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Postharvest methyl salicylate treatments delay ripening and maintain quality attributes and antioxidant compounds of 'Early Lory' sweet cherry

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ABSTRACT

The effect of postharvest application of methyl salicylate (MeSA) at two concentrations (0.1 and 1 mM) on quality attributes, bioactive compounds and antioxidant activity was studied in 'Early Lory' sweet cherry. MeSA treatments were effective in reducing respiration rate, weight loss, softening, total acidity losses and the increase in the ripening index during storage at 2 °C for 20 days as compared with non-treated control fruit. In addition, total phenolics, total anthocyanins and total antioxidant activity (TAA) in the hydrophilic extract (H-TAA) remained at higher concentrations at the end of storage in treated fruit. High correlations were found between H-TAA and phenolics or anthocyanin concentrations and between lipophilic TAA (L-TAA) and total carotenoids. Overall, results demonstrated that MeSA applied as postharvest vapours is an effective and environmentally friendly tool to maintain sweet cherry quality during storage with enhanced bioactive compounds concentration and antioxidant activity.

1. Introduction

Spain is the second largest producer of sweet cherries (*Prunus avium* L.) in Europe and is the sixth largest producer in the world with more than 30,000 ha and producing about 105,000 t annually. A wide range of cultivars are grown actually, from early to late season harvesting. 'Early Lory' is one of the earliest cultivars having low chilling requirements and being harvested beginning of May (Nogueroles-Pérez, 2005).

Sweet cherries are a nutritionally dense food rich in anthocyanins, quercetin, hydroxycinnamates, potassium, fiber, vitamin C, carotenoids, and melatonin. These constituent nutrients and bioactive food components support the potential preventive health benefits of cherry intake in relation to cancer, cardiovascular disease, diabetes, inflammatory diseases, among others (McCune et al., 2011; Ballistreri et al., 2013). However, several factors such as degree of ripeness at harvest, postharvest storage conditions, and processing, each can significantly alter the amounts of nutrients and bioactive components (Serrano et al., 2009, 2011; Valero et al., 2011; Díaz-Mula et al., 2012). In addition, the sweet cherry quality is deeply reduced during transit, storage and retailing, mainly due to visual and textural changes, increased microbial contamination and decay (Valero and Serrano, 2010).

In recent years, there has been an increasing interest in using salicylic acid (SA) and its derivatives acetyl salicylic acid (ASA) and methyl salicylate (MeSA) owing to their potential to extend the shelf-life of fresh produce and to reduce chilling injury and susceptibility to decay (Cao et al., 2010; Sayyari et al., 2011a,b). Specifically in sweet cherry, SA and ASA applied as dip postharvest treatment delayed the ripening process, maintained fruit quality attributes such colour, firmness and acidity, and enhanced bioactive compounds with antioxidant activity (Valero et al., 2011). In addition, SA and ASA when applied as preharvest treatments during sweet cherry on-tree growth led to fruit with greater size and weight, firmness, total soluble solids (TSS), total phenolics and anthocyanins and antioxidant activity at time of harvest (Giménez et al., 2014).

MeSA could be applied either as a vapour or as dips (Sayyari et al., 2011a; Glowacz and Rees, 2016) when prepared in aqueous solution. A MeSA preharvest application (at 0.5, 1 or 2 mM) in three sweet cherry tree cultivars ('Sweetheart', 'Sweet Late' and 'Lapins') induced fruit with higher fruit quality attributes at harvest and delayed the postharvest ripening process as manifested by a lower degree in colour changes, and lower acidity and firmness losses in

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fruit from treated trees with respect to controls, leading to maintenance of fruit quality (Giménez et al., 2015). In addition, preharvest MeSA treatments increased hydrophilic antioxidant activity (H-TAA) due to increased levels of phenolics and anthocyanins at harvest, which were also maintained at higher levels during storage (Valverde et al., 2015). These MeSA effects included a delay on the postharvest ripening process which was attributed to the higher content in antioxidant compounds such as phenolics and anthocyanins as well as the higher activity of the antioxidant enzymes catalase (CAT), peroxidase (POX), superoxide dismutase (SOD) and ascorbate peroxidase (APX) which would contribute to scavenging reactive oxygen species (ROS) related to fruit ripening and senescence process (Valverde et al., 2015).

On the other hand, postharvest treatment with exogenous MeSA delayed the postharvest ripening process in pomegranate, manifested by maintenance of fruit firmness, total soluble solids (TSS) and total acidity (TA) while significant losses occurred in control pomegranates (Sayyari et al., 2011a). This treatment was also effective in reducing chilling injury (CI). Accordingly, CI was retarded in tomato (Fung et al., 2006) and mango (Han et al., 2006) fruit by MeSA postharvest treatment throughout protecting cell wall and membranes structure from dysfunction caused by lipid peroxidative injury.

However, as far as we know there is no scientific literature on the role of postharvest MeSA treatments on sweet cherry quality attributes. In this sense, the aim of this work was to evaluate the effect of postharvest MeSA treatments (at 2 concentrations, 0.1 and 1 mM) on 'Early Lory' sweet cherry cultivar quality during 20 days of cold storage, with special focus on antioxidant activity and related bioactive compounds, given their implication in the beneficial effect of sweet cherry consumption for the human health.

2. Material and methods

2.1. Plant material and experimental design

Sweet cherries were manually harvested at commercial ripening stage and transferred to laboratory in 2 h. A total of 780 fruits, homogeneous in colour and size and without visual defects were selected. Three lots of 20 cherries were selected at random and used to analyse fruit properties at harvest time. The remaining 720 fruits were divided into 9 lots of 80 fruits to perform MeSA treatments at 20 °C in triplicate (0, control, 0.1 and 1.0 mM MeSA concentration, purchased from Sigma, Sigma–Aldrich, Madrid, Spain). After placing the cherries in a 10 L air-tight container, the head space was calculated (9.4 L) in which the appropriate volume of MeSA (0.167 and 1.67 mL) to reach the desired concentration (0.1 and 1 mM, respectively) was deposited on filter paper placed inside a 25 mL plastic vial (to avoid direct contact with fruit) at the bottom of the container. The container was immediately hermetically-sealed and taking into account the rapid volatilization of MeSA the desired concentration was achieved very quickly, as reported by Wang et al. (2015). Control fruit were also sealed in similar containers, but without MeSA addition. Duration of the treatment was 16 h, after which the fruits from each replicate were grouped randomly in lots of 20 fruits and stored in a temperature-controlled chamber at 2 °C, in permanent darkness and with a relative humidity of 90%. After 5, 10, 15 and 20 days of storage one lot from each replicate and treatment was taken for analytical determinations.

2.2. Weight loss and respiration rate determination

Weight loss of each individual lot was calculated as % with respect to the weight at day 0. Respiration rate was measured (at 20 °C for day 0 and at 2 °C for all sampling dates) by placing each lot in a 1 L glass jar hermetically sealed with a rubber stopper for 30 min and CO_2 was quantified using a Shimadzu™GC-14B gas chromatograph (Kyoto, Japan), equipped with thermal conductivity detector (TCD). Results were the mean ± SE and expressed as mg CO_2 kg^{-1} h^{-1}.

2.3. Fruit quality parameters

Colour was determined on each cheek of 20 fruit from each replicate by using a Minolta colorimeter (CRC200, Minolta Camera Co., Japan), using the CIELab coordinates and expressed as Hue angle. Fruit firmness was determined independently in 20 fruit of each replicate using a TX-XT2i Texture Analyzer (Stable Micro-systems, Godalming, UK) interfaced to a personal computer, with a flat steel plate mounted on the machine. For each fruit, the cheek diameter was measured and then a force that achieved a 3% deformation of the fruit diameter was applied. Results were expressed as the force-deformation ratio (N mm^{-1}) and were the mean ± SE. After that the 20 fruits of each lot were cut in small pieces to obtain a homogeneous sample for each replicate. Total soluble solids (TSS) were determined in duplicated in the juice obtained from 5 g of each sample with a digital refractometer Atago PR-101 (Atago Co., Ltd., Tokyo, Japan) at 20 °C, and expressed as g 100 g^{-1} (mean ± SE). Total acidity (TA) was determined in duplicate in the same juice by automatic titration (785 DMP Titrino, Metrohm) with 0.1 N NaOH up to pH 8.1, using 1 mL of diluted juice in 25 mL distilled H_2O, and results (mean ± SE) expressed as g malic acid equivalent 100 g^{-1} fresh weight. The ratio between TSS and TA was calculated and expressed as a ripening index.

2.4. Bioactive compounds and antioxidant activity

Total phenolics were extracted according to protocol described in Serrano et al. (2009) using water:methanol (2:8) containing 2 mM NaF (to inactivate polyphenol oxidase activity and prevent phenolic degradation) and quantified in duplicate using the Folin–Ciocalteu reagent and results (mean ± SE) were expressed as mg gallic acid equivalent 100 g^{-1} fresh weight. Total anthocyanins were extracted and determined according to previously reported (Serrano et al., 2005) and calculated as cyanidin 3-glucoside equivalent (molar absorption coefficient of 23,900 L cm^{-1} mol^{-1} and molecular weight of 449.2 g mol^{-1}) and results (mean ± SE) expressed as mg 100 g^{-1} FW. Total carotenoids were extracted according to Valero et al. (2011). Briefly, 2 g of sweet cherry fruit were extracted with acetone and shaken with diethyl ether and 10% NaCl for separation of the two phases. The lipophilic phase was washed with Na_2SO_4 (2%), saponified with 10% KOH in methanol, and the pigments were subsequently extracted with diethyl ether, evaporated and then made up to 25 mL with acetone. Total carotenoids were estimated by reading the absorbance at 450 nm and expressed as mg of β-carotene equivalent 100 g^{-1} FW, taking into account the $\varepsilon^{1\%}_{cm} = 2560$ and results were presented as means ± SE.

Total antioxidant activity (TAA) was quantified in duplicated for each sample as previously described (Serrano et al., 2009). Briefly, 5 g fresh flesh tissue were homogenised in 5 mL of 50 mM Na-phosphate buffer pH 7.8 and 3 mL of ethyl acetate, then centrifuged at 10,000 × *g* for 15 min at 4 °C. The upper fraction was used for total lipophilic antioxidant activity (L-TAA) and the lower for total hydrophilic antioxidant activity (H-TAA). In both cases, TAA was determined using the enzymatic system composed of the chro-mophore 2,2′-azino-bis-(3-ethylbenzothiazoline-6-sulfonic acid) diammonium salt (ABTS), the horse radish peroxidase enzyme (HRP) and its oxidant substrate (hydrogen peroxide,

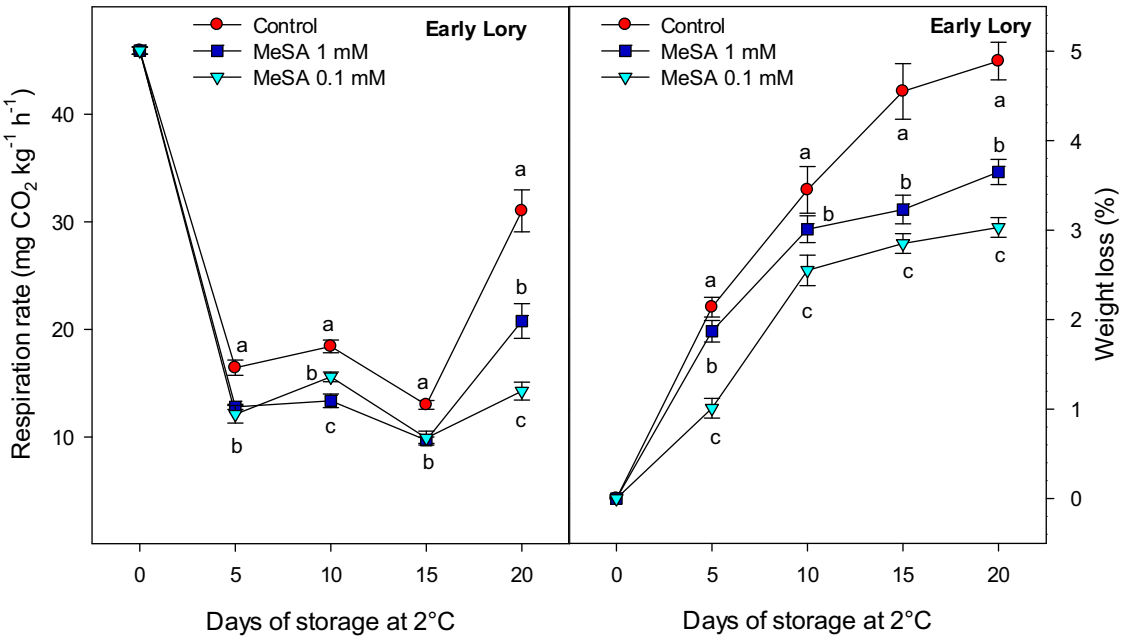

Fig. 1. Respiration rate and weight loss of control and MeSA-treated cherries (at 0.1 and 1 mM) during storage at 2 °C. Data are the mean ± SE. Different letter show significant differences ($P < 0.05$) for each sampling date among treatments.

H_2O_2), in which $ABTS^{\bullet+}$ radicals are generated and monitored at 730 nm. The reaction mixture contained 2 mM ABTS, 15 μM H_2O_2 and 25 μM HRP in 50 mM Na-phosphate buffer (pH 7.8) in a total volume of 1 mL. The decrease in absorbance after adding the extract was proportional to TAA of the sample. A calibration curve was performed with Trolox ((R)-(+)-6-hydroxy-2,5,7,8-tetramethyl-croman-2-carboxylic acid) (0–20 nmol) from Sigma (Madrid, Spain), and results are expressed as mg of Trolox equivalent 100 g^{-1} FW.

2.5. Statistical analysis

Data for the analytical determinations were subjected to analysis of variance (ANOVA). Sources of variation were treatment and storage. Mean comparisons were performed using HSD Tukey's test to examine if differences for each sampling date were significant at $P < 0.05$ among treatments. Linear regressions were performed between H-TAA and phenolics or anthocyanins and between L-TAA and carotenoids. All analyses were performed with SPSS software package v. 21.0 for Windows.

3. Results

3.1. Weight loss and respiration rate

Weight loss increased over time in storage for all control and treated cherries, although the application of MeSA (either at 0.1 or 1 mM) significantly delayed the weight loss with final values of ≈5% in control and ≈3 and 3.7% for 0.1 and 1 mM MeSA treated cherries, respectively (Fig. 1). Respiration rate at harvest was 45.91 ± 0.33 mg CO_2 kg^{-1} h^{-1} and drastically decreased when fruit were placed under cold storage conditions (within the first 5 days), remained without significant changes until day 15 of storage and then strongly increased until the end of the experiment (Fig. 1). However both MeSA treatments led to significantly lower respiration rate during the entire time of storage, especially after 20 days, at which significant differences were also shown between 0.1 and 1 mM MeSA treatments, the 0.1 mM concentration being the most effective on reducing respiration rate. CO_2 and O_2 concentration were measured after 16 h of treatments and the obtained results were ca. 2.8 and 18 kPa respectively in both control and MeSA-treated containers, and thus no anaerobic metabolism in cherry fruit could be expected with this atmosphere composition.

3.2. Fruit quality attributes

Fruit firmness at harvest was 1.67 ± 0.03 N mm^{-1} and significantly decreased during storage reaching final values of 1.34 ± 0.02 N mm^{-1} in control fruits, and significantly higher, 1.49 ± 0.04 and 1.61 ± 0.03 N mm^{-1} in MeSA-treated at 1 and 0.1 mM, respectively (Fig. 2). Similarly, total acidity (TA) decreased also during storage from initial levels of 0.88 ± 0.04 to 0.66 ± 0.02 g 100 g^{-1} in control cherries, the decreases being significantly less in MeSA-treated cherries, without significant differences between 1 and 0.1 mM treatments (Fig. 2). Total soluble solids (TSS) at harvest were 10.60 ± 0.21 g 100 g^{-1} and significantly increased in control fruits up to 11.30 ± 0.07 g 100 g^{-1} at the end of the experiment, while remained unchanged for both 1 and 0.1 mM MeSA-treated cherries (data not shown). Both TA retention and TSS maintenance in treated cherries led to less increases in ripening index (TSS/TA ratio) in MeSA-treated cherries compared with controls which exhibited a continuous and significant increase (from ≈11 to 17) during storage (Fig. 3). Finally, colour expressed as Hue angle decreased significantly along storage for all control and treated cherries without significant differences attributable to treatments although a significant delay was observed for the cherries treated with a 0.1 mM concentration during the first days of storage (Fig. 3).

3.3. Antioxidant activity and related bioactive compounds

Total antioxidant activity (TAA) was determined separately in both hydrophilic (H-TAA) and lipophilic (L-TAA) sweet cherry

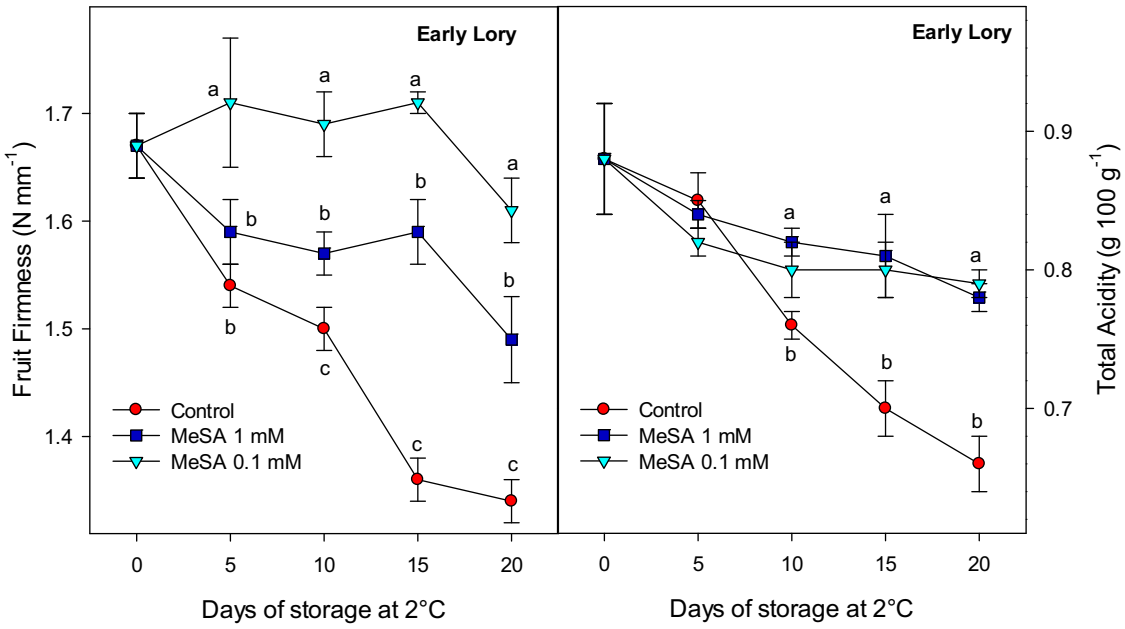

Fig. 2. Fruit firmness and total acidity (TA) of control and MeSA-treated cherries (at 0.1 and 1 mM) during storage at 2 °C. Data are the mean ± SE. Different letter show significant differences ($P < 0.05$) for each sampling date among treatments.

extracts, and results showed that H-TAA was 4-6-fold higher than L-TAA (Fig. 4). In treated cherries both H-TAA and L-TAA exhibited a similar change, that is a continuous increase along storage with final concentrations of ≈125 and 35 mg 100 g^{-1}, respectively. The same behaviour was also found in control fruits for L-TAA while for H-TAA after an initial increase until day 10 of storage, a reduction was observed reaching significantly lower H-TAA (≈90 mg 100 g^{-1}) levels at the end of storage compared with treated cherries.

With respect to total anthocyanins, levels at harvest (≈20 mg 100 g^{-1}) increased significantly in both control and treated cherries until day 15 of storage and thereafter decreased until the end of storage (Fig. 5). However, concentrations of total anthocyanins were significantly higher in MeSA-treated than in control fruit, especially for the 0.1 mM dose. Total carotenoids at harvest (0.15 ± 0.01 mg 100 g^{-1}) increased significantly as storage progressed in control and treated cherries without significant

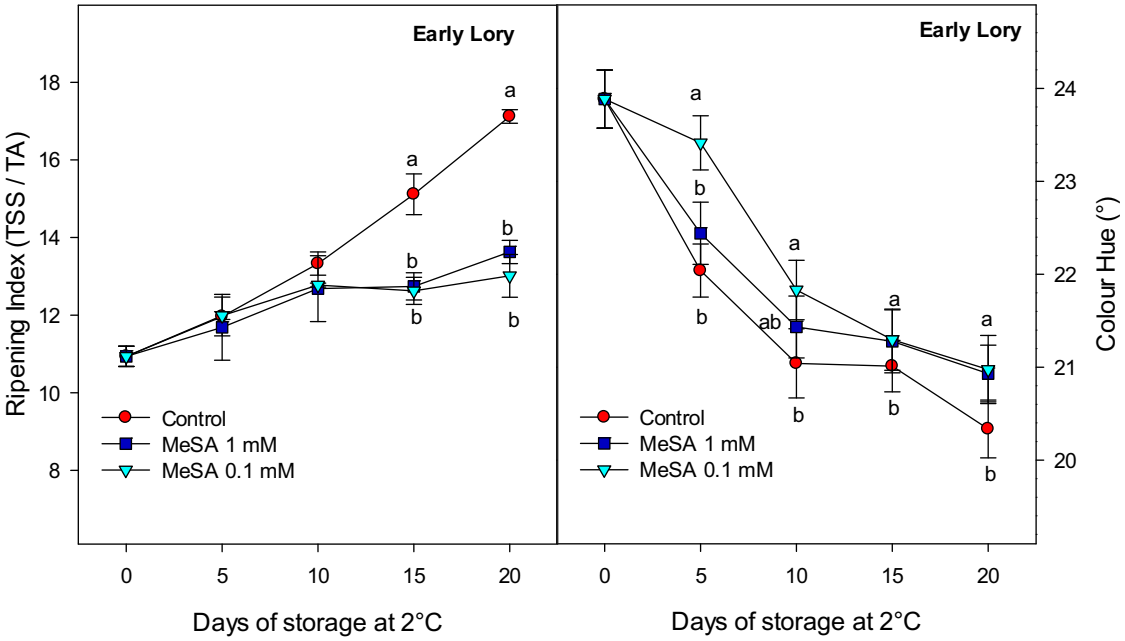

Fig. 3. Ripening index (TSS/TA) and colour (Hue angle) of control and MeSA-treated cherries (at 0.1 and 1 mM) during storage at 2 °C. Data are the mean ± SE. Different letter show significant differences ($P < 0.05$) for each sampling date among treatments.

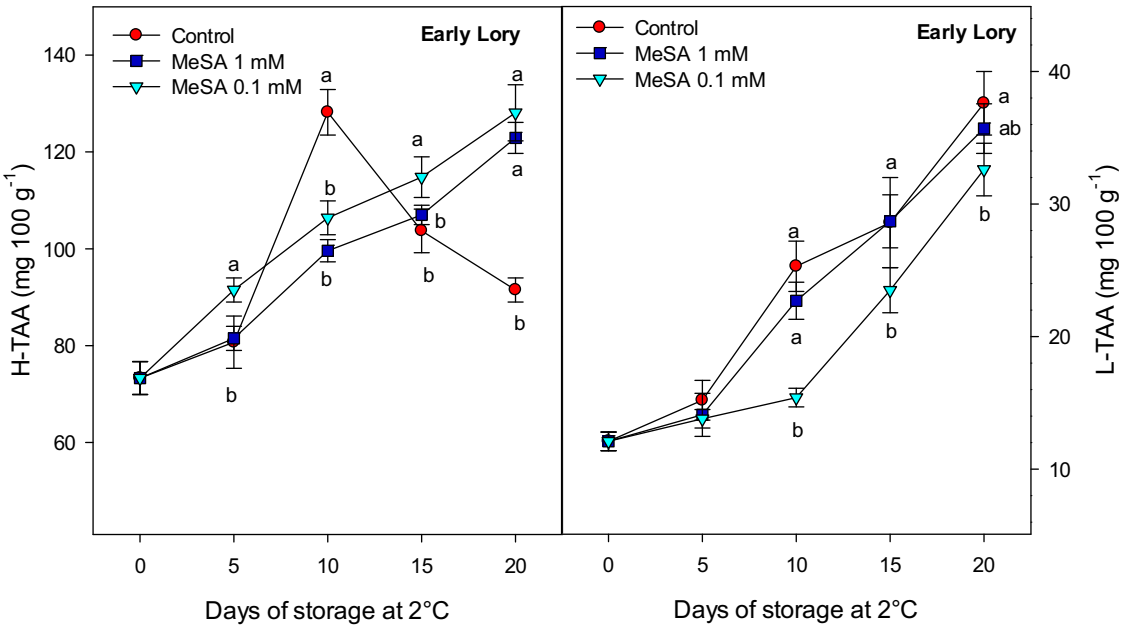

Fig. 4. Hydrophilic and lipophilic total antioxidant activities (H-TAA and L-TAA) of control and MeSA-treated cherries (at 0.1 and 1 mM) during storage at 2 °C. Data are the mean ± SE. Different letter show significant differences ($P < 0.05$) for each sampling date among treatments.

differences among treatments at the end of storage (Fig. 5). In relation to total phenolics a sharp increase was observed for control fruit during the first 5 days of storage from ≈65 to 85 mg 100 g^{-1} and remained unchanged until day 15 and decreased significantly at the end of storage (Fig. 6). However, in treated fruit the increase in phenolic concentration was delayed and went on until the end of storage. In fact, after the prolonged cold storage the levels of total phenolics were higher in MeSA-treated cherries than in controls, the most effective dose being 0.1 mM (a 30% more phenolics). Linear regressions were performed between H-TAA and anthocyanins or phenolics (Fig. 6), and results revealed that both bioactive compounds were positively correlated with H-TAA ($r^2 > 0.57$). In addition, L-TAA was also positively correlated with carotenoids ($y = 63.49x + 5.21$; $r^2 = 0.818$).

4. Discussion

Postharvest treatments with salicylates have been shown to improve fruit quality characteristics, such as appearance and texture and to maintain nutritional content during post-harvest

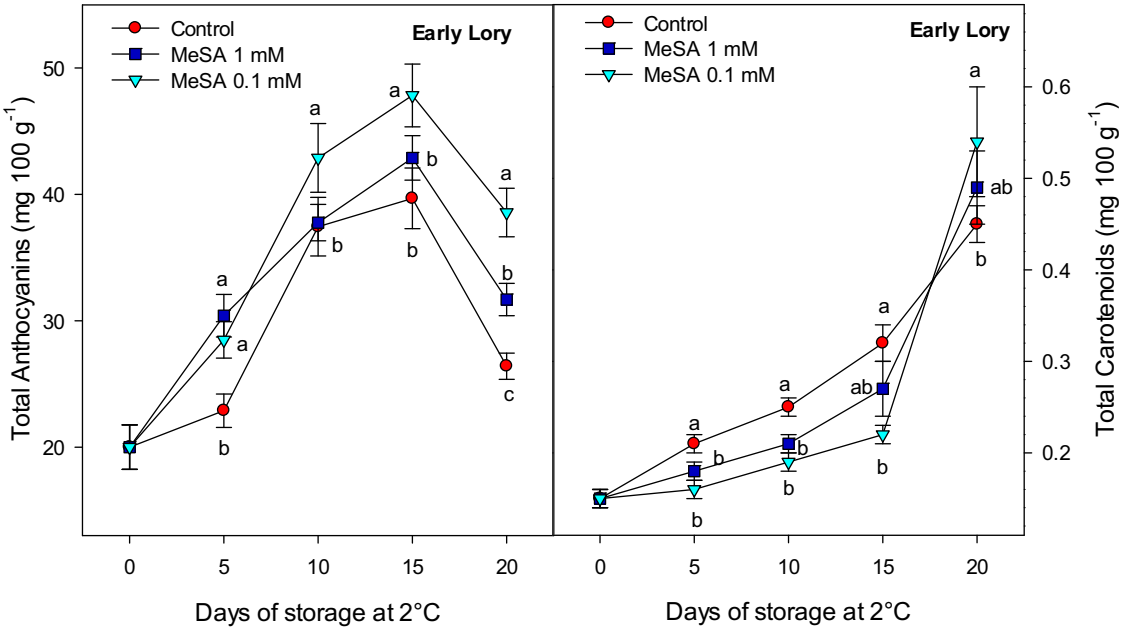

Fig. 5. Total anthocyanins and total carotenoids concentration of control and MeSA-treated cherries (at 0.1 and 1 mM) during storage at 2 °C. Data are the mean ± SE. Different letter show significant differences ($P < 0.05$) for each sampling date among treatments.

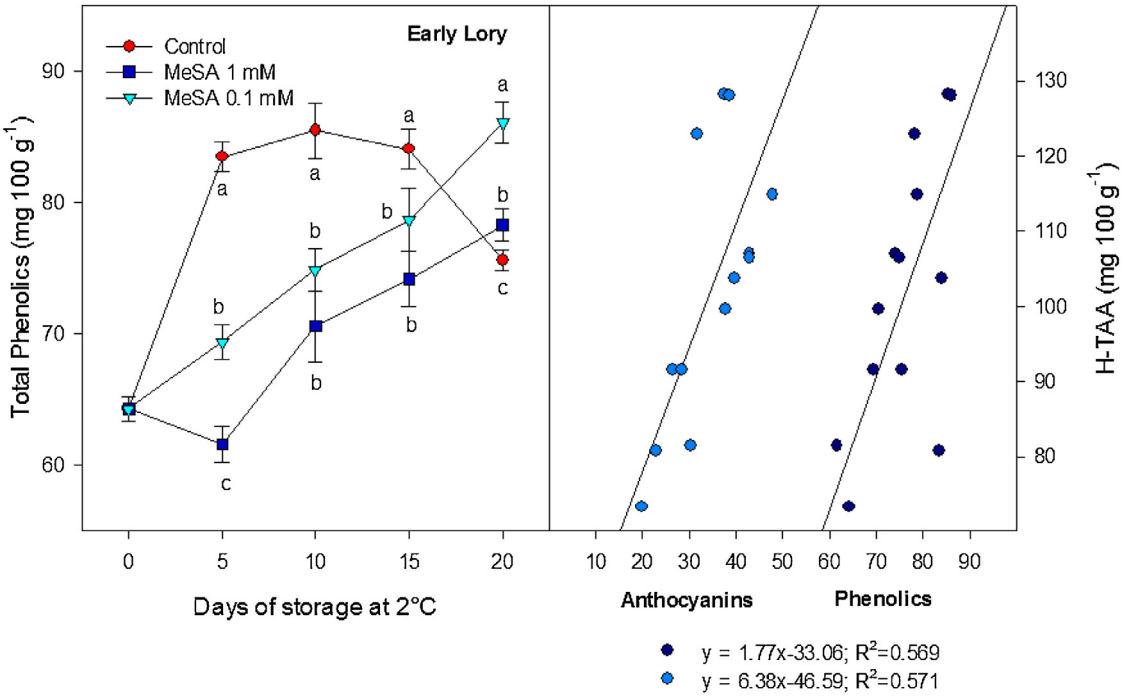

Fig. 6. Total phenolics of control and MeSA-treated cherries (at 0.1 and 1 mM) during storage at 2 °C (data are the mean ± SE) and linear regressions between hydrophilic total antioxidant activity (H-TAA) and total phenolics or total anthocyanins. Different letter show significant differences ($P < 0.05$) for each sampling date among treatments.

storage, with a net effect on delaying the postharvest ripening process and extending their storability (Glowacz and Rees, 2016). Respiration rate is a good measure of physiological activity, since it increases with tissue damage and deterioration. In 'Early Lory' sweet cherry MeSA treatments at both concentrations significantly reduced respiration rate over cold storage as compared with controls. The lower respiration rate in treated fruit would indicate a lower deteriorative metabolism and maintenance of respiratory substrates, and in turn a delay on the senescence process. Accordingly, lower respiration rate was found in banana (Srivastava and Dwivedi, 2000), Qingnai plum (Luo et al., 2011), custard apples (Mo et al., 2008) and pomegranates after dipping treatments with SA or ASA (Sayyari et al., 2011b). Postharvest MeSA treatments reduced also weight loss during storage, especially at the lower concentration (0.1 mM) in agreement with previous reports such as for peaches, strawberries and sweet peppers dipped in SA at 0.5–2.0 mM (Shafiee et al., 2010; Rao et al., 2011; Tareen et al., 2012). This effect on reducing weight loss could be related to the lower respiration rate found in treated fruit leading to slower rates of deterioration.

Texture loss during storage is a serious problem for the fresh produce industry because it reduces marketability of the product. Our results show a significant effect of postharvest MeSA treatment on maintaining fruit firmness along storage, the main effect being found with the 0.1 mM doses. Similarly, softening was reduced in kiwifruit and pomegranate dipped in ASA (Sayyari et al., 2011b; Yin et al., 2013), in custard apple, bell pepper and peach treated with SA (Mo et al., 2008; Rao et al., 2011; Tareen et al., 2012), and pomegranate treated with MeSA vapours (Sayyari et al., 2011a). Firmness was also reduced in mangos treated with MeSA (Han et al., 2006) but was not affected by SA dipping treatment (Ding et al., 2007). In the above fruit, the firmness retention has been related either to reduced chilling injury or inhibition of ethylene production in the climacteric fruit (Glowacz and Rees, 2016). Specifically in sweet cherry, postharvest SA and ASA at 1 mM retarded softening during cold storage (Valero et al., 2011) which was associated with delayed ripening process, although inhibition of the cell-wall degrading enzymes such as polygalaturonase, pectin-methylesterase and cellulose could be also involved (Asghari and Aghdam, 2010).

The changes in colour, level of TSS and TA content could also be associated with fruit maturity. Usually, during postharvest sweet cherry storage TSS increases and colour Hue and TA decrease (Bernalte et al., 2003; Serrano et al., 2009; Serradilla et al., 2013, 2011), although after the application of MeSA lower increases in TSS and higher TA retention were obtained leading to a lower ripening index at the end of storage. Similar effects were obtained with the application of SA and ASA to sweet cherry (Valero et al., 2011), as well as in pepper, banana and custard apple dipped in SA (Srivastava and Dwivedi, 2000; Mo et al., 2008; Rao et al., 2011). On the other hand, TSS and sugars were not affected in pomegranates treated with SA (Sayyari et al., 2009) or with ASA (Sayyari et al., 2011b), in which the content of TSS remained unchanged over the whole storage period of 3 months. Overall, these quality parameters were maintained in MeSA-treated cherries showing a clear effect on delaying the postharvest ripening process. It is worthy to mention that no persistence of MeSA odour and/or flavour was detected at the concentration used in this study, according to previous reports for pomegranate (Sayyari et al., 2011a) or tomatoes (Wang et al., 2015).

In recent years, the study of bioactive compounds and antioxidant activity of fruit and vegetables is of great interest due to the relationship between phytochemical intake and reduced risk of suffering a wide range of human diseases (McCune et al., 2011; Ballistreri et al., 2013; Fang, 2015). In this sense, it is important to point out that treatment of 'Early Lory' sweet cherry with MeSA (at 0.1 and 1 mM) enhanced the content of total anthocyanins and total phenolics at the end of the storage, while in control fruit significant decreases occurred, the same behaviour being observed for H-TAA. We have found significant correlations between H-TAA and total phenolics and total anthocyanins concentrations, according to previous reports in other sweet cherry cultivars (Serrano et al., 2009; Serradilla et al., 2013). Specifically, these correlations were also found between the

antioxidant activity and the major individual phenolic compounds in sweet cherry, such as *p*-coumaroylquinic acid and epicatechin (González-Gómez et al., 2010). In addition, L-TAA was highly correlated with total carotenoids indicating that these pigments are the main lipophilic compounds with antioxidant activity. Thus, for knowing the potential of sweet cherry as a functional fruit with health implications, both H-TAA and L-TAA should be determined.

This is the first report in which increased levels of antioxidant activity and concentration of bioactive compounds have been obtained as a consequence of postharvest MeSA treatment. Nevertheless, it has been found in some studies that treatments with SA and ASA after harvest increased antioxidant activity of fresh produce during storage, which was attributed to the fact that ASA and MeSA are converted to SA in fruit tissues, the latter being postulated as the main compound having physiological activity as a plant hormone (Raskin, 1992; Hayat and Ahmad, 2007). Thus, higher antioxidant activity was observed in peaches (Tareen et al., 2012), pomegranates (Sayyari et al., 2011b), orange (Huang et al., 2008) and cornelian fruit (Dokhanieh et al., 2013) treated with SA. In addition, SA and ASA postharvest treatments led to maintenance of antioxidant activity in sweet cherry, while decreases occurred in control fruit, which were related to the over-ripening and senescence processes (Valero et al., 2011). In addition, there is some evidence about the use of MeSA as preharvest treatments and its effect on quality and antioxidant properties in fruit commodities. Specifically in three sweet cherry cultivars ('Sweetheart', 'Sweet Late' and 'Lapins') MeSA applied at three concentrations (0.5, 1 and 2 mM) led to fruit with greater size and weight and higher quality attributes, the greatest effect being found for the 1 mM dose (Giménez et al., 2015). These treated fruit also showed higher content of bioactive compounds at time of harvest and after prolonged storage period (Valverde et al., 2015) leading to fruit with higher H-TAA. Moreover, the activity of the antioxidant enzymes CAT, POD, APX and SOD was higher in fruit treated with MeSA as compared with controls. Thus, MeSA applied either as pre- or postharvest treatments could increase health-promoting properties of cherry fruit consumption, due to its effect on increasing antioxidant and bioactive compounds (McCune et al., 2011; Ballistreri et al., 2013). In addition, the increase of both, antioxidant compounds and the activity of antioxidant enzymes by MeSA treatments could lead to additional effects on delaying the fruit postharvest senescence process and maintaining fruit quality properties along storage for longer time. However, the molecular mechanism involved in these physiological responses remains unclear and deserves father research. Finally, MeSA is widely used as flavouring agent or fragrance and is affirmed by US FDA as GRAS (generally recognized as safe) and widely accepted as safe food additive in many countries (FDA, 2005).

5. Conclusions

In this work we report for the first time that postharvest treatment with MeSA is an innovative tool to maintain the quality of sweet cherry during storage, since treated fruit showed lower deterioration through reduction in respiration rate, weight loss, softening and TA loss. In addition, MeSA was also able to maintain the content of bioactive compounds (total phenolics, anthocyanins and carotenoids) and antioxidant activity at higher concentrations with respect to control fruit at the end of the storage period. Overall results suggest that optimal quality attributes could be maintained up to 10 days of cold storage (based on firmness, TA, ripening index, bioactives and antioxidant activity) in control fruit, while this period could be extended up to 20 days in MeSA treated fruit, especially with the 0.1 mM concentration.

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