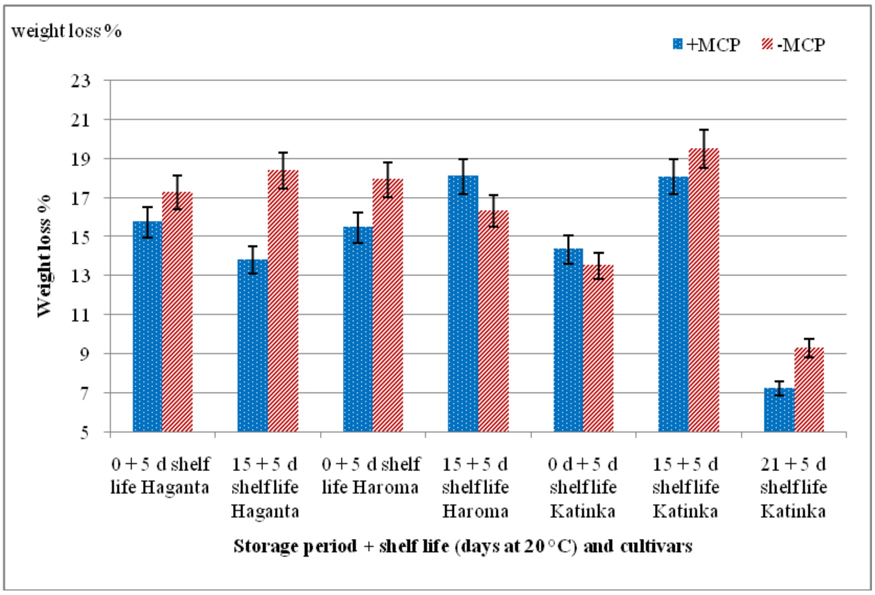

Fig. 7. Effect of 1-MCP on fruit weight loss of 'Katinka', 'Haganta' and 'Haroma' cultivars after treatment 0, 15 and 21 days of cold storage followed by 5 days shelf life.

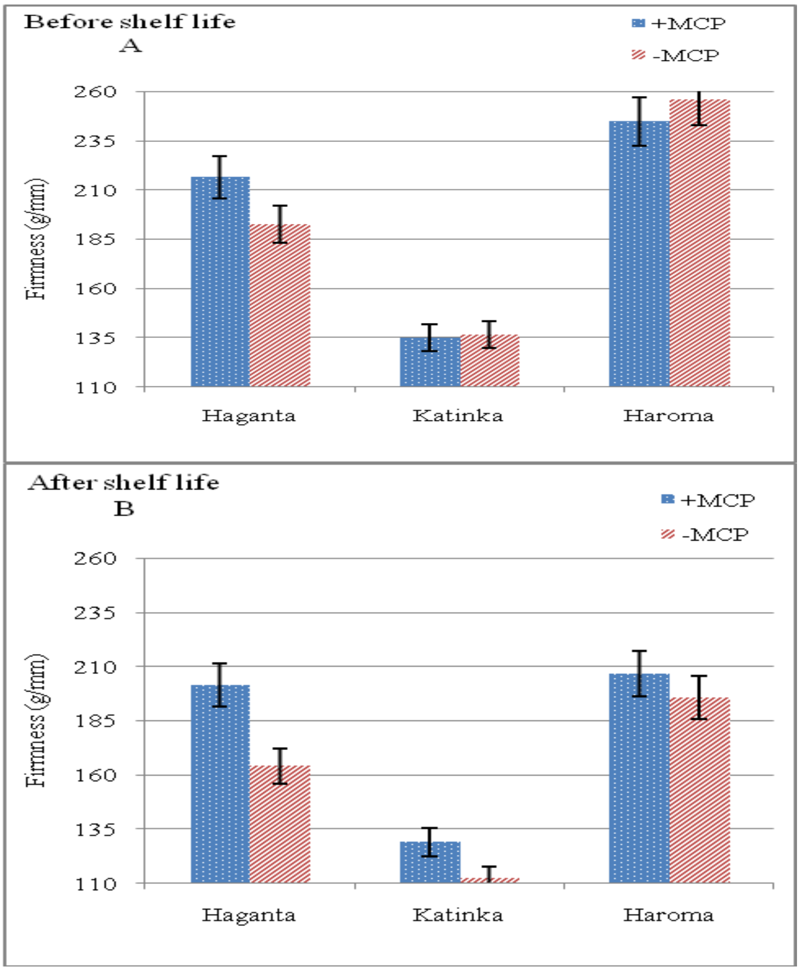

Fig. 8. Effect of 1-MCP on fruit firmness of 'Katinka', 'Haganta' and 'Haroma' cultivars before (A) and after (B) shelf life at 20 °C (5-7 days at room temperature).

Conclusions

The early ripening plum 'Katinka' has a rapid postharvest loss of fruit quality associated to a climacteric like increase in respiration and ethylene production compared to the late ripening cultivar 'Haganta'. The 1-MCP treatment reduced and delayed the increase of respiration and ethylene production during shelf life at 20 °C following harvest and cold storage. Soluble solids content (SSC) of 1-MCP treated fruits was low at the beginning of storage but was significantly higher SSC at the end of storage. Moreover, 1-MCP treatment significantly decreased weight loss and delayed fruit softening. Thus, the 1-MCP treatment has the potential to control ripening and extend shelf and storage life of European plum.

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تأثير المعاملة بالميثايل سيكلوبروبان (MCP-١) على نضج وجودة ثمار البرقوق الأوروبي (*Prunus domestica* L)

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أجريت هذه الدراسة على ثمار صنفين من البرقوق الأوروبي خلال موسمي ٢٠١٢ و ٢٠١٣. و قد هدف هذا البحث الى معرفة تأثير أحد مثبطات الإيثلين (ميثيل سيكلوبروبين، (MCP-١ على معدل التنفس و انتاج الايثلين و كذلك جودة الثمار أثناء فترة ما بعد الحصاد. وقد أظهرت النتائج انخفاض كل من معدل انتاج الايثلين بما يزيد عن ٣٠% و تأجيل قمة الكليمكترك و كذلك انخفاض معدل انتاج الايثلين في الثمار المعاملة ب (MCP-١). و قد تبين أيضا من النتائج أن المعاملة أدت لإطالة فترة النضج من خلال انخفاض نسبة المواد الصلبة الذائبة في بداية فترة التخزين وزيادتها بشكل معنوي في نهاية فترة التخزين مقارنتا بالكنترول. المعاملة كذلك أدت الى انخفاض كل من الفقد في الوزن و فقد الصلابة مقارنة بالكنترول. لم يلاحظ اتجاه ثابت لتأثير المعاملة على الحموضة. بناءا على النتائج من هذه الدراسة فان المعاملة ب (MCP-١) قد تكون وسيلة فعالة لإطالة حياة ثمار البرقوق بعد الحصاد.

الكلمات المفتاحية : الاثيلين، النضج، جودة الثمار، التنفس، (MCP-١) .