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Methyl salicylate treatments of sweet cherry trees improve fruit quality at harvest and during storage

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ABSTRACT

The aim of this work was to evaluate the effect of methyl salicylate (MeSA) treatments of sweet cherry trees on fruit quality properties at harvest time and during cold storage. Experiments were performed during two consecutive years by using two cultivars, 'Sweet Heart' and 'Sweet Late' in 2013, and three cultivars, 'Sweet Heart', 'Sweet Late' and 'Lapins' in 2014. In the 2013 experiments, three MeSA concentrations (0.5, 1 and 2 mM) were applied at three key points of on-tree fruit development and results showed that the 1 mM concentration was the most appropriate in terms of increasing fruit size and quality parameters (improved colour, firmness and total soluble solids) at the time of harvest. Sensory analysis revealed that appearance, firmness and sweetness scores were higher in 1 mM MeSA treated cherries than in the control ones. Thus, 1 mM concentration was chosen for the 2014 experiments, in which it was found that MeSA treatments did not affect total fruit yield. The fruits from both control and 1 mM MeSA treated trees was stored at 2 °C and a relative humidity (RH) of 85% for 28 days and results showed that preharvest MeSA treatments delayed the postharvest ripening process, manifested by a lower degree in colour changes, and less loss of acidity and firmness in treated fruits with respect to controls, leading to maintenance of fruit quality. Overall, preharvest treatments with 1 mM MeSA at three key dates of sweet cherry growth and ripening improved fruit quality attributes at the time of harvest and after postharvest storage, showing that MeSA could be a safe and environmentally friendly tool with potential practical application to improve sweet cherry fruit quality.

1. Introduction

Salicylic acid (SA) is a plant hormone with diverse regulatory roles in the metabolism of plants, such as disease resistance mechanisms and systemic acquired resistance (SAR) as well as influencing other development features such as seed germination, seedling establishments, cell growth, stomatal closure, responses to abiotic stress and fruit yield (Raskin, 1992; Vlot et al., 2009). Methyl salicylate (MeSA) is a volatile plant compound synthesized from SA having also a role in plant defence mechanisms, plant development, fruit ripening processes and plant responses against several abiotic stress factors (Hayat and Ahmad, 2007). Thus, postharvest treatment with exogenous MeSA decreased chilling injury (CI) of tomato (Fung et al., 2006), and mango (Han et al., 2006) fruits by protecting cell wall structure and cell membranes from dysfunction caused by lipid peroxidative injury. Accordingly, in pomegranate fruits, CI was reduced by postharvest treatment with MeSA, due to maintenance of membrane structure and selective permeability. In addition, other parameters related to fruit quality, such as fruit firmness, total soluble solids (TSS) and total acidity (TA) were also maintained in MeSA treated fruits while significant losses occurred in control pomegranates (Sayyari et al., 2011).

Sweet cherry (*Prunus avium* L.) is a stone fruit appreciated by consumers due to excellent appearance, precocity and quality attributes, especially those related to bright red colour, firmness, sweetness and flavour (Díaz-Mula et al., 2009; Valero and Serrano, 2010; Serradilla et al., 2012). To improve sweet cherry quality parameters (such as size, colour, total soluble solids or firmness) at the time of harvest, several preharvest treatments have been carried out. Thus, gibberellic acid (alone or combined with prohexadione-Ca) applied to cherry trees at different points of fruit development led to obtaining fruit of increased mass and

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size, TSS and firmness and improved resistance to pitting (Zhang and Whiting, 2011; Einhorn et al., 2013). In addition, cherry trees treated with oxalic acid (OA) at 0.5, 1.0, and 2.0 mM at 98, 112, and 126 days after full blossom (DAFB) led to fruit with higher volume, mass, colour, firmness, total anthocyanins, total phenolics, and antioxidant activity than control ones, although no significant differences were found in TSS or TA (Martínez-Esplá et al., 2014).

Preharvest treatment with SA or acetylsalicylic acid (ASA), applied by foliar spray to sweet cherry trees, increased fruit mass, colour, firmness and antioxidant activity at commercial harvest (Giménez et al., 2014). On the other hand, SA or ASA postharvest treatments of sweet cherry delayed the postharvest ripening process, manifested by a lower degree in colour changes, a lower loss of acidity and firmness, and a maintained higher content of bioactive compounds and antioxidant activity, leading to fruits with higher quality attributes as compared with control fruits (Valero et al., 2011). However, the commercial applications of postharvest treatment to preserve fruit quality is restrictive due to legal directives of the different countries and more research is needed to find preharvest treatments with effect on maintaining fruit quality attributes during storage, especially in fruits that deteriorate quickly, such as sweet cherry (Esti et al., 2002; Alique et al., 2005; Serrano et al., 2009).

As far as we know, there is no scientific literature about the possible effect of MeSA treatment, either at pre- or postharvest, on quality parameters of sweet cherry fruits. Therefore, this is the first study in which the effect of preharvest MeSA treatments on sweet cherry trees was evaluated for crop yield and fruit quality parameters at harvest time and during cold storage for long periods. In the 2013 experiment, three MeSA concentrations (0.5, 1.0 and 2.0 mM) were applied to 'Sweet Heart' and 'Sweet Late' cultivars and in year 2014 only the 1.0 mM concentration was chosen and applied to 'Sweet Heart', 'Sweet Late' and 'Lapins' cultivars.

2. Materials and methods

2.1. Plant material

The experiments were carried out in a commercial orchard "Fincas Toli S.L." of sweet cherry 'Sweet Heart' and 'Sweet Late' cultivars, located in Jumilla (Murcia, Spain) during the spring-summer of 2013 and 2014. Another trial was conducted in a commercial in a commercial orchard "Cerezas Aitana" (Alicante, Spain) of sweet cherry 'Lapins' cultivar during 2014.

2.2. Experimental design

In the 2013 experiment, two separated rows, one for each cultivar were selected in the orchard "Fincas Toli S.L". Twelve trees were selected in each cultivar-row according to completely randomized design with three replicated trees per treatment. The treatments evaluated were: control (distilled water) and methylsalicylate (MeSA) at 0.5, 1.0 and 2.0 mM. In the 2014, 10 trees (replicates) of each cultivar were selected completely at random for each following treatments: control (distilled water) and MeSA at 1.0 mM, since this was the dose with which the best results were previously obtained in the 2013 experiment. For both years, the first and the last two trees of each row were considered guard trees and each treated trees was separated by two un-treated trees to avoid cross-contamination. Treatments were performed by foliar spraying with freshly prepared MeSA solutions (containing 0.5% of Tween 20) by using a mechanical mist sprayer (7.5 L/tree, which was enough to wet the entire tree canopy). This procedure was repeated at 3 dates of the growth cycle, which corresponded to key events in the fruit developmental process, according to previous experiments: T1 (at pit hardening), T2 (initial colour changes) and T3 (onset of ripening) (Fig. 1). In the 2013 experiment, one week before the T1 treatment, 20 fruits were labelled around the equatorial perimeter of each tree, in which fruit growth was followed by measuring polar, suture and cheek diameters, and then fruit volume was calculated as previously reported (Díaz-Mula et al., 2009). On a weekly basis, from 1 week before the T1 treatment to commercial harvesting, 20 fruits (similar to those labelled previously) for each tree (or replicate) were picked for further analytical determinations: fruit mass, firmness, colour, TSS and TA. All sweet cherry fruits were harvested at commercial ripening stage, according to the Technician's company and based on visual colour using the CTIFL chart, which was 5 for 'Lapins' cultivar and 4 for 'Sweet Heart' and 'Sweet Late' cultivars, according to previous report (Díaz-Mula et al., 2009). In the 2013 storage experiment, 300 fruits, homogeneous in colour and size and without visual defects were selected for each cultivar from control and 1.0 mM MeSA treated trees. These 300 fruits were randomly grouped in 15 lots of 20 fruits, weighted and stored at 2 °C and RH of 85%. Three lots were taken at random after 0, 7, 14, 21 and 28 days of storage +1 day at 20 °C and RH of 70% for analytical determinations. Other lots of 100 fruits from each tree were selected from control and 1.0 mM MeSA treated trees to perform sensory analysis. In the 2014 experiment, the total fruit production, from each of the 10 treated or control trees, was recorded and yield expressed as kg per tree. From each tree, 3 lots of 100 fruits were taken at random and used to calculate fruit mass at harvest. Then 300 fruits, homogeneous in colour and size and without visual defects were selected for each cultivar from control and 1.0 mM MeSA treated trees and randomly grouped in 15 lots of 20 fruits for storage as in the 2013 experiment.

2.3. Fruit quality parameters

Colour was determined in each cheek of 20 fruits from each replicate by using a CR-200 chroma meter (Konica Minolta, Inc., Tokio, Japan), using the CIELab coordinates and expressed as the colour a*/b* index. Fruit firmness was determined independently in 20 fruits of each replicate using a TX-XT2i Texture Analyzer (Stable Microsystems, 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 ($N\,mm^{-1}$). After that, the 20 fruits of each lot or replicate were cut into small pieces to obtain a homogeneous sample for each replicate. TSS were determined in duplicate 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 $g\,100\,g^{-1}$. TA was determined in duplicate in the same juice by automatic titration (785 DMP Titrino, Metrohm AG, Herisau, Switzerland) with 0.1 N NaOH up to pH 8.1, using 1 mL of diluted juice in 25 mL of distilled H_2O, and results were expressed as g of malic acid equivalent $100\,g^{-1}$ of fresh weight.

2.4. Sensory analysis

The sensory analysis was performed in the 2013 experiment for the control and 1.0 mM MeSA treatment. Ten panellists, previously trained with commercial samples of sweet cherries of different cultivars, were asked to perform a sensory characterisation of the studied batches. From the 100 cherries harvested at the last sampling date from each tree (or replicate), cultivar and treatment, one sample of five fruits chosen at random was presented and evaluated for each panellist. Descriptive analysis was performed according to international standard methods (ISO 4121, 2003) to evaluate

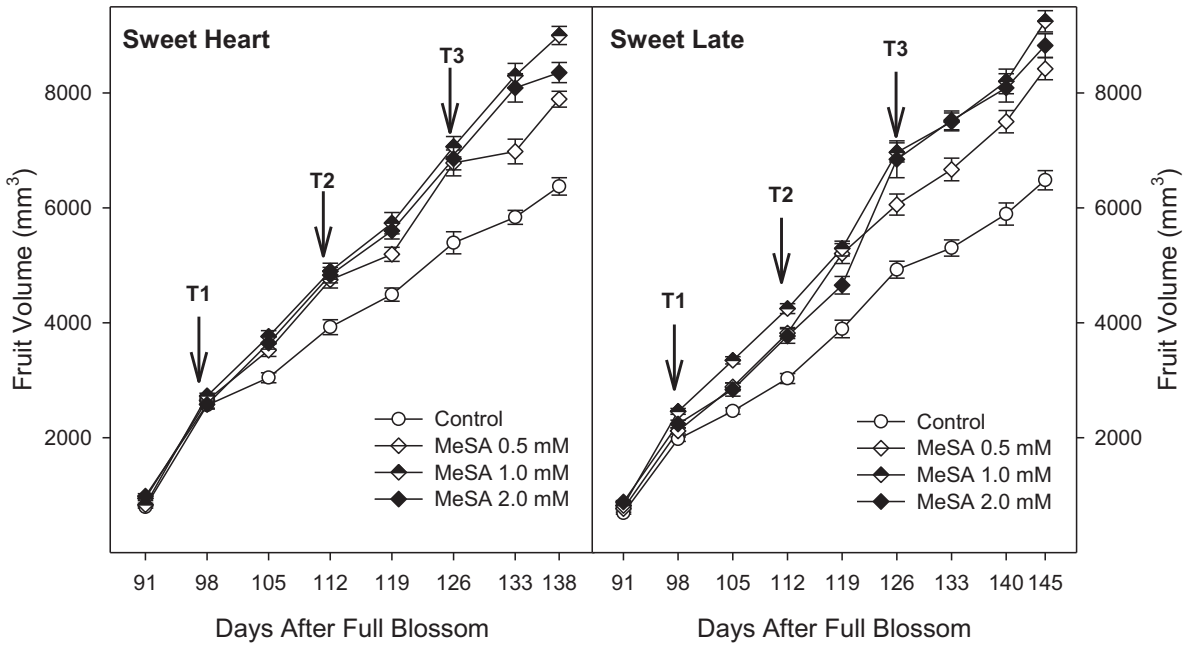

Fig. 1. Fruit volume (mm^3) in 'Sweet Heart' and 'Sweet Late' cultivars during on-tree fruit development as affected by methyl salycilate (MeSA) treatment at 0.5, 1.0 and 2.0 mM, in 2013 experiment. T1, T2 and T3 show the days of treatments. Data are the mean ± SE.

appearance, skin colour, sweetness, sourness, and firmness by using a numbered scale from 1 (poor) to 5 (excellent).

2.5. Statistical analysis

The experiments were conducted in a completely randomised design for each cultivar, either located in Jumilla ('Sweet Heart' and 'Sweet Late') or in Alicante ('Lapins'), or year. For the fruit growth and on-tree ripening experiments, the number of replicates were 3 and 10 in years 2013 and 2014, respectively. For the storage experiments, 3 replicates were used for both years. The dependent variables (fruit colour, firmness, fruit mass, kg $tree^{-1}$, TSS, TA and volume) were subjected to analysis of variance (ANOVA) and means were compared with the Fisher's protected Least Significant Difference (LSD) test at alpha = 0.05 or test at $P = 0.05$. The different experimental errors were calculated including the error between replicate trees, among fruits within the same tree, and among fruits within the same lot. In the case of the 2014 harvest data (fruit mass and kg $tree^{-1}$), the effect of treatment (fruit treated vs. control fruit) was studied using a Two-Sample T test considering equal or unequal variances according to the Folded F test. Finally, the data from sensorial analysis were analysed using the non-parametric Kruskal–Wallis test and mean ranks of cultivars were compared at $P = 0.05$ using Dunn's test. Data from all experiments were analysed using Statistix 10 (Analytical Software, Tallahassee, FL).

3. Results and discussion

3.1. Fruit growth on tree and crop yield

In the 2013 experiment, it was found that cherry fruit volume increased along development on tree, although it was generally higher in those cherries treated with the three MeSA concentrations for both cultivars, which were individually studied, the effect being evident from the first application (T1). Moreover, because there was significant ($P < 0.001$) effect of the interaction day × treatment in both cultivars, we separately studied the effect of treatment on fruit volume (mm^3) for each sampling date. Overall, the highest effect was obtained with the 1.0 mM dose, for which increases of fruit volume of 41 and 42% were achieved for 'Sweet Heart' and 'Sweet Late' cultivars, respectively, at the time of harvest (Fig. 1). A similar behaviour was observed when studying fruit mass curves (data not shown) with the final fruit mass at harvest time being significantly higher in all MeSA treated fruits than in controls (Table 1). The most prominent effect was obtained with the 0.5 and 1.0 mM MeSA treatments for the 'Sweet Heart' cultivar and with the 1.0 and 2.0 mM concentrations for the 'Sweet Late' one (Table 1). Based on the results of fruit volume and mass, the 1.0 mM dose was chosen to perform the experiment in the 2014. In this year, a significant ($P < 0.05$) increase of 12, 36 and 19% in mass was obtained for 1.0 mM MeSA treated 'Sweet Heart', 'Sweet Late' and 'Lapins' cultivars, respectively, with respect to controls (data not shown). However, total yield, expressed as kg of fruit per tree, was not affected ($P > 0.05$) by MeSA treatment, with production about 52, 35 and 27 kg per tree, for 'Sweet Heart', 'Sweet Late' and 'Lapins' cultivars, respectively.

Results show that MeSA treatments could improve the economic performance of this crop, since although the total yield was not modified, larger cherries were obtained, which are more appreciated by consumers and reach higher prices at markets compared to small ones. Accordingly, SA and ASA treatments of sweet cherry trees and SA treatment of peach tree (applied at three dates during the growth cycle) increased fruit mass without a significant effect on the total yield (Ali et al., 2014; Giménez et al., 2014; Hendricks et al., 2015). However, MeSA applied to pepper plants at the beginning of the flowering stage, led to fruits with an increased mass at harvest time, but in this case the total yield was also enhanced due to an increase of fruit number (Elwan and El-Hamahmy, 2009). This different behaviour could be attributed to the fact that in pepper plants, continuous flowering occurs along the growth cycle, while in sweet cherry trees a single flowering stage exists and treatments started 98 DAFB. Accordingly, in olive trees, foliar spray with SA increased fruit mass, size and yield due to an increase in both flower number and density, since treatments were performed one month before flowering (El-Razek et al., 2013). Thus, it could be interesting to investigate whether MeSA treatments applied to cherry trees before flowering, combined with treatments during fruit growth,

Table 1
Data at harvest time for fruit mass, total acidity (TA) and firmness of two sweet cherry cultivars treated with methyl salicylate (MeSA) during the 2013 experiment.

Cultivar	MeSA (mM)	Mass (g)	TA (g 100 g^{-1})	Firmness (N mm^{-1})
'Sweet Heart'	0	7.07 ± 0.12	1.59 ± 0.05	2.89 ± 0.09
	0.5	9.11 ± 0.30	1.53 ± 0.02	3.18 ± 0.10
	1.0	9.02 ± 0.15	1.69 ± 0.05	3.59 ± 0.08
	2.0	8.61 ± 0.07	1.72 ± 0.07	3.18 ± 0.08
'Sweet Late'	0	6.84 ± 0.17	1.35 ± 0.04	2.61 ± 0.09
	0.5	8.14 ± 0.16	1.40 ± 0.03	3.65 ± 0.12
	1.0	8.97 ± 0.20	1.48 ± 0.02	4.01 ± 0.13
	2.0	8.84 ± 0.30	1.43 ± 0.02	4.03 ± 0.13

Data are the mean ± SE.

would be able to increase the fruit number production by tree apart from the fruit size.

3.2. Fruit quality parameters evolution during fruit on-tree growth and ripening

In the 2013 experiment, the treatment, the DAFB, and their interaction affected ($P < 0.05$) the colour index (a*/b*) on both cultivars. For that, the effect of treatments was studied separately for each day. Overall, the colour index increased during development (Fig. 2), the evolution being retarded in MeSA treated cherries, from 112 to 133 DAFB and from 126 to 140 DAFB, for 'Sweet Heart' and 'Sweet Late', respectively. However, at the time of harvest sweet cherries of both cultivars treated with MeSA at 1.0 mM showed a significantly ($P < 0.05$) higher colour index compared to control ones, while no significant ($P > 0.05$) effect was obtained for 0.5 and 2.0 mM MeSA concentrations. With respect to TSS (Fig. 3), a continuous increase throughout growth and ripening was also observed for all control and treated fruits, although the 0.5 mM MeSA concentration induced a significant delay in TSS accumulation in both cultivars. However, at the time of harvest, 'Sweet Heart' treated cherries had a significantly ($P < 0.05$) higher concentration of TSS compared to controls ($\cong 18.9$ g 100 g^{-1}) for all the applied MeSA concentrations, the highest effect being found with the 1.0 or 2.0 mM MeSA concentration, for which TSS concentrations ca. 21 g 100 g^{-1} were reached. Similarly, TSS in 'Sweet Late' was higher in treated than in control fruits, the 1.0 mM MeSA treated cherries having significantly the highest content of TSS (20.25 ± 0.20 g 100 g^{-1}).

Similarly, TA increased along the growth cycle but without significant differences between control and treated cherries, and then just data at the last sampling date are provided for this quality parameter (Table 1). TA at harvest date was significantly ($P < 0.05$) higher in 1.0 and 2.0 mM MeSA 'Sweet Heart' treated cherries than in controls, while for 'Sweet Late' cultivar just 1.0 mM dose led to fruit with higher TA content. On the contrary, fruit firmness decreased along on-tree growth and ripening in both control and treated samples (data not shown), but at the time of harvest MeSA treatments on sweet cherry trees led to significantly higher fruit firmness for both cultivars, especially with the 1.0 mM for 'Sweet Heart' and with the 1.0 and 2.0 mM doses for 'Sweet Late' (Table 1). The increases in TSS and TA concentrations and in red colour intensity and decreases in firmness observed in 'Sweet Heart' and 'Sweet Late' cultivars during on-tree ripening are in agreement with previous reports on a wide range of sweet cherry cultivars (Serrano et al., 2005; 2009; Díaz-Mula et al., 2009; Serradilla et al., 2012). At harvest, 1.0 mM MeSA treatment led to cherry fruits with a higher a*/b* colour index, and thus these fruits would also have higher concentration of anthocyanins than control ones, since a close association between an increased a*/b* colour index and accumulation of anthocyanins has been reported for a wide range of cherry cultivars (Díaz-Mula et al., 2009; Serrano et al., 2009; Ballistreri et al., 2013). However, according to the technician's company and based on TSS and visual colour (using the CTIFL chart) harvest date was the same for all fruits (control and treated) although colour analytical determination with Minolta colorimeter (a more precise determination of colour parameter) revealed significant differences in colour, which is attributed to the treatments. Moreover, panellists did not find significant differences in colour between control and treated cherries (as will be commented below), in agreement with the technician's criterion. Similarly to colour, TSS and TA increased during development in control and treated fruits although at harvest the concentration of 1.0 mM MeSA led to fruits with significantly higher TSS content and TA than controls for both cultivars. It is interesting to point out that firmness levels at time of harvest were also significantly higher in cherries treated with all MeSA concentrations than in controls.

There is no available information about the effect of preharvest MeSA treatment on fruit quality parameters, although some evidences exist with its close analogue SA. For instance, preharvest treatment of oranges with SA (at 2, 4, 6 and 8 mM) increased fruit firmness and β-carotene and lycopene concentrations and reduced fruit rot at time of harvest (Huang et al., 2008; Ahmad et al., 2013). In table grapes, another non-climacteric fruit like sweet cherry, preharvest treatments with SA at 2 mM induced berries with higher firmness than controls at harvest time (Khalil, 2014). In these non-climacteric fruits the on-tree ripening process was not affected by SA treatments and both control and treated fruits were harvested at the same date. Accordingly, in the present experiments, no effect of the MeSA treatment on the date that cherry fruits reached their commercial ripening stage was observed, and control and treated fruits were harvested at the same date. However, in climacteric fruits such as peach preharvest application of SA (at 1, 2 and 3 mM) significantly delayed the on-tree ripening process due to the inhibition of ethylene production (Ali et al., 2014).

Thus, since the best results on improving cherry quality at time of harvest were obtained with the 1.0 mM dose, these fruits were then selected to analyse sensory properties at harvest time as well as the evolution of quality parameters during a prolonged cold storage period. With respect to sensory analysis, panellists gave significantly ($P < 0.05$) higher scores for appearance, sweetness and firmness to cherries treated with MeSA at 1.0 mM concentration as compared with control ones (Fig. 4), while scores for sourness and colour were not significantly ($P > 0.05$) different between control and treated fruits on both cultivars. These results are in agreement with those obtained for fruit size, TSS and firmness evaluated by objective instrumental analysis. In addition, no off-flavours were detected in sweet cherries from treated tress, showing that MeSA treatments had no effect on the characteristic fruit flavour.

3.3. Evolution of quality parameters along storage

Because there were significant interactions ($P < 0.05$) between the storage time and treatment (1.0 mM MeSA treated vs. untreated) on all cultivars for the different quality parameters, we studied the effect of MeSA treatment for each sampling date. At har-

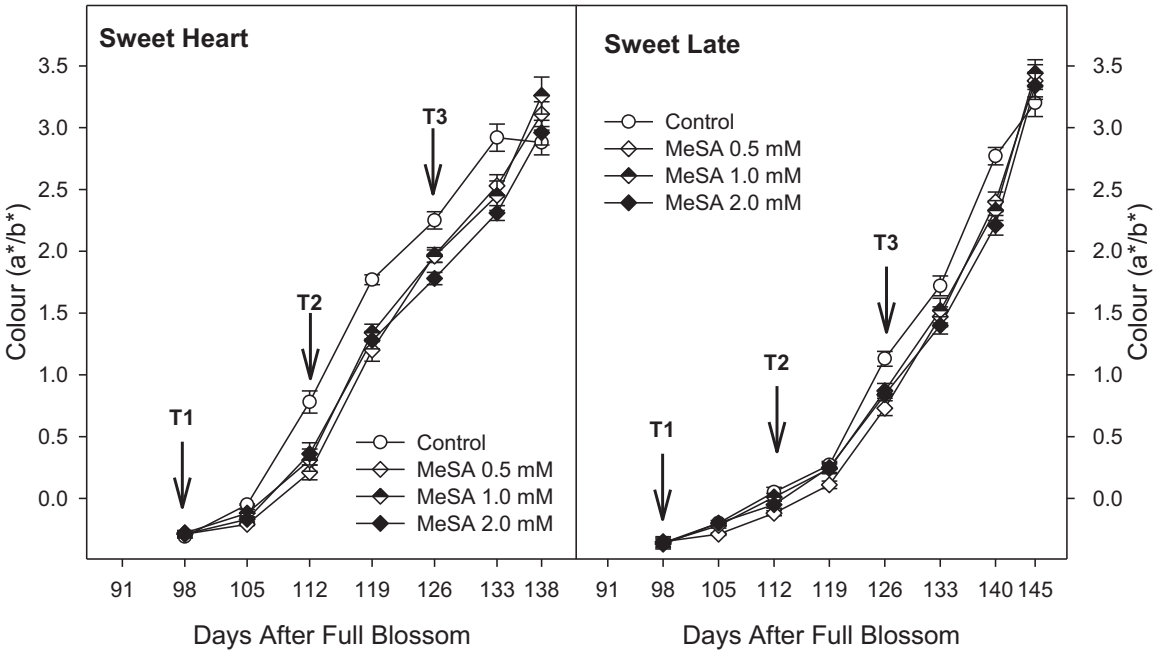

Fig. 2. Fruit colour index (a*/b*) in 'Sweet Heart' and 'Sweet Late' cultivars during on-tree fruit development as affected by methyl salycilate (MeSA) treatment at 0.5, 1.0 and 2.0 mM, in 2013 experiment. T1, T2 and T3 show the days of treatments. Data are the mean ± SE.

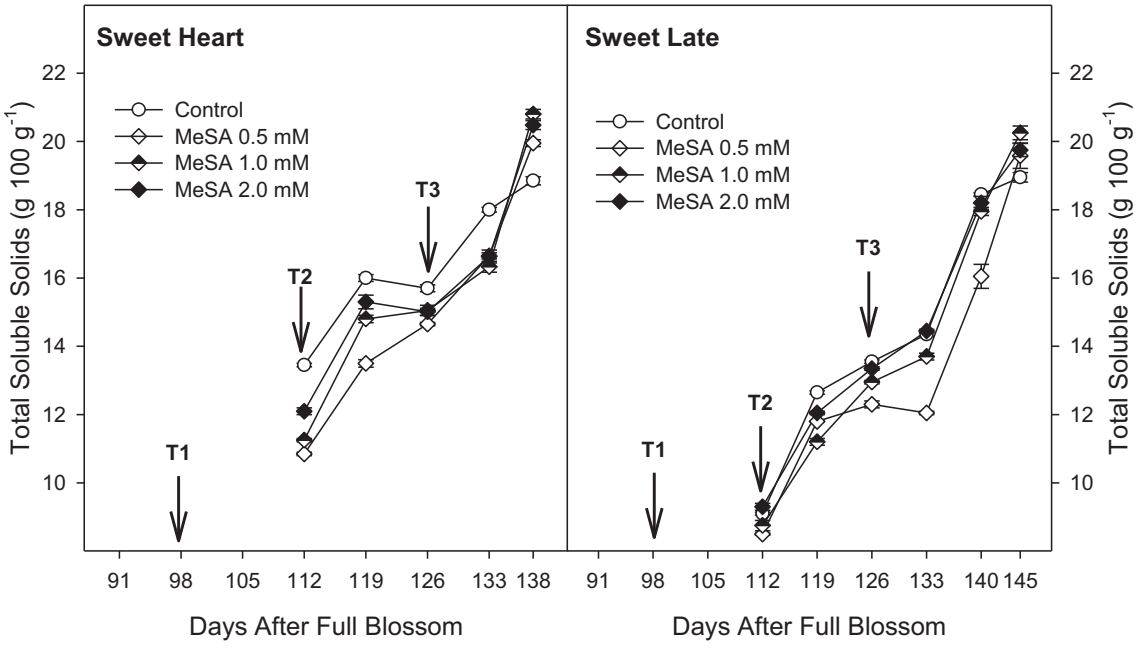

Fig. 3. Total soluble solids (TSS, g 100 g^{-1}) in 'Sweet Heart' and 'Sweet Late' cultivars during on-tree fruit development as affected by methyl salycilate (MeSA) treatment at 0.5, 1.0 and 2.0 mM, in 2013 experiment. T1, T2 and T3 show the days of treatments. Data are the mean ± SE.

vest, colour index (a*/b*) was significantly higher in treated than in control fruits (Fig. 5) for the three cultivars and both growing seasons, the differences being maintained after 28 days of storage at 2 °C +1 day at 20 °C. In addition, the colour index of control and treated fruits increased from day 0 until the end of storage. Similarly, the content of TSS was significantly higher ($P < 0.05$) in treated than in control fruits at harvest time for all cultivars and both growing seasons and generally, these differences were maintained until the end of storage (Fig. 6). During storage, TSS generally increased in the control and treated 'Sweet Heart' and 'Sweet Late' cultivars for both the 2013 and the 2014 experiments, while no changes were detected for 'Lapins' cultivar. On the contrary, TA significantly ($P < 0.05$) decreased in control and treated fruits for all cultivars and growing seasons during postharvest storage (Fig. 7), although acidity values were always higher in treated than in control cherries. On the other hand, fruit firmness also diminished throughout storage time for control and treated fruits, cultivars and growing seasons (Fig. 8). In addition, was always significantly ($P < 0.05$) higher in treated than in control cherries. Thus, MeSA treatment significantly retarded fruit softening leading to firmer cherries at the end of storage. Taking into account results of TA and firmness losses it could be inferred that the evolution of the postharvest ripening process

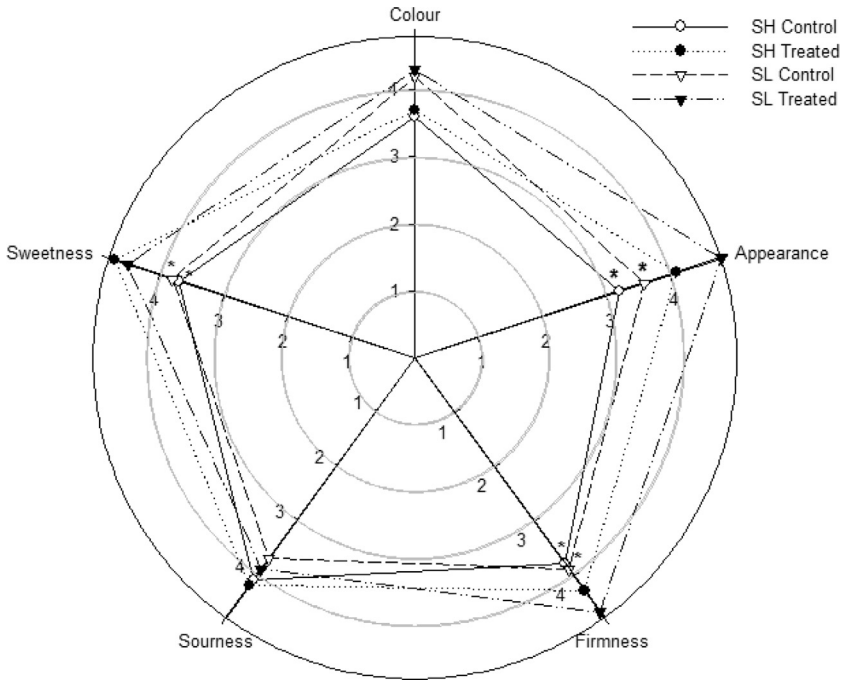

Fig. 4. Results from sensory analysis performed at harvest, in 2013 experiments, in 'Sweet Heart' (SH) and 'Sweet Late' (SL) fruits from control or 1.0 mM methyl salycilate (MeSA) treated trees. Scores for quality attributes ranked from 0 (poor) to 5 (excellent). Data are the mean ± SE.

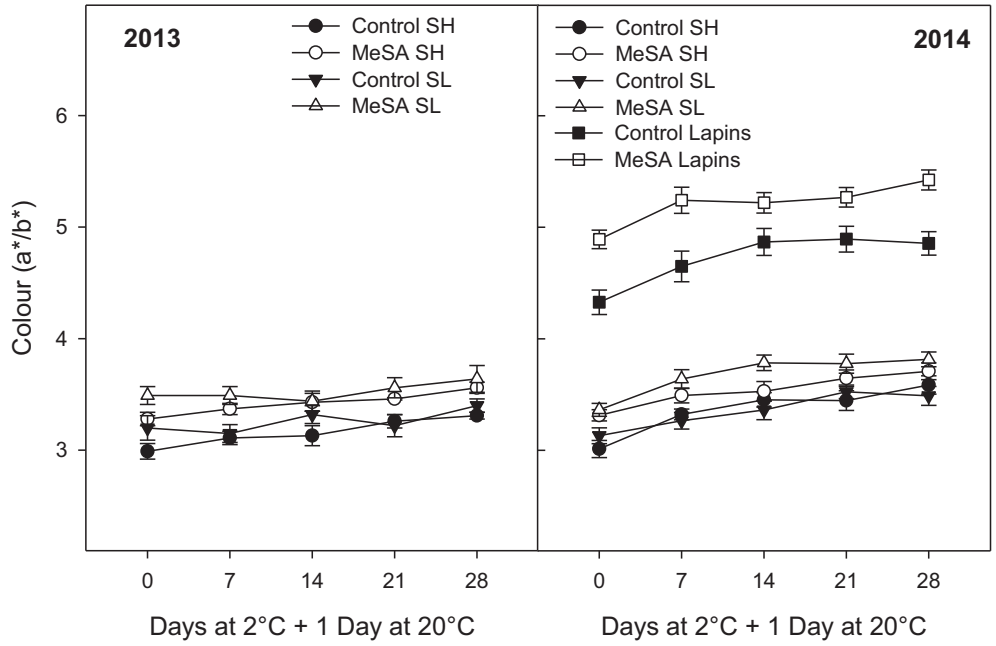

Fig. 5. Evolution of fruit colour (a*/b*) during storage for control and 1.0 mM methyl salycilate (MeSA) treated 'Sweet Heart' (SH), 'Sweet Late' (SL) and 'Lapins' sweet cherries, in 2013 and 2014 experiments. Data are the mean ± SE.

was delayed in MeSA treated cherries by 1–2 weeks with respect to control ones.

Postharvest storage of sweet cherries was accompanied by a significant increase in colour and TSS and a decrease in firmness and acidity, in agreement with previous reports in other sweet cherry cultivars (Serrano et al., 2009), although for TSS evolution important differences exist depending on cultivar and ripening stage at harvest. Thus, TSS slightly diminished in 'Ambrunes' (Alique et al., 2005), 'Sciazza', and 'Ferrovia' (Esti et al., 2002), remained unchanged in 'Van' (Bernalte et al., 2003), and increased in 'Burlat' (Remón et al., 2003) and in a wide range of cherry cultivars (Serrano et al., 2009). MeSA treatment to cherry trees had significant effects on quality parameters, since higher colour, TSS, TA and firmness were observed in treated cherries compared to controls at the time of harvest, and maintained higher during the storage period also. Thus, since these parameters are the most important quality attributes of sweet cherry and related with the flavour of freshly harvested fruit (Esti et al., 2002; Bernalte et al., 2003; Serrano et al., 2009) it can be inferred that MeSA treatment was effective on main-

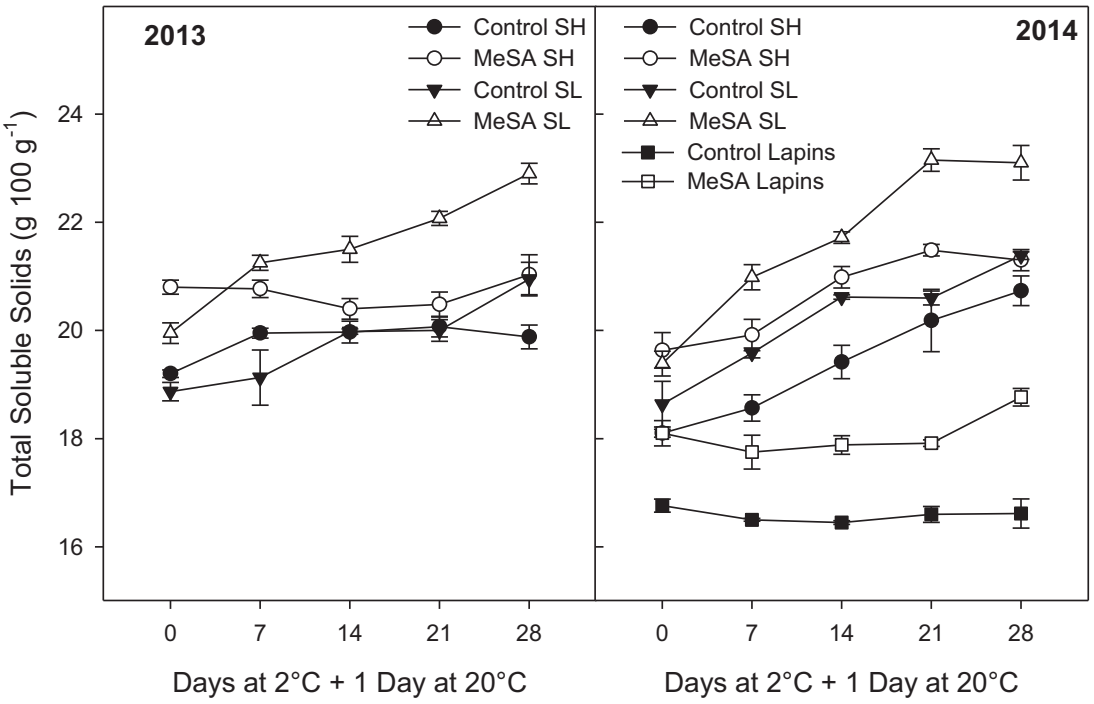

Fig. 6. Evolution of total soluble solids (TSS, g 100 g^{-1}) during storage for control and 1.0 mM methyl salycilate (MeSA) treated 'Sweet Heart' (SH), 'Sweet Late' (SL) and 'Lapins' sweet cherries, in 2013 and 2014 experiments. Data are the mean ± SE.

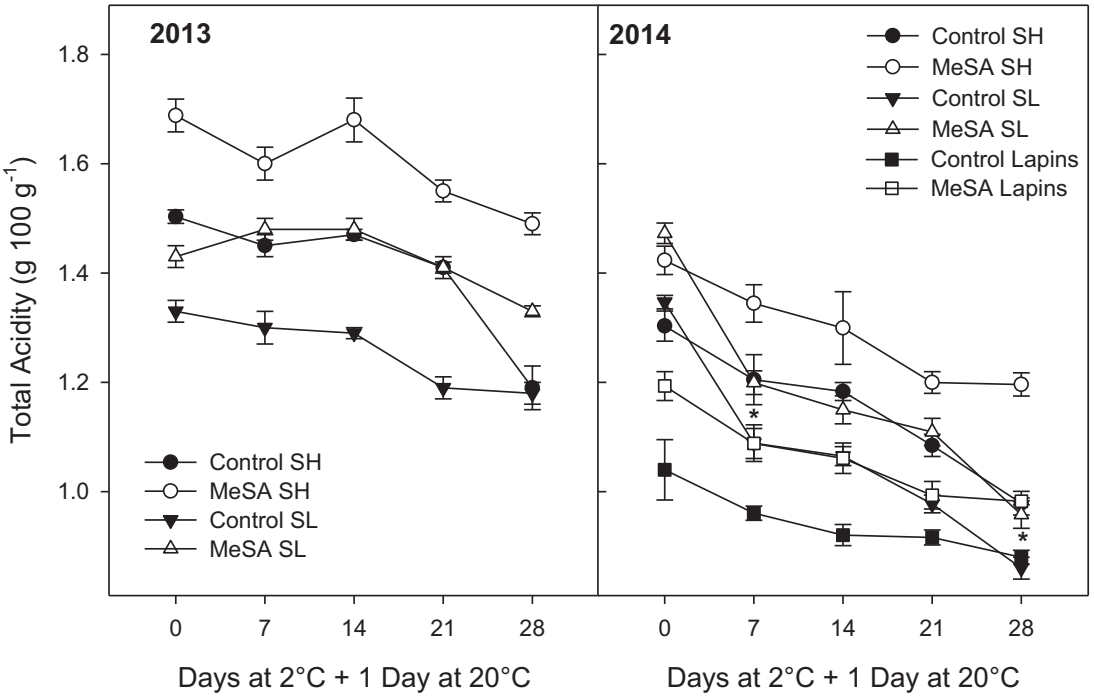

Fig. 7. Evolution of total acidity (TA, g 100 g^{-1}) during storage for control and 1.0 mM methyl salycilate (MeSA) treated 'Sweet Heart' (SH), 'Sweet Late' (SL) and 'Lapins' sweet cherries, in 2013 and 2014 experiments. Data are the mean ± SE.

taining cherry quality properties demanded by consumers by more than one week as compared to control cherries.

No literature exits about the effect of preharvest MeSA treatment on fruit quality evolution during storage for comparative purposes, and little information exists about the effect of postharvest MeSA treatment. Thus, in sensitive fruit to CI, such as pomegranate (Sayyari et al., 2011) and mango (Han et al., 2006), postharvest MeSA alleviated CI symptoms and reduced softening. In the case of pomegranate, MeSA also led to higher concentrations in antioxidant compounds (total phenolics and anthocyanins) and antioxidant capacity (Sayyari et al., 2011). In tomato fruits, the effect of postharvest MeSA treatments was depending on the ripening stage, since at turning stage retarded the ripening process, while acceleration was observed at mature green stage (Ding and Wang,

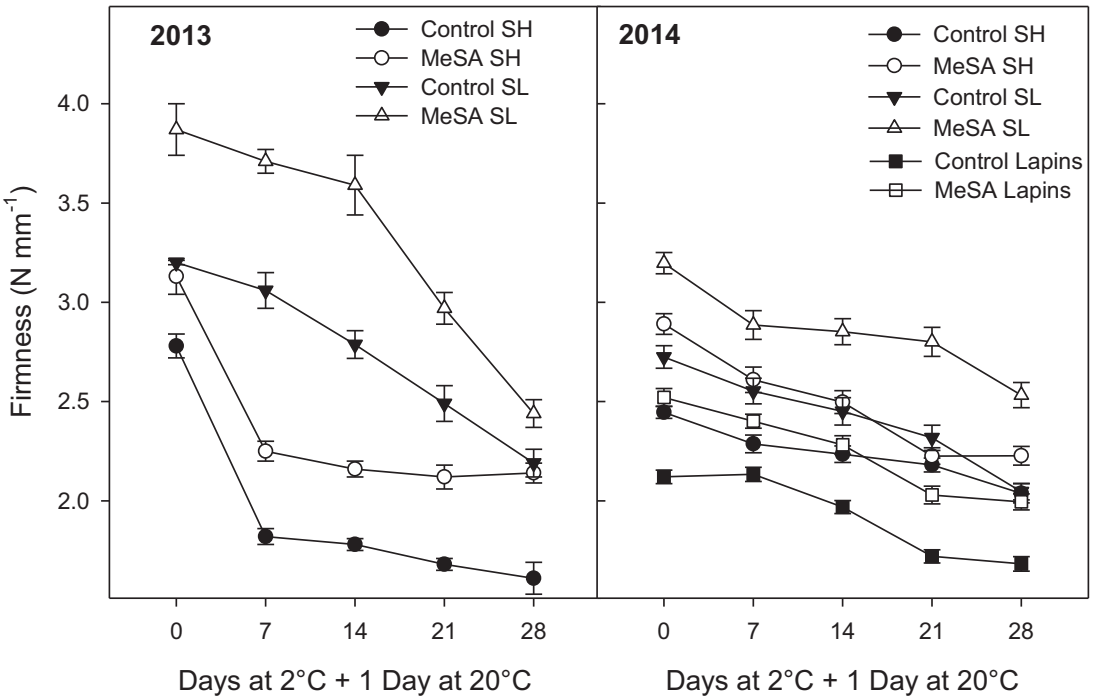

Fig. 8. Evolution of fruit firmness (N mm^{-1}) during storage for control and 1.0 mM methyl salycilate (MeSA) treated 'Sweet Heart' (SH), 'Sweet Late' (SL) and 'Lapins' sweet cherries, in 2013 and 2014 experiments. Data are the mean ± SE.

2003). By other hand, preharvest treatment of orange trees with SA at 8 mM maintained higher TA and firmness in orange fruits during storage (Ahmad et al., 2013). In table grape, preharvest treatment with SA at 2 mM maintained higher firmness and delayed berry ripening during 15 or 30 days of storage. Moreover, the combination of preharvest and postharvest SA was more effective in maintaining table grape quality than pre- or post-harvest treatment alone, since berries had improved firmness, lower mass loss and better appearance of both berries and rachis after long storage time (Khalil, 2014). Postharvest SA treatment also maintained higher firmness in sugar apple (Mo et al., 2008) and peach (Wang et al., 2006) during cold storage. Specifically in sweet cherry, postharvest treatments with SA or ASA delayed the loss of firmness and acidity in two cultivars ('Cristalina' and 'Prime Giant') with a net increase of the shelf life period (Valero et al., 2011). The mechanism by which MeSA delays the postharvest ripening process in sweet cherries is still unknown, although it could be related to a delay in the postharvest ripening process due to an increase of the endogenous levels of SA induced by the MeSA treatment. In this sense, the ripening process in kiwifruit correlated with a decrease in endogenous SA levels, and the application of ASA increased endogenous levels of SA and delayed changes associated with ripening and senescence such as softening, lipoxygenase activity and associated superoxide free radical production (Zhang et al., 2003). Moreover, in sweet cherry it has been found that the activity of the antioxidant enzymes catalase (CAT), peroxidase (POD), ascorbate peroxidase (APX) and superoxide dismutase (SOD) was higher in fruit treated with MeSa than in controls (Valverde et al., 2015), which could be responsible for the delay in senescence process observed in cherries from MeSA treated trees. On the other hand, both preharvest and postharvest application of SA induced sweet cherry resistance to postharvest decay caused by *Monilinia fructicola* (Yao and Tian, 2005) and *Penicillium expansum* (Xu and Tian, 2008). In our case, no symptoms of decay were observed in control or treated fruits throughout the storage period, neither in the 2013 nor in the 2014 experiments and then, the possible effect of MeSA treatment on inducing fruit resistance to microbial decay could not be evaluated.

4. Conclusion

In conclusion, an improvement of cherry fruit quality by MeSA tree treatments was obtained at harvest, since the parameters related to the consumer's acceptance of sweet cherry (mainly size, colour, firmness and TSS content) were enhanced. In addition, the postharvest ripening process was delayed in fruits from treated trees and important quality parameters, such as TA and firmness were maintained at higher levels in treated fruits during postharvest storage. Thus, taking into account that MeSA is a naturally occurring substance considered as GRAS (generally recognised as safe), preharvest treatments with 1.0 mM MeSA at key dates of sweet cherry developmental stages could be considered as a safe and environmentally friendly tool to improve fruit quality at time of harvest and during storage. In the future, the impact of these treatments on bioactive compounds and antioxidant activity deserves further research studies.

Conflict of interest

Authors declare that they have no conflicts of interest.

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