

## The effect of 1-Methylcyclopropene application incorporated with packaging on the expression of ethylene-related genes and quality maintenance of cherry tomato cultivars

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### Abstract

Longevity of four Cherry tomato (*Lycopersicon esculentum* Mill.) cultivars as the perishable climacteric fruit and the expression of ethylene biosynthesis genes (*SAMI*, *ACS4*, *ACO1* and *ACO4*) under packaging (LDPE film) and packaging plus 1-MCP (5  $\mu\text{L L}^{-1}$  for 48 h at 20°C) treatments at 20°C for 16 days were studied. The results of weight loss and firmness showed that there is no remarkable difference between packaging and packaging plus 1-MCP in four tomato cultivars, but the fluctuations of TSS and pH were more minor in packaging plus 1-MCP compared to the other treatments. Base on the physicochemical characteristics and quality maintenance, cultivars were graded from high to low durability; Yellow pear, Orang Santa, Black berry and Orange berry, respectively. The study of expression pattern of genes *SAMI*, *ACS4*, *ACO1* and *ACO5* in Yellow pear and Orange berry cultivars at storage showed that they were drastically expressed higher in control than packaging and packaging plus 1-MCP treatments. The expression level of *ACO5* gene was the same in both cultivars, but the expression level of *ACO1* and *ACS4* genes in the yellow pear cultivar was higher than the orange berry. In contrast, the expression level of *SAMI* gene in the yellow pear cultivar was lower than the orange berry. Totally, despite being deeply different in the genetic background of these cultivars, packaging and 1-MCP plus packaging treatment reduced the perishability, and improved the maintenance quality of cherry tomato fruit. Also, further molecular studies and evaluation of ethylene in these cultivars are suggested.

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### Keywords

Cherry tomato

1-MCP

Ethylene biosynthesis

Gene expression

Packaging

### Introduction

Iran is the seventh producer of tomatoes (*Lycopersicon esculentum* Mill.) in the

world (FAO, 2020) and, recently consumption of cherry tomatoes with different shapes, colour, and small size

It is of great pleasure and delight to announce that the paper has been approved by the reviewers of the journal and currently passing the final procedure to be published. Therefore, the paper should be referenced mentioning DOI.

fruits became popular in Iran, but they have a short longevity. Researches showed that cherry tomatoes should be stored at 10 °C or higher to avoid chilling injury (Jimenez & Cantwell, 1996; Roberts *et al.*, 2002) and decrease tomato flavour quality (Maul *et al.*, 2000).

Previous studies have confirmed ethylene as a critical plant hormone plays pivotal functions in the ripening and senescence process of the tomato fruit which is considered as a climacteric fruit (Colombié *et al.*, 2017; Seymour *et al.*, 2013). The ethylene production and respiratory rate increase during tomato ripening and storage period (Hoeberichts *et al.*, 2002; Klee & Giovannoni, 2011; Silva, 2008). The ethylene biosynthesis is initiated with the perception of a stimulus via the plant receptors localized in the endoplasmic reticulum (Zhong *et al.*, 2008). The precursor of the ethylene is methionine that is converted to S-AdoMet (SAM) by the action of SAM synthetase, and subsequently, this product is altered to 1-aminocyclopropane-1-carboxylate (ACC) through ACC synthase (ACS). Eventually, ethylene is released from ACC by ACC oxidase (ACO) enzyme (Wang *et al.*, 2002). Genes encoding SAM, ACS, and ACO play an essential role in regulating ethylene biosynthesis in such a way that their elevated expression leads to an increased ethylene biosynthesis (Alexander & Grierson, 2002). The maintenance of quality and marketability of tomato fruit during post-harvest storage and delivery to consumers is limited due to high ethylene formation resulted in softening and losing the marketing. Some inhibitors such as 1-Methylcyclopropene (1-MCP) was applied to retard the ethylene function and biosynthesis could improve the freshness and quality of perishable fruit during the postharvest storage (Acuna *et al.*, 2011; Amornputti *et al.*, 2016; Blankenship & Dole, 2003; Yokotani *et al.*, 2009). Earlier, the efficiency of 1-MCP in the blocking of the ethylene receptor and inhibiting ethylene generation in banana, apple,

apricot, plum, avocado, peach, and pear have been reported (Acuna *et al.*, 2011; Amin *et al.*, 2014; Botondi *et al.*, 2014; Guillén *et al.*, 2007; Nock & Watkins, 2013). Besides, inhibiting ethylene-related reactions by binding to ethylene receptors, 1-MCP can also diminish ethylene production by inhibiting the expression of genes in ethylene biosynthesis pathway (Tatsuki & Endo, 2006). Application of 1-MCP on apple fruit down regulated the *ETR1*, *ETR2*, *ETR5*, *ERSs*, *CTR1*, *EIN2A*, *EIL4* and *ERFs* genes, while had a limited effect on *ACS3*, and *ACO3* (Yang *et al.*, 2013). 1-MCP treatment on tomato fruit delayed ripening for 8 days associated with a delay in the ethylene production and the expression of ACS, and some ethylene receptor genes, while a steady increase in ACO gene expression was observed (Tassoni *et al.*, 2006).

Also, numerous studies were carried out, among which storage under modified atmosphere packaging (MAP) could be named. Basically, MAP plays pivotal roles during the commercial handling of the mentioned crops by reducing the respiration rate, metabolic activity, and microbial growth (Amin *et al.*, 2014).

Since cherry tomatoes are often consumed as fresh products, it is required to evaluate the longevity and shelf-life ability before introducing of these cultivars to breeding programme. In this study, the longevity of four pure cultivars under 1-MCP and packaging treatments were investigated. Additionally, the expression profiling of *ACO1*, *ACO5*, *ACS4*, and *SAM1* genes involved in ethylene biosynthesis were experimented.

## Material and methods

### Plant materials and treatments

Four pure cultivars of cherry tomato fruits (Yellow pear, Orange berry, Orange Santa, and Black cherry) were harvested from college farm at a stage equivalent to commercial ripeness (breaker stage) and immediately transported to the horticulture laboratory of the Faculty of Agriculture

(Shahrood University of Technology, Iran). The uniform and intact fruits were selected and randomly divided into three experimental groups namely control (free 1-MCP and un-packed fruits), Modified atmosphere packaging treatment (packaged with polyethylene (PE) bags 20 cm x 30 cm x 0.1 mm), and 1-MCP plus packaging (5  $\mu\text{L L}^{-1}$  1-MCP and packaged with PE bags). To treat the 1-MCP, the tomato fruits were incubated with 5  $\mu\text{L L}^{-1}$  1-MCP (SmartFresh TM, Rohm and Hass Co., Spring House, PA) in 1 L container for 48 hours at 20 °C. On each treatment, 8 fruits were used and all experiments were repeated thrice. The physicochemical experiments were performed at a 4-day interval during storage at 20 °C.

#### **Weight loss**

Cherry tomato fruits were weighted initially at 0 and at the end of each storage interval. The weight loss percentage was calculated based on the following formula: Weight loss percentage = [(primary weight – secondary weight)/ primary weight] × 100

#### **Fruit firmness**

The fruit firmness was performed on the surface of the fruit after removal of the skin from both sides of the fruit tomatoes were compressed by the probe to a 5 mm penetration depth using a penetrometer (FT 327) equipped with a 3 mm diameter conical probe.

#### **Total soluble solids (TSS) and pH**

To measure TSS and pH, the tomato fruits were juiced. The pH measurement was done with a pH-meter (WT model, Made in Germany). The TSS was determined using a handheld refractometer (ATAGO master 5EM, Japan) and shown in Brix degrees.

#### **RNA isolation and q-RT-PCR**

The expression profiling of *ACO1*, *ACO5*, *ACS4*, and *SAM1* was performed using quantitative real-time PCR (q-RT-PCR). The flesh of two selected cherry tomato

cultivars were frozen and ground in liquid nitrogen using a mortar and pestle. Total RNA was extracted using the RNeasy plant mini kit based on the manufacturer's instructions (Qiagen, Hilden, Germany). The quantity and quality of the extracted RNA was assessed via a NanoDrop spectrophotometer (BioTek, EPOCH, serial 121004C, USA), and agarose gel electrophoresis respectively. Subsequently, DNA contamination was eliminated by the RNase-free DNase kit (Qiagen, Hilden, Germany). The first strand cDNA was synthesized with one  $\mu\text{g}$  of extracted RNA using iScript cDNA synthesis kit (Bio-Rad, Hercules, CA, USA) as the manufacturer's recommendation. One  $\mu\text{l}$  of the resulting cDNA was used in a 10  $\mu\text{l}$  PCR reaction using a QuantiTect SYBR Green PCR Kit and run and analysed using an ABI step one System (Foster City, California 94404, USA). Reaction components included 5  $\mu\text{l}$  of SYBR®Green PCR Master Mix, 2  $\mu\text{l}$  reverse and forward primers, 2  $\mu\text{l}$  of deionized water, and 1  $\mu\text{l}$  of cDNA. *ACO1*, *ACO5*, *ACS4*, and *SAM1* expression levels were normalized according to the constitutively expressed *elongation factor (EF-1a; Solyc06g005060)* (Heidari *et al.*, 2021) gene and then calculated based on the comparative Ct method (Schmittgen and Livak, 2008). The q-RT-PCR conditions were as follows: 95°C for 5 min followed by 35 cycles of 95°C for 15 s and 60°C for 25 s. The used primers in this study are listed in Table 1 (Zhu *et al.*, 2015; Mou *et al.*, 2016; Van de Poel *et al.*, 2012). The real-time PCR was carried out in three technical and two biological replicates.

**Table 1.** Primers used in this study

Name	Sequence (Forward)	Sequence (Reverse)	Product size	T <sub>m</sub> (C°)	Accession number
<i>ACO1</i>	GGAGGCATCATACTTCTG T	CATCACTTCCTGGATT GTA	210	F:60 R:61	Solyc07g049530
<i>ACO5</i>	ACGAACAAGTTCCAGGT C	GGTGACAGGGATACA AGAG	230	F:60 R:61	Solyc07g026650
<i>ACS4</i>	GGGGTTATTCAGATGGGT C	CCACCAGCCATTACTA CAC	220	F:62 R:61	Solyc05g050010
<i>SAMI</i>	CGAGGAGATTGGTGCTG GTG	TCGTGTTGGGTGGAGA TAAG	230	F:61 R:61	Solyc01g101060
<i>EF</i>	TTATCACCATTGGTGCTG AG	CGATGTTTCCATACAG ATCCTT	160	F:60 R:60	Solyc06g005060

### Statistical analysis

The experiment of present study was conducted as a completely randomized design in a factorial arrangement. The obtained data were subjected to the analysis of variance (ANOVA) using SPSS software (IBM SPSS Statistics 19, USA). The data were appeared as the mean  $\pm$  standard error (SE), and mean comparison was performed through Duncan's multiple range test at  $p < 0.05$ .

## Results and Discussion

### Physicochemical characteristics

#### Weight loss

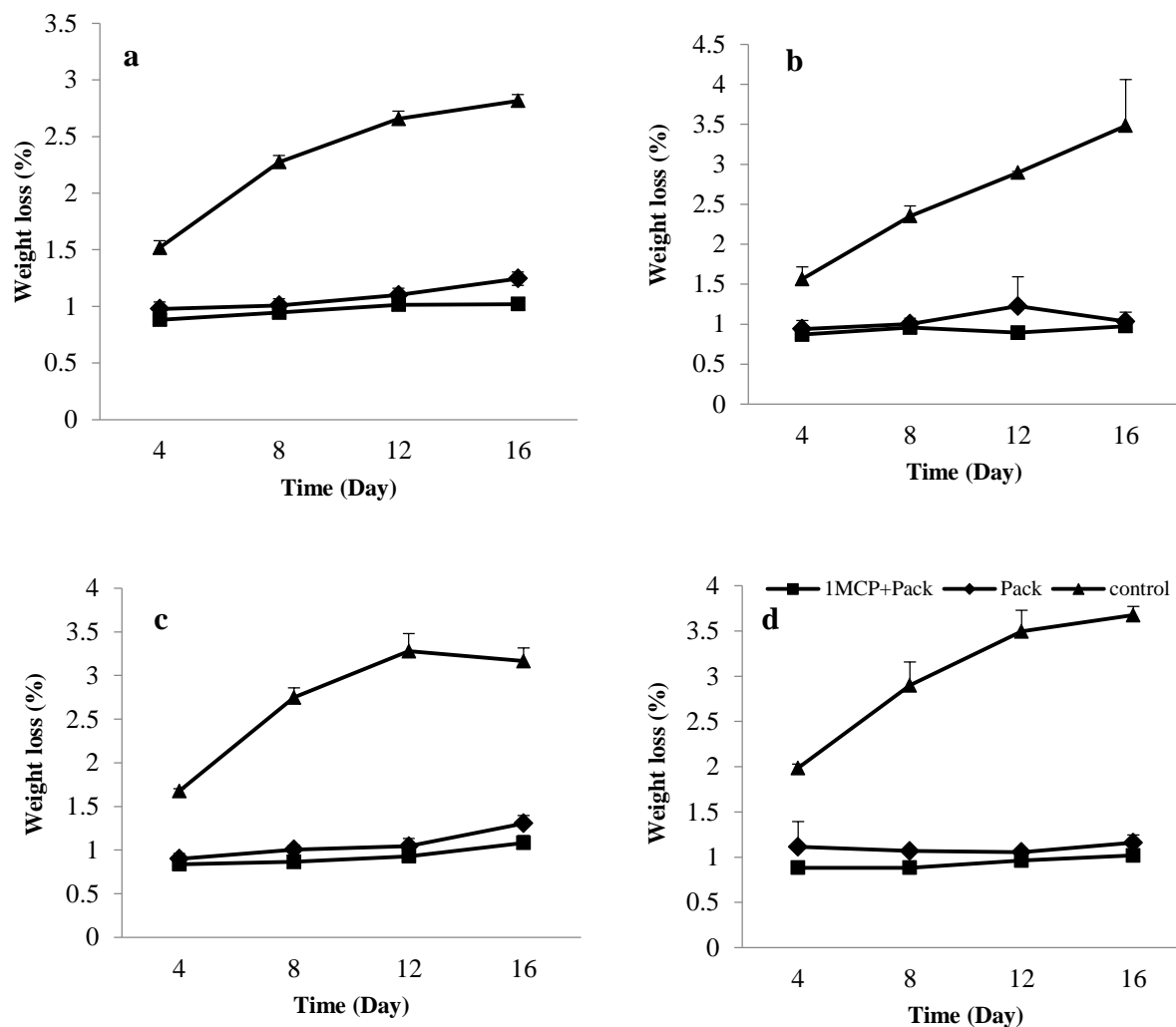
To identify the longevity of four cherry tomato cultivars, the results of qualitative characteristics including weight loss, firmness, total soluble solids, and pH were reported in Fig. 1. The results of packaging and 1-MCP plus packaging on postharvest longevity of four cultivars showed that, the weight loss percentage was dramatically increased in control fruits of four cultivars (about 40 %) during 16 d of storage. There was no significant difference in the weight loss between the packaging and 1-MCP plus packaging treatments in all cultivars during the storage (Fig. 1). The weight loss percentage in Yellow pear, Orange berry, Orange Santa, and Black cherry fruits using 1-MCP plus packaging treatment was inhibited by 71.9, 65.7, 72.2, and 63.7 % compared to the control after 16 d of storage, respectively.

Investigation on the storage of four tomato cultivars including Yellow pear, Orange

berry, Orang Santa, and Black berry under packaging, and 1-MCP plus packaging treatments revealed that the weight loss significantly increased in control fruits during the storage and a difference of weight loss was recorded between four cherry tomato cultivars. The difference between cultivars in the amount of moisture reduction and weight loss during storage related to the difference in skin thickness and chemical composition, structure and thickness of protective layers in their fruit. But packaging and 1-MCP plus packaging decreased effectively weight loss, softening, and reduction in the qualitative characters (Fig. 1). The weight loss can be considered as an indicator of quality loss (Lima *et al.*, 2006). Moisture loss is the main cause of fruit weight loss during storage, which can cause economic losses due to shrinkage and reduced fruit marketability. Previous studies have reported about beneficial effects of using packaging and 1-MCP on maintaining the firmness, preventing chlorophyll and starch degradation, slowing down the respiration, blocking the production of ethylene (Blankenship & Dole, 2003; Lima *et al.*, 2006). During the storage, the weight loss was accelerated with an increase in evaporation and transpiration rates due to unequal water vapor pressure in the apoplastic space and around the fruit as well as a rapid increase in respiration rate (Muñoz-Robredo *et al.*, 2012). A rapid increase in the respiration rate of fruit accelerates the ripening and the senescence

process which resulted into the weight loss of product (GA *et al.*, 2013; Valero *et al.*, 2006). Our results showed that packaging via the creation of modified atmosphere packaging could successfully inhibit the weight loss of cherry tomato fruits. The results of modified atmosphere packaging

as a useful preservation system on maintaining of fruit quality could be resulted from the protected relative humidity and the reduced respiration rate of packaged fruit (Kader & Watkins, 2000).



**Figure 1.** Effect of 1-MCP and packaging on weight loss changes in 4 cherry tomato cultivars at 20° C for 16 d. Four cultivars including Black berry (a), Yellow pear (b), Orang berry (c) and Orange santa (d). Each data point is the mean of three replications. Vertical bars represent standard error of means.

### Firmness

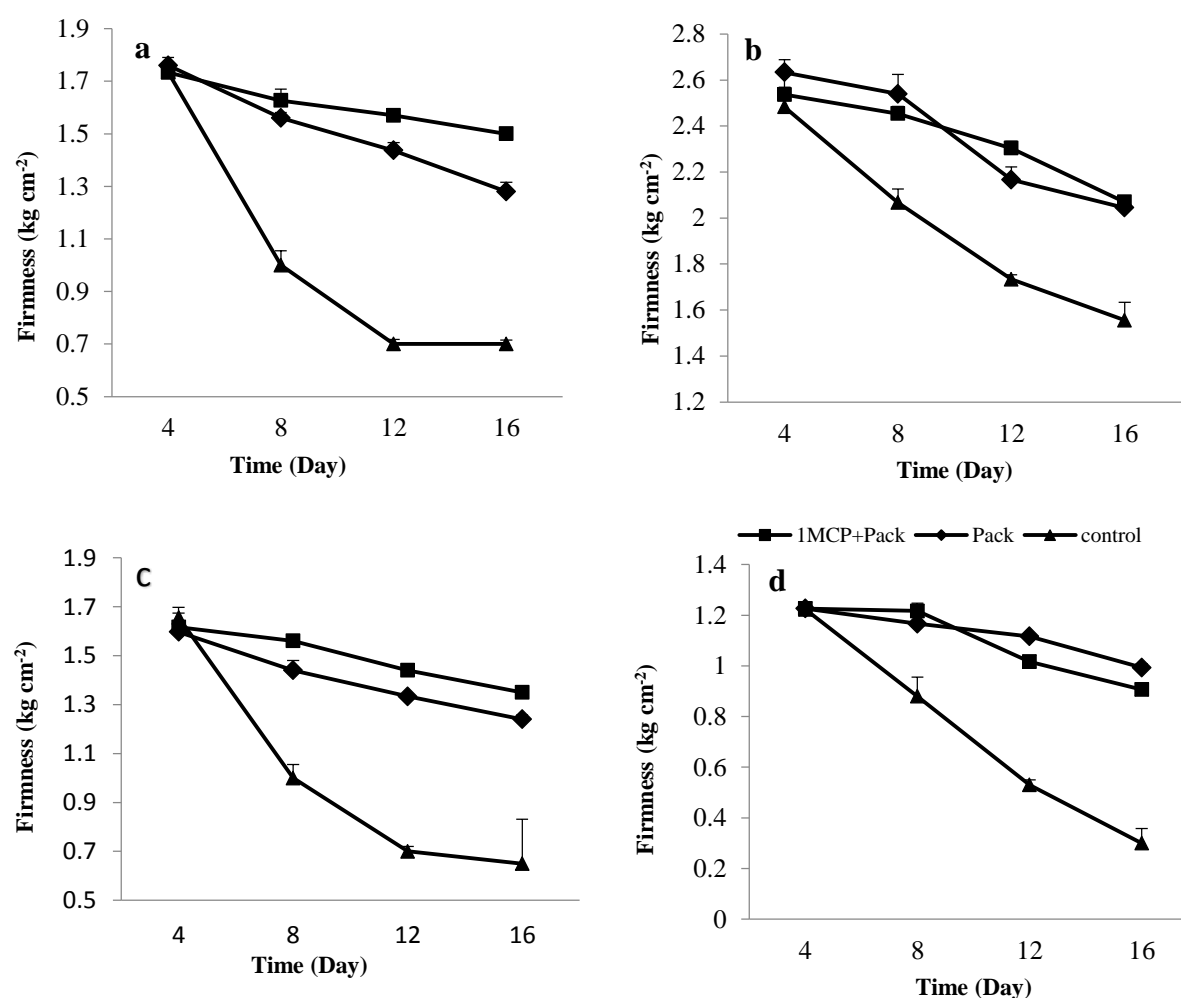
A drastically decline in firmness fruit was observed in control of four cultivars during 16 d of storage while, the application of 1-MCP plus packaging led to lower changes of firmness in four cherry tomato cultivars. So that, using 1-MCP plus packaging treatment on the tomato fruit of Yellow pear, Orange berry, Orange santa, and

black berry cultivars showed about 24.84, 51.85, 66.90, and 53.3 % higher firmness in comparison with control during 16 d of storage, respectively (Figure 2).

Similarly, previous studies have reported a difference decrease in the firmness of fruit during storage as a result of cultivar effect (Yoo *et al.*, 2021). The differences of firmness reduction in cultivars can be

related to the differences in cellular connections, the amount of cell compaction, the number of cells per unit volume, the thickness of the cell wall and the difference in their type of metabolism (Blankenship *et al.*, 2003). The firmness of tomato fruits decreases by the progression of ripening as a result of converting of insoluble protopectin to soluble pectic acid and pectin (Wrzodak & Gajewski, 2015). In most cherry tomatoes, the surface/weight ratio of berries is high and firmness reduction in the control fruit can be related to this, while the minimum firmness changes were obtained in treated cherry tomato with packaging and 1-MCP

plus packaging. Firmness is strongly related to weight loss and transpiration rate. Similar to the weight loss, reduction in firmness of tomato fruit is related to the increase in respiration rate and reduction in relative humidity during the storage. The effect of 1-MCP plus packaging on preservation firmness of tomato fruit resulted from the diminishing of ethylene biosynthesis as well as increase in CO<sub>2</sub> and reduction in O<sub>2</sub> concentration because when ethylene is removed, the cell wall degrading enzymes are not stimulated and the cell wall strength is maintained (Dong *et al.*, 2014; Kesta *et al.*, 2013)



**Figure 2.** Effect of 1-MCP and packaging on firmness changes in 4 cherry tomato cultivars at 20° C for 16 d. Four cultivars including Black berry (a), Yellow pear (b), Orang berry (c) and Orange santa (d). Each data point is the mean of three replications. Vertical bars represent standard error of means.

### Total soluble solids and pH

The results obtained with the respect to the TSS and pH in the packaging and 1-MCP

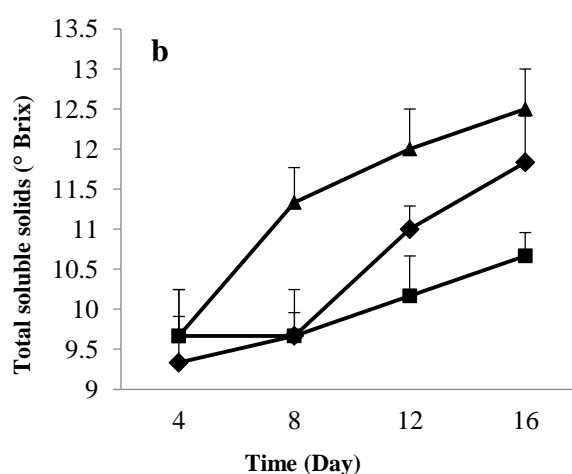
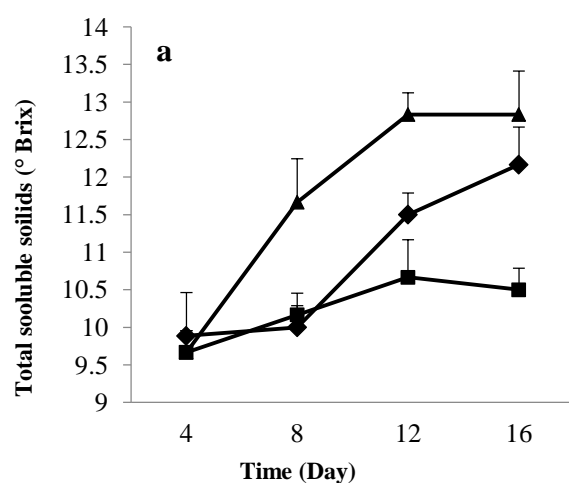
plus packaging treatments are given in Fig. 3 and Fig. 4. The TSS was enhanced by increasing storage time in the fruits of control, packaging and 1-MCP plus packaging during 16 d of storage. The results showed that using 1-MCP plus packaging were more efficient in preserving TSS in Yellow pear and Black berry cultivars compared to Orange berry and Orang Santa at the end of storage.

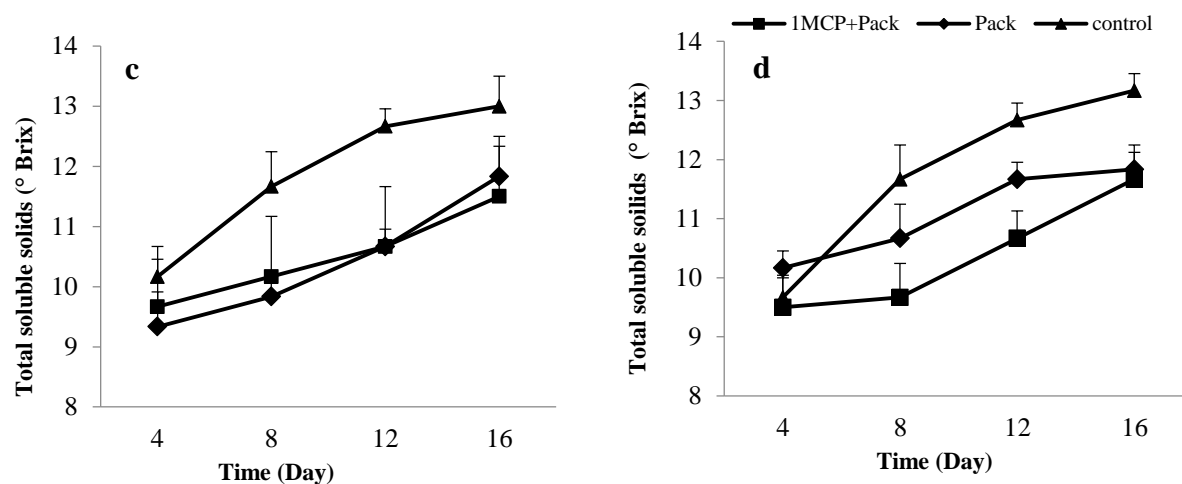
1-MCP plus packaging significantly decreased pH changes of four tomato cultivars during storage compared to the control. After the 16 days of storage, the pH changes from maximum to minimum value was obtained in black berry, Orange berry, Orange santa, and Yellow pear cultivars. It is well documented that the majority composition of TSS in fruit are included sugars while amino acid, vitamins, and minerals were found at the minimum amount (Rong-yu & Yao-wen, 2003). A lower fluctuation of TSS was observed in all tomato cultivars under packaging and packaging plus 1-MCP compared to control. An increase in TSS during storage of tomato fruit, specifically in the control fruit, resulted from accelerating the ripening process and weight loss (Rong-yu & Yao-wen, 2003). 1-MCP plus packaging showed a lower fluctuation of TSS than packing and control in yellow pear and black berry cultivars. The increase in sugar during the

storage is associated with an increase in the ethylene content and activity in the fruit tissue, so it can be concluded that the responses of the four cherry tomato cultivars to 1-MCP were different on controlling the ethylene activity and biosynthesis.

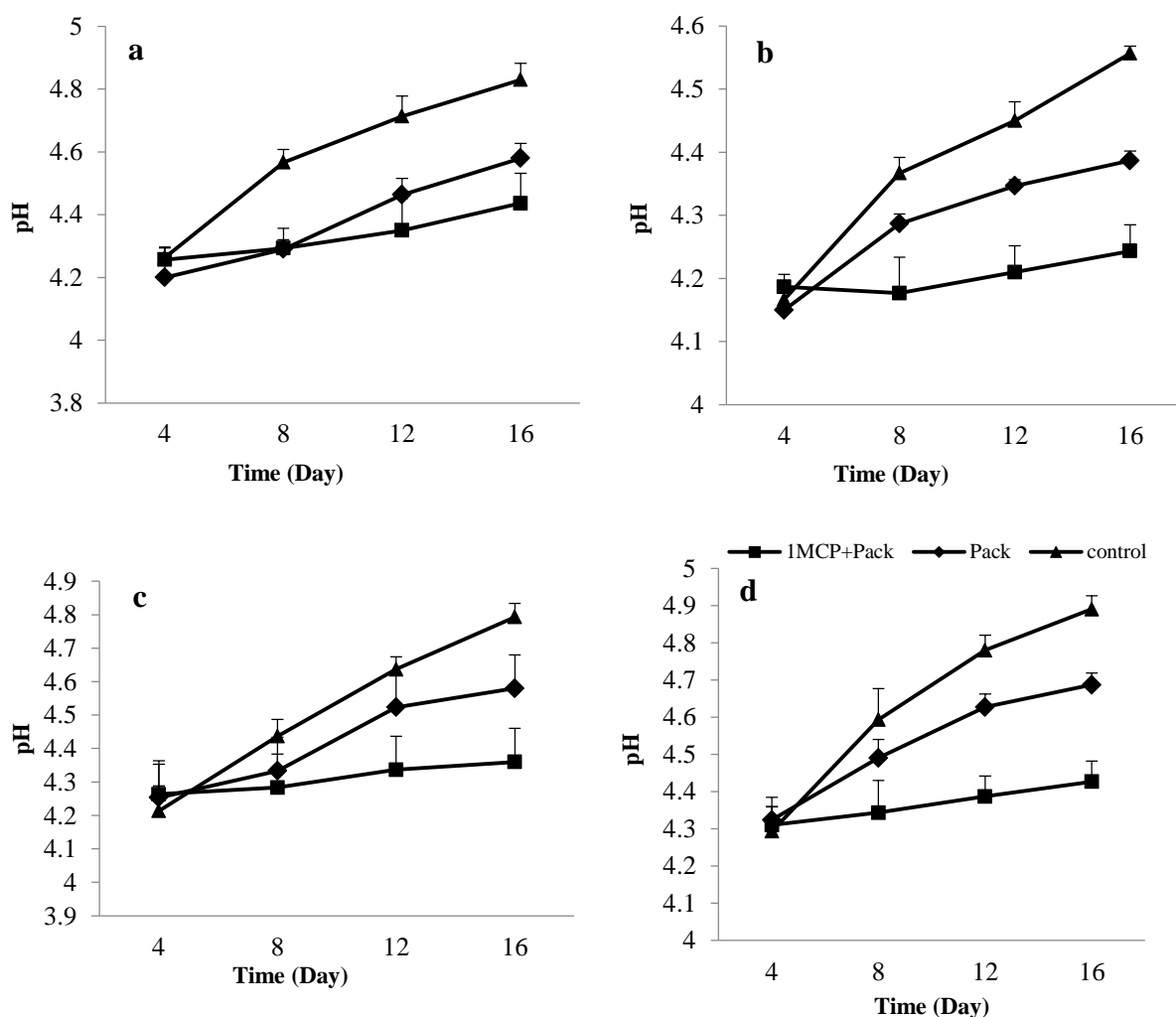
In this study, a higher fluctuations of pH were noticed in the control fruit compared to packaging and packaging plus 1-MCP in all of cherry tomato cultivars. The preservation of the organic acids during the storage is associated with a lower fluctuations of pH (Alikhani *et al.*, 2009). A lower change in pH in packaging plus 1-MCP treatment could be related to the inhibition effect of this treatment on the ethylene biosynthesis (Alikhani *et al.*, 2009).

Overall results of physiological study during storage showed that the four cherry tomato cultivars, despite being deeply different in their genetic background, from the physiological point of view recorded acceptability shelf life and behaved very similarly in response to packaging and 1-mcp plus packaging. However, these four cultivars were graded in terms of durability and quality maintenance; Yellow pear, Orang Santa, Black berry and Orange berry, respectively. So, the expression of ethylene-related genes was evaluated in Yellow pear and Orange berry cultivars.





**Figure 3.** Effect of 1-MCP and packaging on total soluble solids changes in 4 cherry tomato cultivars at 20° C for 16 d. Four cultivars including Black berry (a), Yellow pear (b), Orang berry (c) and Orange santa (d). Each data point is the mean of three replications. Vertical bars represent standard error of means.



**Figure 4.** Effect of 1-MCP and packaging on pH changes in 4 cherry tomato cultivars at 20° C for 16 d. Four cultivars including Black berry (a), Yellow pear (b), Orang berry (c) and Orange santa (d). Each data point is the mean of three replications. Vertical bars represent standard error of means.

### Gene expression analysis

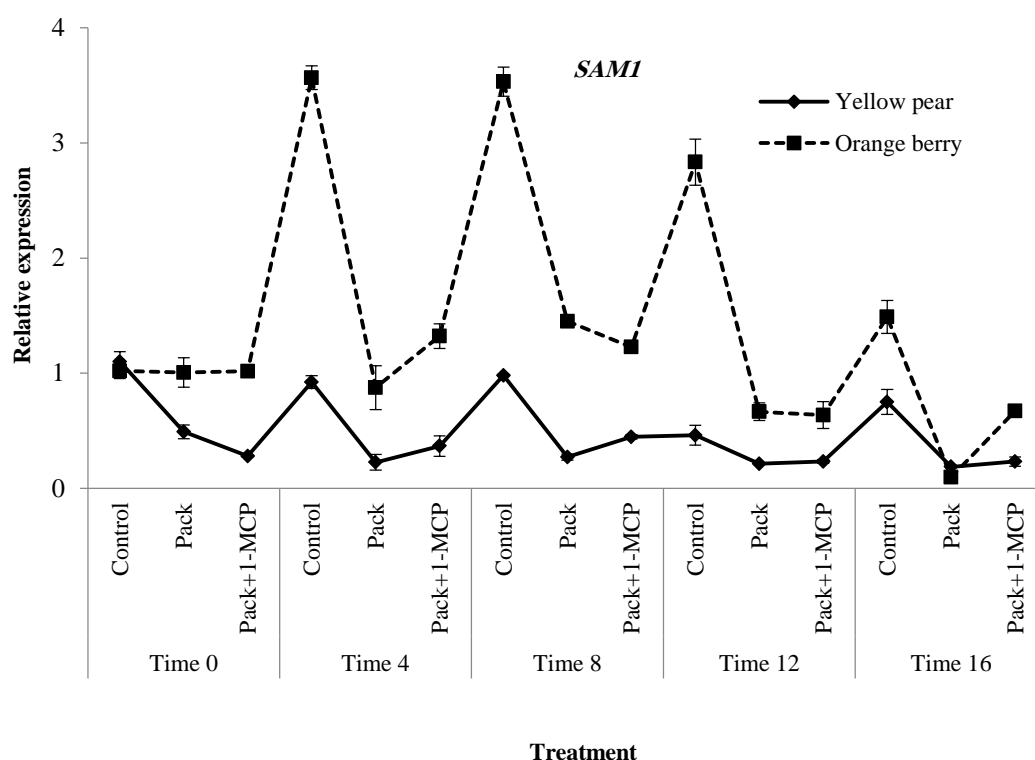


Based on the results of physicochemical characteristics of four cherry tomato cultivars under packaging and 1-MCP plus packaging treatments, Yellow pear and Orange berry were selected to monitor the expression pattern of four genes involved in ethylene biosynthesis.

### *SAM1*

The transcript level of *SAM1* gene in Yellow pear was surprisingly lower than

Orange berry in all of treatments during the storage. The highest expression level of *SAM1* gene was observed in the control of Orange berry at 4<sup>th</sup> and 8<sup>th</sup> d of storage. The results showed that packaging and packaging plus 1-MCP treatments decreased the transcript level of *SAM1* gene in the both cultivars (Fig 5).

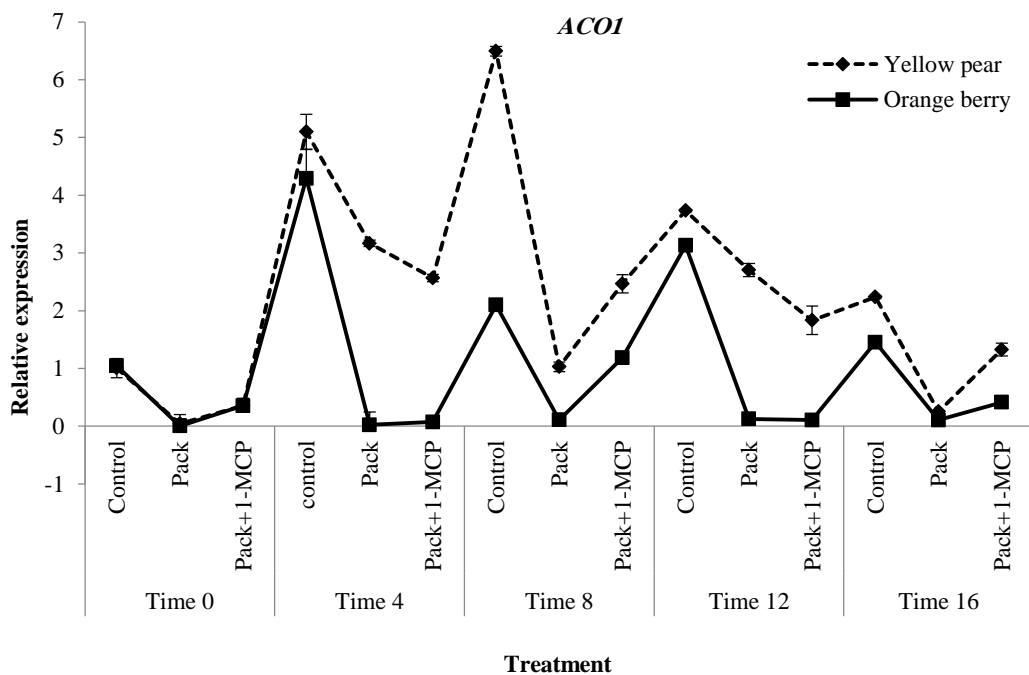


**Figure 5.** The expression pattern of *SAM1* at two cultivars and different days after harvesting (4, 8, 12 and 16 are days after harvesting, respectively). The y axis was calculated using a modified 2-DDCt formula with EF as references. The values presented were obtained from 3 biological replicates. Values are the means  $\pm$  SE.

### *ACO1*

The *ACO1* gene expressed in all treatments of yellow pear and the maximum level was obtained in control after 8 d of the storage. This gene expressed in the control of

orange berry, while packaging and 1-MCP plus packaging decreased the expression of *ACO1* gene to minimum level during the storage (Fig. 6).

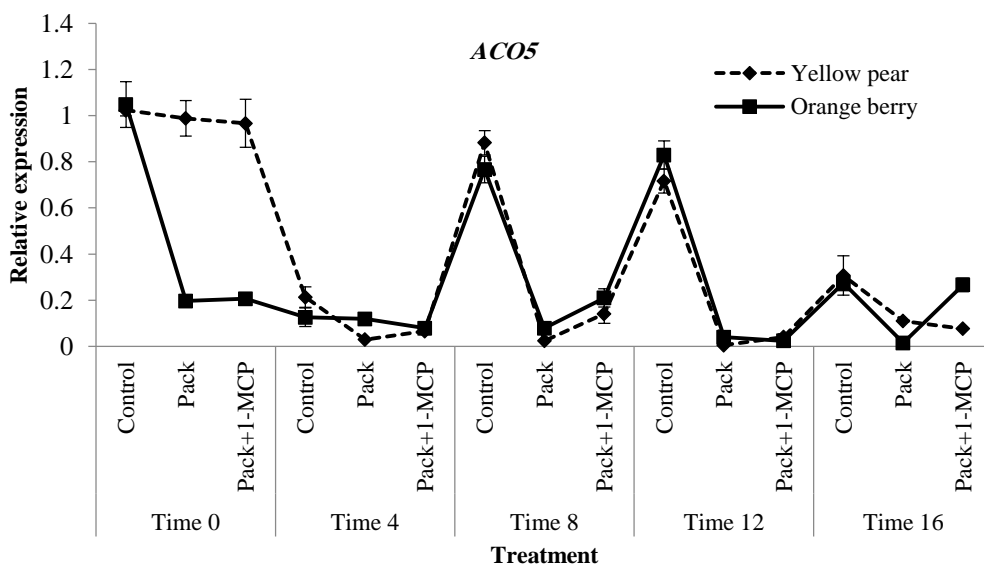


**Figure 6.** The expression pattern of *ACO1* at two cultivars and different days after harvesting (4, 8, 12 and 16 are days after harvesting, respectively). The y axis was calculated using a modified 2-DDCt formula with EF as references. The values presented were obtained from 3 biological replicates. Values are the means  $\pm$  SE.

#### *ACO5*

The *ACO5* gene was lowly expressed and, there were no remarkable differences in the both cultivars during the storage except in the beginning of experiments. However,

packaging and 1-MCP plus packaging decreased significantly the expression of *ACO5* gene compared to control fruits during the storage (Fig. 7).

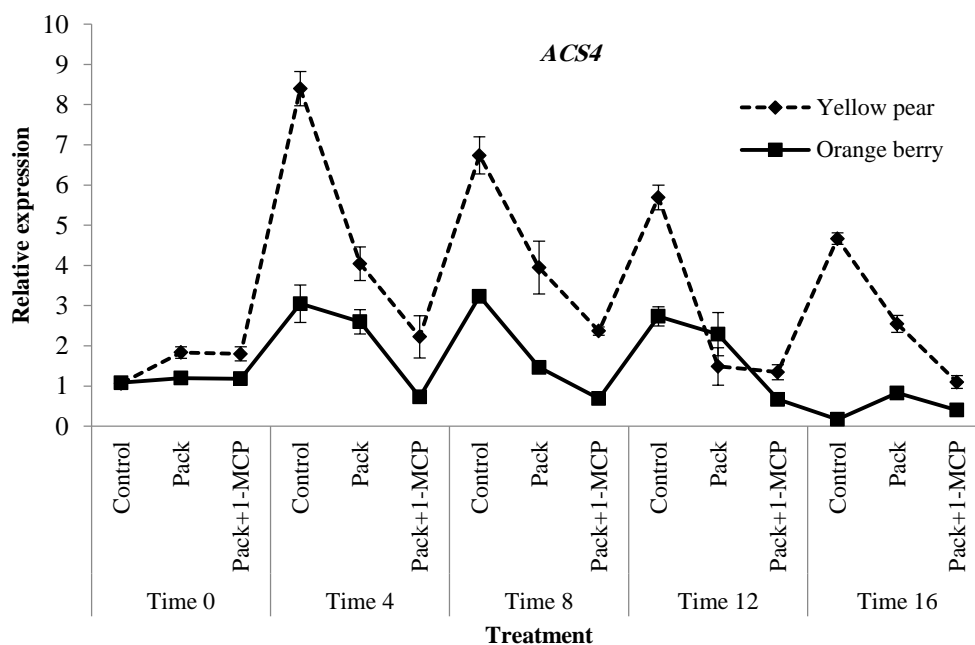


**Figure 7.** The expression pattern of *ACO5* at two cultivars and different days after harvesting (4, 8, 12 and 16 are days after harvesting, respectively). The y axis was calculated using a modified 2-DDCt formula with EF as references. The values presented were obtained from 3 biological replicates. Values are the means  $\pm$  SE.

### ACS4

The highest expression level of *ACS4* was detected in Yellow pear at 4<sup>th</sup> d of the storage and subsequently, this trend was gradually decreased. The transcript level of *ACS4* was significantly higher in Yellow pear compared to Orange berry in all

treatments during the storage. The expression level of this gene was decreased using packaging and packaging plus 1-MCP in the both cultivars of cherry tomato (Fig. 8).



**Figure 8.** The expression pattern of *ACS4* at two cultivars and different days after harvesting (4, 8, 12 and 16 are days after harvesting, respectively). The y axis was calculated using a modified 2-DDCt formula with EF as references. The values presented were obtained from 3 biological replicates. Values are the means  $\pm$  SE.

Ethylene plays an essential role in regulate ripening and senescence processes and impacts directly qualitative properties of the product (Yang *et al.*, 2013). Also, during the ripening process, ethylene could induce its reproduction by an auto-catalytic process and trigger the expression some genes such as *ACS* and *ACO* (Pech *et al.*, 2008) which are two critical enzymes that catalyze the ethylene biosynthesis pathway (Giovannoni, 2004). Here, the study of expression pattern of genes *SAMI*, *ACS4*, *ACO1* and *ACO5* in two cultivars at storage showed that they were drastically higher in control than packaging and 1-MCP plus packaging treatments (Figure 5-8). However, the expression level of gene *ACO5* was the same in both cultivars, but the expression level of *ACO1* and *ACS4* genes in the yellow pear cultivar was

higher than the orange berry. In contrast, the expression level of *SAMI* gene in the yellow pear cultivar was lower than the orange berry. Similarly, previous study has reported the different expression levels of these genes as a result of differences in cultivar (Yoo *et al.*, 2021). In both cultivars, 1-MCP plus packaging significantly suppressed the expression of *ACS4* gene compared to packaging. Previous research exhibited that at least nine sub-families of *LeACS* are involved in the regulation of *ACS* (Klee & Giovannoni, 2011). It was proved that using 1-MCP led to the reduction of the ethylene biosynthesis, which was essentially related to the down-regulation of *ACS* (Amornputti *et al.*, 2016). The result of *ACO1* and *ACO5* gene expression as the sub-family of *ACO* gene showed

that the level expression of *ACO1* gene was higher than the *ACO5* gene. The expression level of *ACO1* gene in orange berry was suppressed in packaging and packaging plus 1-MCP treatments, while the expression of *ACO5* gene in both cultivars was sharply reduced. It is reported that packaging reduces the O<sub>2</sub> concentration and increases the CO<sub>2</sub> concentration blocking the initiation an auto-catalytic event. Low O<sub>2</sub> concentration may decrease the ethylene production via interfering with the activity of ACC oxidase requiring O<sub>2</sub> to function correctly. In addition, high CO<sub>2</sub> concentrations could reduce the ethylene generation probably via its impact on the conversion of ACC to ethylene through ACC oxidase (De Wild *et al.*, 2003). Similarly, using packaging and 1-MCP plus packaging in banana at 14 °C lead to the generation of ethylene at a lower level which this result was attributed to the low expression of ACO (Ketsa *et al.*, 2013). The expression of three genes belonging to the sub-family of ACO in apple fruit under 1-MCP treatment revealed that the expression of *ACO1* enhanced and *ACO3* reduced while *ACO2* was down-regulated (Yang *et al.*, 2013). The ethylene production was repressed completely using 1-MCP treatment in apple fruit within the early days during conservation at 20 °C (Tatsuki *et al.*, 2006). The repression of *SAM1*, *ACS4*, and *ACO1* in packaging and 1-MCP plus packaging might be resulted in suppression

of ethylene due to feedback inhibition accordance with the repression of *Md-ACS1* expression with 1-MCP treatment in tomato which was reported by Pang *et al.* (2006). It is well recorded that 1-MCP efficacy could be affected by various factors, including cultivars, storage conditions, temperature, the length of the assay, and the harvest stage (Blankenship & Dole, 2003; Mir *et al.*, 2001).

### Conclusions

The results of this study demonstrated that the four cherry tomato cultivars were graded in terms of durability and quality maintenance; Yellow pear, Orang Santa, Black berry and Orange berry, respectively. Application of packaging and 1-MCP plus packaging in these cultivars led to the increase of qualitative features and the shelf life as well. It can be concluded that packaging and 1-MCP plus packaging increased the shelf life of these cultivars by suppression the expression of ethylene related genes especially, *SAM1*, *ACS4* and *ACO1*. To further corroborate the achieved results, it is required to precisely measure two enzymes level (ACC and ACO) and the amount of ethylene production during the storage.

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## اثر کاربرد ۱-متیل سیکلوپروپن همراه با بسته بندی بر بیان ژن های مرتبط با اتیلن و حفظ کیفیت ارقام گوجه فرنگی گیلاسی

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### چکیده

قابلیت ماندگاری چهار رقم گوجه فرنگی گیلاسی (*Lycopersicon esculentum*. Mill) و بیان ژن های بیوسنتز اتیلن (SAM1)، ACS4، ACO1 و ACO4) با تیمارهای بسته بندی (فیلم LDPE) و بسته بندی همراه با تیمار 1-MCP (۵ میکرو لیتر در لیتر) به مدت ۴۸ ساعت در دمای ۲۰ درجه سانتی گراد) در دمای ۲۰ درجه سانتی گراد به مدت ۱۶ روز مورد مطالعه قرار گرفتند. نتایج افت وزن و سفتی بافت میوه نشان دادند که بین بسته بندی و بسته بندی همراه با 1-MCP در چهار رقم گوجه فرنگی تفاوت قابل توجهی وجود نداشت، اما تغییرات مواد جامد محلول و pH در تیمار بسته بندی همراه با 1-MCP نسبت به سایر تیمارها کمتر بود. بر اساس نتایج فیزیوشیمیایی درجه بندی ارقام گوجه فرنگی رقم یلوو پیپر، اورنج سانتا، بلک بری و اورنج بری به ترتیب از ماندگار تا حساس انجام شد. بررسی الگوی بیان ژن های SAM1، ACS4، ACO1 و ACO5 در ارقام یلوو پیپر و اورنج بری نشان داد که بیان این ژن ها در شاهد با اختلاف معنی دار بیشتر از تیمارهای بسته بندی و بسته بندی همراه با 1-MCP صورت گرفت. سطح بیان ژن ACO5 در هر دو رقم یکسان بود، اما سطح بیان ژن های ACO1 و ACS4 در رقم یلوو پیپر بیشتر از اورنج بری بود. در مقابل، میزان بیان ژن SAM1 در رقم یلوو پیپر کمتر از اورنج بری مشاهده شد. در مجموع، با وجود تفاوت ژنتیکی این ارقام، بسته بندی و تیمار بسته بندی همراه با 1-MCP منجر به کاهش فسادپذیری و بهبود کیفیت نگهداری میوه گوجه گیلاسی شد.

واژه های کلیدی: بسته بندی، بیان ژن، بیوسنتز اتیلن، گوجه فرنگی چری، 1-MCP