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Methyl jasmonate effects on table grape ripening, vine yield, berry quality and bioactive compounds depend on applied concentration

María E. García-Pastor[a], María Serrano[b,*], Fabián Guillén[a], Salvador Castillo[a], Domingo Martínez-Romero[a], Daniel Valero[a], Pedro J. Zapata[a]

[a] Department of Food Technology, EPSO, University Miguel Hernández, Ctra. Beniel km 3.2, 03312, Orihuela, Alicante, Spain
[b] Department of Applied Biology, EPSO, University Miguel Hernández, Ctra. Beniel km 3.2, 03312, Orihuela, Alicante, Spain

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ABSTRACT

In the present research the effect of preharvest metyil jasmonate (MeJA) treatment on the ripening process and fruit quality parameters at harvest was evaluated, for the first time, in two table grape cultivars, 'Magenta' and 'Crimson', during two years, 2016 and 2017. MeJA treatments (applied when berry volume was ca. 40% of its final one, at veraison and 3 days before the first harvest date) affected grape ripening process and vine yield differently depending on applied concentration. Thus, MeJA at 5 and 10 mM delayed berry ripening and decreased berry weight and volume as well as vine yield, in a dose-dependent way, in both cultivars, although the effect on 'Crimson' was more dramatic than in 'Magenta'. However, treatments with MeJA at 1, 0.1 and 0.01 mM accelerated ripening and increased total phenolics and individual anthocyanin concentrations, the major effects being obtained with 0.1 mM concentration. In addition, total soluble solids (TSS) and firmness levels were also increased by these MeJA treatments. These results might have a great agronomic and commercial importance since fruit with higher size and harvested earlier would reach higher prizes at markets and berries with higher firmness and TSS would be more appreciated by consumers. Moreover, MeJA treatments increased the content of antioxidant compounds, such as phenolics and individual anthocyanins, leading to enhance the homogeneous pigmentation of the whole cluster, with additional effects on increasing the health beneficial effects of grape consumption.

1. Introduction

Table grape (*Vitis vinifera* L.) is considered one of the most appreciated fruit around the world, the Spanish production being 399,144 tons in 2017 (MAPA, 2017). Table grape marketing value depends on cluster size and shape as well as on berry size, colour, juiciness, sugar/acidity ratio and aroma. Veraison is a key point of berry development, in which pigmentation of skin starts (due to synthesis of anthocyanins in red cultivars), sugars and aroma compounds increase and acid content and firmness decrease, while berry growths until the end of ripening (Kuhn et al., 2014). However, some seedless red skin cultivars, such as 'Magenta' and 'Crimson' in spite of having very good taste and aroma have a heterogeneous berry pigmentation in the cluster, probably due to the high temperatures in the Southeast of Spain during berry ripening, which prevent proper colour development (Ferrara et al., 2015), leading to diminution of their market quality. In this sense, abscisic acid (ABA) and ethephon (an ethylene- releasing compound) treatments at veraison stage have been shown to increase skin anthocyanin concentration although most of these studies have been performed with wine grape cultivars (Marzouk and Kassem, 2011; Kuhn et al., 2014). Specifically, in 'Crimson Seedless' ABA and sucrose treatments improved table grape coloration allowing earlier harvest (Ferrara et al., 2015; Olivares et al., 2017), as well as regulated deficit irrigation applied during post-veraison stage, due to increases in anthocyanin concentration in berry skin (Conesa et al., 2016). However, the high cost of ABA reduces its practical application and the effects of ethephon on colour development are inconsistent and can cause berry softening. Therefore, more research is needed to find out other compounds with commercial application possibilities.

Jasmonic acid (JA) and its volatile derivative methyl jasmonate (MeJA), known as jasmonates (JAs), are considered as hormones acting in the regulation of a wide range of physiological processes in plants, including growth, photosynthesis, reproductive development and responses to abiotic and biotic stresses (Creelman and Mullet, 1997; Dar et al., 2015). Nevertheless, the most studied effect of these compounds has been their role as elicitors or signalling agents triggering the plant

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* Corresponding author.
E-mail address: m.serrano@umh.es (M. Serrano).

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defence responses against herbivores and pathogens' attacks (Wasternack, 2014). In this sense, post- and preharvest MeJA treatments of table grape and wine grape cultivars, respectively, primes defence responses, leading to increase disease resistance against *Botrytis cinerea*, the major postharvest disease that limits table grape storage (Jiang et al., 2015; Jia et al., 2016). However, in recent years it has been also reported that JAs, applied as pre- or postharvest treatments, have also effects on fruit ripening and quality parameters at harvest and during storage (Serrano et al., 2018).

Currently, most of the knowledge about MeJA effects on fruit quality attributes and ripening is derived from postharvest treatments. Thus, it has been reported that postharvest MeJA treatments have effects on reducing a wide range of stress-induced injuries during the postharvest period, such as chilling injury (CI), infection by some pathogens, and mechanical damage among others (Peña-Cortés et al., 2005; Sayyari et al., 2011; Wang et al., 2015). In addition, it has been reported that postharvest treatments with MeJA promote climacteric fruit ripening by increasing ethylene production in fruit such as peach, mango, tomato, apple and plum and even in non-climacteric fruit such as strawberry (Peña-Cortés et al., 2005; Serrano et al., 2018). However, papers about the effect of preharvest MeJA treatments on fruit growth and ripening on tree, and on fruit quality parameters at harvest are more limited and different results have been obtained depending on applied concentration, fruit species and developmental stage at which treatments were performed. For instance, in peach, MeJA 0.4 mM applied at S3 stage delayed fruit ripening throughout down-regulation of crucial ripening-related genes (Ziosi et al., 2008), while this process was accelerated with MeJA 10 mM treatments applied at the same development stage (Janoudi and Flore, 2003). MeJA treatments, at 5, 10 and 20 mM, to apple trees at early developmental stage delayed the ripening process, while this process was accelerated when MeJA was applied at the latest developmental stages (Rudell et al., 2005). On the other hand, a delay in the ripening process was found in 'Black Splendor' and 'Royal Rosa' plum cultivars with MeJA treatment at 0.5 mM applied at three key points of fruit development, while no effect was observed when 1 and 2 mM MeJA doses were applied (Martínez-Esplá et al., 2014).

Specifically, in wine grapes, several reports have shown that MeJA treatments to vineyard led to increase phenolic content, mainly anthocyanins, flavonols and stilbenes, on grape and wine although huge differences between growing season and varieties were found (Portu et al., 2015, 2016, 2018a; Gómez-Plaza et al., 2017). Nevertheless, no information is available in these papers regarding the effects of MeJA treatments on grape ripening process. Only in a recent paper, a 10-days delay on the technological maturity (ºBrix and pH) as a consequence of MeJA vineyards treatment has been reported in the wine variety 'Sangiovese' (D'Onofrio et al., 2018).

However, as far as we know, no information is available about the effects of preharvest MeJA treatments on table grape and just in one recent paper the effect of postharvest MeJA treatment has been evaluated, showing an increase in antioxidant activity and total phenolic and anthocyanin concentrations in 'Red Globe' cultivar (Flores et al., 2015). Thus, the aim of this research was to evaluate the effects of MeJA treatments on two table grape cultivars, 'Magenta' and 'Crimson', mainly focused to increase anthocyanin content in these poor-coloured cultivars.

2. Materials and methods

2.1. Plant material and experimental design

This study was performed during two growing seasons (2016 and 2017) with two different *Vitis vinifera* L. seedless table grape cultivars, 'Magenta' and 'Crimson', which were 7 and 10 years old, respectively and planted 2.5 x 3 m in a sandy soil in a commercial orchard in Calasparra (Murcia, Spain). MeJA (purchased from Sigma-Aldrich, Madrid Spain, CAS Number 39924-52-2) treatments were performed by foliar spray application of 1.5 L per vine of 1, 5 and 10 mM MeJA in 2016 and 0.01, 0.1 and 1 mM MeJA in 2017, containing 0.5% Tween 20 as surfactant. Treatments were made early in the morning and during favourable weather conditions where rainfall or winds were not forecasted for the following 24 h. Control vines were sprayed with 0.5% Tween 20 aqueous solution. MeJA treatments were applied three times, the first one when berry volume was ca. 40% of its final one, the second one at veraison stage and the third one 3 days before the first harvest date (Table 1). Pruning, thinning, fertilization and irrigation were carried out during the experiments according to standard cultural practices for table grape. A completely randomized block design with three replicates of three vines for each treatment, cultivar and year was set up.

Table 1
Dates of methyl jasmonate (MeJA) treatments (T1, T2 and T3) of 'Magenta' and 'Crimson' cultivars.

	'Magenta'		'Crimson'	
Treatment	2016	2017	2016	2017
T1	24th June	27th June	23rd June	26th June
T2	8th July	18th July	9th July	12th July
T3	18th July	21st July	25th July	28th July

2.2. Determination of vine yield

Clusters were harvested when berries reached the characteristic size, colour and soluble solid content (°Brix) of each cultivar in order to pick up full mature grapes, so that for both cultivars and years four harvests were performed and production of each vine (kg vine^{-1}) was measured for each harvest date. Vine production was expressed as accumulated yield (kg vine^{-1}) until the last harvest date (mean ± SE of three replicates of three vines).

2.3. Fruit quality parameters

Berry volume and weight were measured in three replicates of 60 berries (20 berries from each vine) taken at random from the clusters harvested at dates indicated in Fig. 4 legend. After that, 30 berries from each replicate (10 berries from each vine) were used to measure individually in each one colour (by using a Minolta colorimeter, CRC200, Minolta Camera Co., Japan, and expressed as L*, a* and b* parameters) and firmness (by using a TX-XT2i Texture Analyzer, Stable Microsystems, Godalming, UK, to measure the force that achieved a 5% deformation of the berry diameter and expressed as N mm^{-1}). Data of colour and firmness are the mean ± SE of three replicates of 30 berries. Then, the 30 berries of each replicate were cut and ground to obtain a homogeneous juice sample in which total soluble solids (TSS) were determined in duplicated 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 was determined also in duplicated in the same juice by automatic titration (785 DMP Titrino, Metrohm) with 0.1 N NaOH up to pH 8.1 and results (mean ± SE) expressed as g tartaric acid equivalent 100 g^{-1} fresh weight.

2.4. Total phenolics and individual anthocyanin quantification

The remaining 30 berries from each replicate (10 berries from each vine) were cut in small pieces and ground under liquid N_2 and stored at −80 °C until total phenolics and individual anthocyanins were quantified. Total phenolics were extracted as previously reported (Martínez-Esplá et al., 2014) by using 5 g of berry tissues and 10 mL of water:methanol (2:8) containing 2 mM NaF (to inactivate polyphenol oxidase activity and prevent phenolic degradation) and after centrifugation at

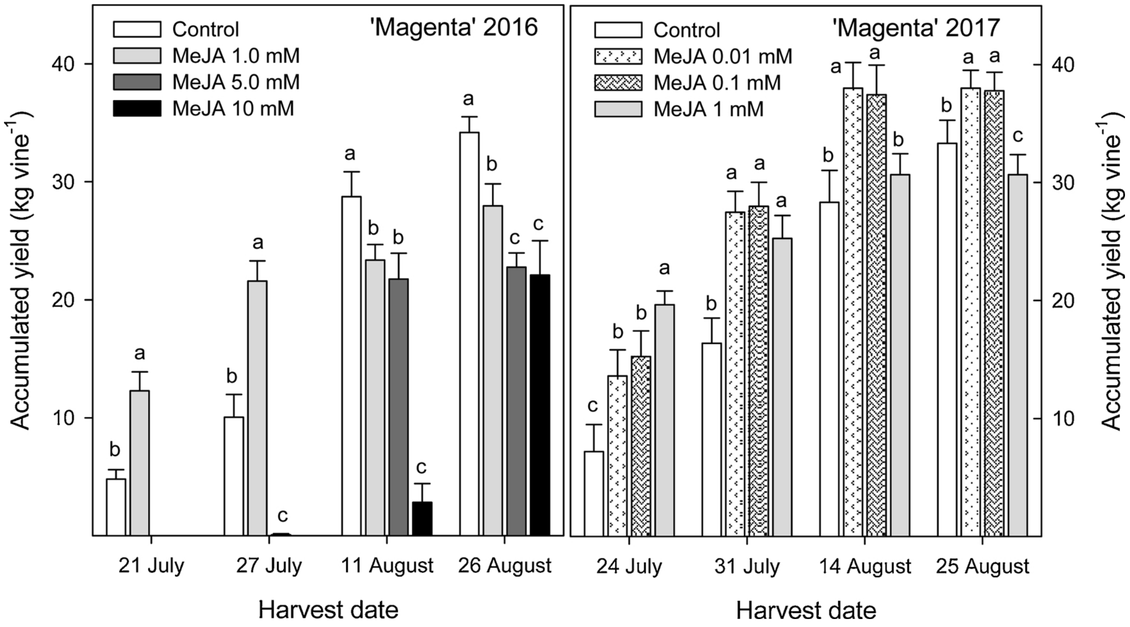


Fig. 1. Accumulated yield in 'Magenta' control and MeJA treated vines in 2016 and 2017 experiments. Data are the mean ± SE of three replicates of three vines for each treatment and cultivar. Different letters show significant differences ($P < 0.05$) among treatments for each harvest date.

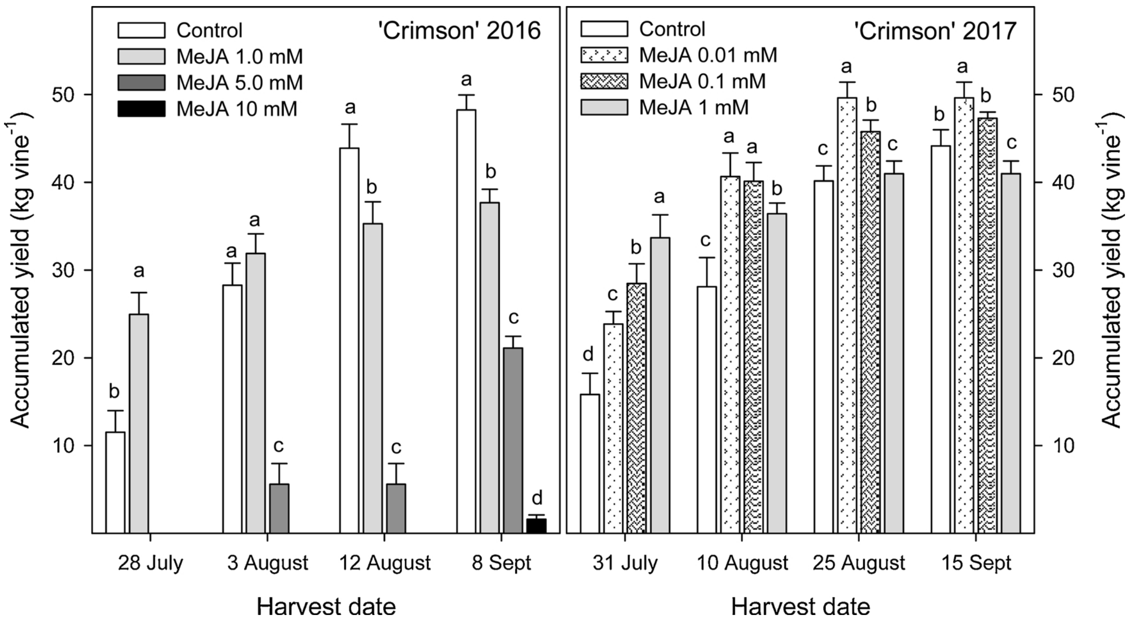


Fig. 2. Accumulated yield in 'Crimson' control and MeJA treated vines in 2016 and 2017 experiments. Data are the mean ± SE of three replicates of three vines for each treatment and cultivar. Different letters show significant differences ($P < 0.05$) among treatments for each harvest date.

10,000 *g* for 15 min phenolics were quantified in the supernatant using the Folin-Ciocalteu reagent and results (mean ± SE) were expressed as mg gallic acid equivalent 100 g^{-1} fresh weigh.

To extract anthocyanins 10 g of frozen berry tissues and 15 mL of methanol/formic acid/water (25:1:24, v/v/v) were manually ground in a mortar and pestle and then sonicated in an ultrasonic bath for 60 min and after that centrifuged at 10,000*g* for 15 min. The supernatant was filtered through a 0.45 µm PVDF filter (Millex HV13, Millipore, Bedford, MA, USA) and used for individual anthocyanin quantification by HPLC analysis as previously reported (Martínez-Esplá et al., 2014). Chromatograms were recorded at 520 nm. Anthocyanin standards were: malvidin 3-glucoside purchased from Sigma-Aldrich, Germany and cyanidin 3-rutinoside and pelargonidin 3-rutinoside purchased from Polyphenols SA (Sandnes, Norway) and results were mean ± SE.

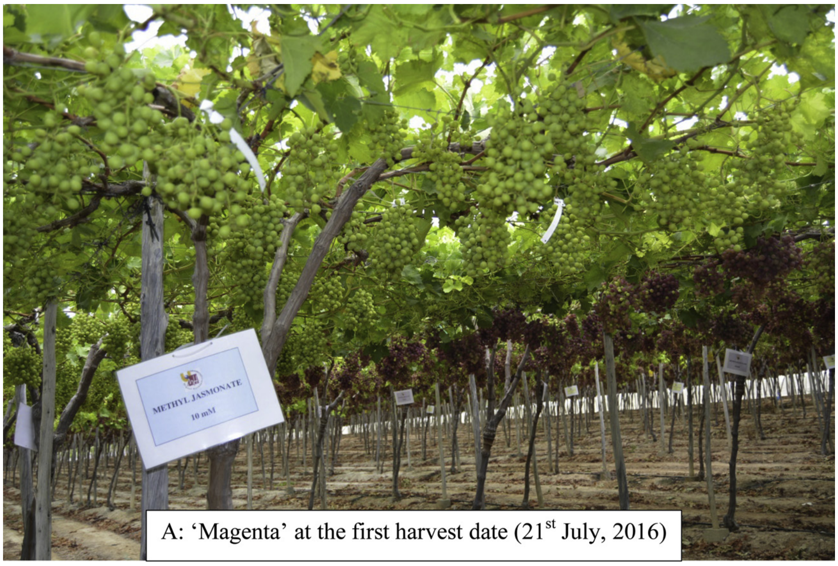
2.5. *Statistical analysis*

A one-way analysis of variance (ANOVA) was performed with data from analytical determinations for each cultivar and year by using the SPSS software package v. 12.0 for Windows. Mean comparisons were performed using HSD Duncan's test to examine if differences were significant at $P < 0.05$

3. Results and discussion

3.1. *Grape ripening and vine yield*

MeJA treatments affected grape ripening process and vine yield differently depending on applied concentration. Clusters were



A: ‘Magenta’ at the first harvest date (21st July, 2016)

B: ‘Crimson’ at the first harvest date (28th July, 2016)

Fig. 3. Photographs showing the visual aspect of 10 mM MeJA treated table grapes at the first harvest date in 2016 experiment, the 21st of July and 28th July for ‘Magenta’ and ‘Crimson’ cultivars, respectively.

harvested when grapes reached the size, colour and soluble solid content characteristic of each cultivar, according to commercial practices. Thus, in the experiment performed in 2016, MeJA 1 mM treatment accelerated the berry ripening process in both cultivars, since accumulated vine yield was higher than in control vines at the first and second harvest dates, while a delay in the ripening process was observed for grapes treated with MeJA 5 and 10 mM, this effect being dose dependent (Figs. 1 and 2). For instance, in ‘Magenta’ treated with MeJA 10 mM the ripening process was delayed for three weeks, since the first grapes reaching the commercial ripening stage (just 2.6 kg vine^{-1}) were harvested at August the 11st while in control vines ca. 29 kg vine^{-1} had ripened and had been harvested by this date. However, the effect of MeJA 10 mM on inhibiting the ripening process was even higher in ‘Crimson’ cultivar, since the first clusters were harvested at the last harvest date, that is, five weeks later than control grapes (Fig. 2). In Fig. 3 it can be observed the green colour of ‘Magenta’ and ‘Crimson’ 10 mM treated grapes at the first harvest date while some of the cluster from control and 1 mM treated vines of both cultivars had reached the red colour characteristic of commercial harvest. In addition, MeJA treatments at 1, 5 and 10 mM decreased total yield in both cultivars, the effect being dose-dependent and higher in ‘Crimson’ than in ‘Magenta’ cultivar. Thus, total yield in control vines was 34.18 ± 1.33 and 48.25 ± 1.68 kg vine^{-1} in ‘Magenta’ and ‘Crimson’ cultivars, respectively, and significantly lower, 22.09 ± 2.9 and 1.59 ± 0.51 kg vine^{-1}, in those treated with MeJA 10 mM.

In the view of these results, treatments with MeJA at 1, 0.1 and 0.01 mM were applied in 2017 and all of them accelerated grape ripening since at the first harvest date more kg of grapes were harvested from all MeJA-treated vines with respect to controls, the effect being significantly higher as increased MeJA concentration from 0.01 to 1 mM. Nevertheless, as in 2016 experiment, MeJA 1 mM decreased vine total yield. However, concentrations of 0.01 and 0.1 mM increased total yield with respect to control vines, without significant differences between both doses (Figs. 1 and 2). Not only MeJA treatments affected vine yield but also berry size and weight since both were reduced by 1, 5 and 10 mM MeJA treatments, in both cultivars, and in a dose

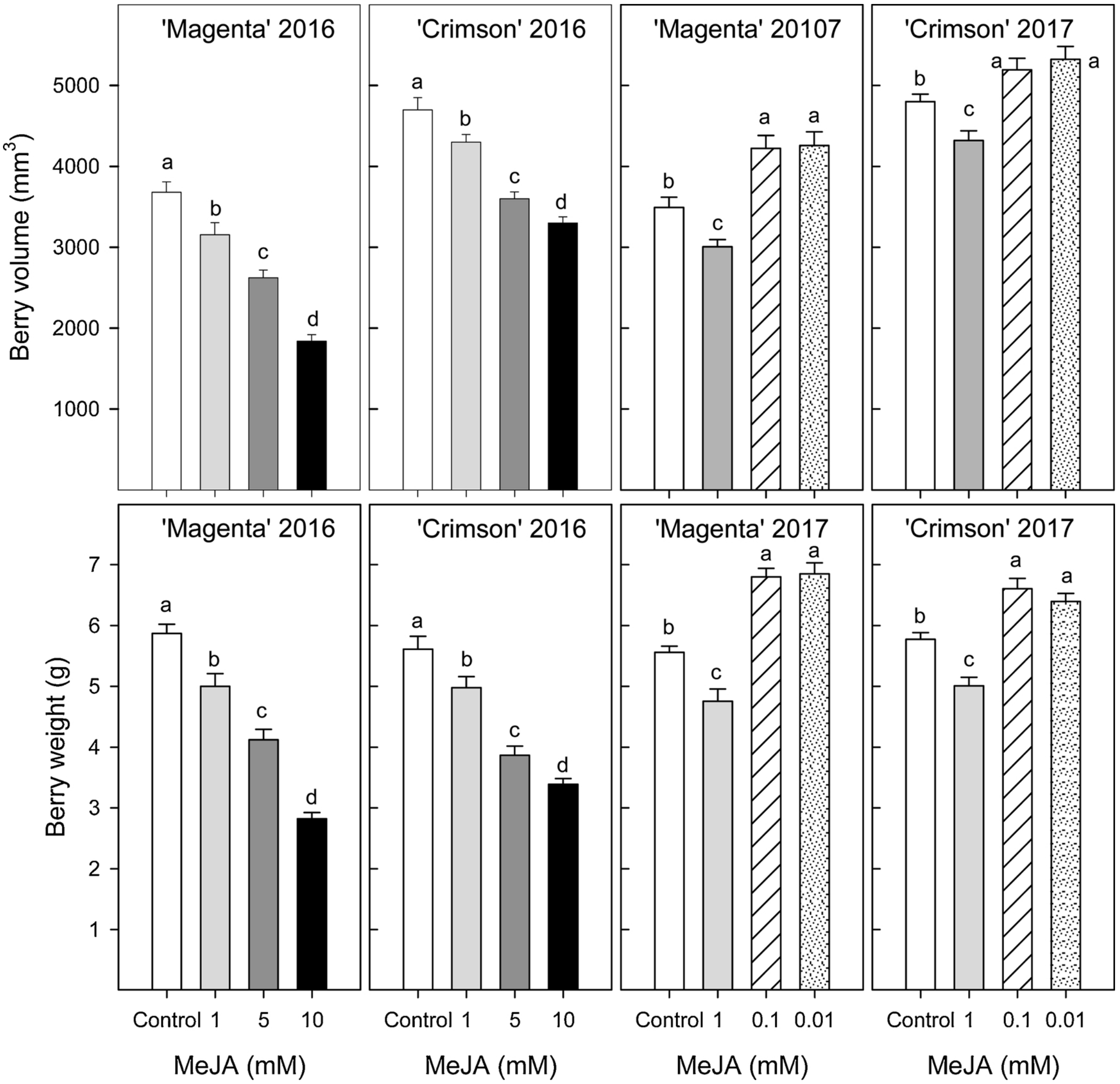


Fig. 4. Effect of vine MeJA treatments on berry volume and weight. Data are the mean ± SE of three replicates of 60 berries (20 berries from each vine) from the 1st harvest for control and MeJA 1 mM and from the 3rd harvest from MeJA 5 and 10 mM for 'Magenta' 2016. For 'Crimson' 2016 data are mean ± SE of three replicates of 60 berries (20 berries from each vine) for the 1st harvest for control and MeJA 1 mM, from the 2nd harvest for MeJA 5 mM and from the 4th harvest for MeJA 10 mM. For 2017 experiment, data are the mean ± SE of three replicates of 60 berries (20 berries from each vine) from the first harvest date for both cultivars and all treatments. Different letters show significant differences ($P < 0.05$) among treatments.

dependent way while increases in size and weight were obtained with 0.1 and 0.01 mM treatments (Fig. 4). Thus, the effects of MeJA treatments on vine yield were due to their effects on berry size which were different depending on applied concentration, without affecting the number of berries per cluster. In fact, cluster thinning was performed according to cultural practices before the MeJA treatments started, so that all clusters were left with similar size and number of berries and no shattering was observed during grape development on vine in control or treated clusters.

The effect of MeJA on fruit size has been published in a limited number of papers and contradictory results have been observed depending on fruit species, applied doses and fruit development stage. Thus, in agreement with the present results, MeJA treatments at 5, 10 or 20 mM of 'Fuji' apples trees at 48 days after full blossom reduced fruit size and weight due to inhibition of cell expansion or elongation (Rudell et al., 2005). However, by using lower concentration, increases in fruit weight and volume were obtained by preharvest 0.5 mM MeJA treatments in 'Black Splendor' and 'Royal Rosa' plum (Martínez-Esplá et al., 2014). On the other hand, a single treatment of peach with 0.8 mM MeJA at 56 DAFB (S2 stage) or 0.2 mM applied at S3 stage did not affect fruit diameter or weight at harvest (Ziosi et al., 2008; Ruiz et al., 2013).

In a similar way, the effect of MeJA treatments on table grape ripening was different depending on the applied concentration, that is, strong inhibition at 10 mM and acceleration at lower doses, mainly at 1 and 0.1 mM. These differences on berry colour between control and 0.1 mM MeJA treated grapes for both cultivars can be observed in Fig. 5. Accordingly, 0.01 and 0.1 mM MeJA treatments of 'Fujiminon' wine grape cultivar induced berry colouring, softening and synthesis of aroma compounds and, in turn, acceleration of the ripening process by increasing the expression level of a series of fruit colouring, cell-wall hydrolysis and aroma metabolism-related genes (Jia et al., 2016). On the other hand, (D'Onofrio et al., 2018) have recently reported that the application of MeJA 10 mM to 'Sangiovese' wine grape cultivar at the lag phase (EL 34) and 5 and 10 days later (EL 35 or veraison) slowed down the berry ripening process delaying by 10 days the technological maturity. However, this effect has not found in several wine cultivars such as 'Tempranillo', 'Monsatrell', Syrah', 'Merlot' or 'Graciano', treated with 10 MeJA at veraison and 3 and/or 6 days later (Portu et al., 2015, 2018a, 2018b; Gómez-Plaza et al., 2017). In all these previously

A: ‘Magenta’ control at the first harvest date (24th July, 2017)

B: ‘Magenta’ 0.1 mM MeJA at the first harvest date (24th July, 2017)

C: ‘Crimson’ control at the first harvest date (31st July, 2017)

D: ‘Crimson’ 0.1 mM MeJA at the first harvest date (31st July, 2017)

Fig. 5. Photographs showing the visual aspect of control and 0.1 mM MeJA treated table grapes at the first harvest date in 2017 experiment, the 24th of July and 31st July for ‘Magenta’ and ‘Crimson’ cultivars, respectively.

published papers, experiments were performed with wine grapes cultivars while the present results show the effect of MeJA treatment on grape ripening for the first time in table grape cultivars. Nevertheless, it is interesting to note that 10 mM MeJA concentration applied before veraison reduced the grape ripening process (Figs. 1–3) while when applied at veraison this effect was not observed in the previous paper commented above. Moreover, this process can be accelerated by applying lower concentration (Figs. 1 and 2). However, the molecular mechanism involved in these effects deserves further research.

3.2. *Grape quality at harvest*

Berry were harvested when reached their commercial ripening stage, mainly assessed by skin colour, and thus, no significant differences were obtained on L*, a* or b* colour parameters between control and MeJA treated berries (Table 2). Samples from MeJA 5 and 10 mM treatments were not analysed based on yield data. However, for both cultivars and years, firmness and TSS were significantly higher in treated than in control berries, the major effects being observed for MeJA 0.1 mM concentration. On the other hand, TA levels were not

Table 2
Colour (L*, a* and b* parameters), total soluble solids (TSS, g 100 g^{-1}), total acidity (TA, g 100 g^{-1}) and firmness (N mm^{-1}) of 'Magenta' and 'Crimson' table grapes at harvest as affected by methyl jasmonate (MeJA) preharvest treatments. *.

Treatments	L*	a*	b*	Firmness	TSS	TA
	'Magenta' 2016					
Control	31.2 ± 0.3^{a}	9.8 ± 0.2^{a}	1.9 ± 0.2^{a}	2.20 ± 0.01^{a}	18.1 ± 0.4^{a}	0.64 ± 0.02^{a}
MeJA 1 mM	31.0 ± 0.3^{a}	10.1 ± 0.2^{a}	2.2 ± 0.2^{a}	2.31 ± 0.03^{b}	19.9 ± 0.1^{b}	0.55 ± 0.01^{b}
	'Magenta' 2017					
Control	33.8 ± 0.5^{a}	10.0 ± 0.4^{a}	1.7 ± 0.3^{a}	1.86 ± 0.03^{a}	18.0 ± 0.1^{a}	0.99 ± 0.01^{a}
MeJA 1 mM	32.3 ± 0.5^{a}	9.4 ± 0.4^{a}	1.8 ± 0.4^{a}	2.03 ± 0.04^{b}	19.1 ± 0.1^{b}	0.89 ± 0.02^{b}
MeJA 0.1 mM	34.7 ± 0.9^{a}	10.7 ± 0.6^{a}	2.3 ± 0.3^{a}	2.23 ± 0.04^{c}	19.2 ± 0.2^{b}	0.95 ± 0.02^{ab}
MeJA 0.01 mM	33.9 ± 0.5^{a}	11.2 ± 0.4^{a}	2.5 ± 0.5^{a}	2.01 ± 0.03^{b}	19.0 ± 0.2^{b}	1.00 ± 0.01^{a}
	'Crimson' 2016					
Control	30.8 ± 0.3^{a}	5.4 ± 0.2^{a}	0.6 ± 0.4^{a}	2.30 ± 0.04^{a}	18.6 ± 0.3^{a}	0.76 ± 0.01^{a}
MeJA 1 mM	32.7 ± 0.4^{a}	6.8 ± 0.4^{a}	1.0 ± 0.3^{a}	2.62 ± 0.02^{b}	19.7 ± 0.2^{b}	0.79 ± 0.02^{a}
	'Crimson' 2017					
Control	27.7 ± 0.6^{a}	9.8 ± 0.3^{a}	2.3 ± 0.3^{a}	3.51 ± 0.09^{a}	17.6 ± 0.1^{a}	1.16 ± 0.01^{a}
MeJA 1 mM	26.9 ± 0.7^{a}	9.2 ± 0.4^{a}	1.9 ± 0.2^{a}	3.84 ± 0.08^{b}	18.85 ± 0.2^{b}	1.17 ± 0.03^{a}
MeJA 0.1 mM	28.8 ± 0.5^{a}	10.6 ± 0.5^{a}	2.9 ± 0.3^{a}	4.58 ± 0.09^{c}	19.4 ± 0.1^{c}	1.20 ± 0.01^{a}
MeJA 0.01 mM	28.2 ± 0.5^{a}	10.1 ± 0.4^{a}	2.1 ± 0.4^{a}	3.93 ± 0.11^{b}	18.9 ± 0.1^{b}	1.21 ± 0.03^{a}

* Different letters show significant differences ($P < 0.05$) between treatments.

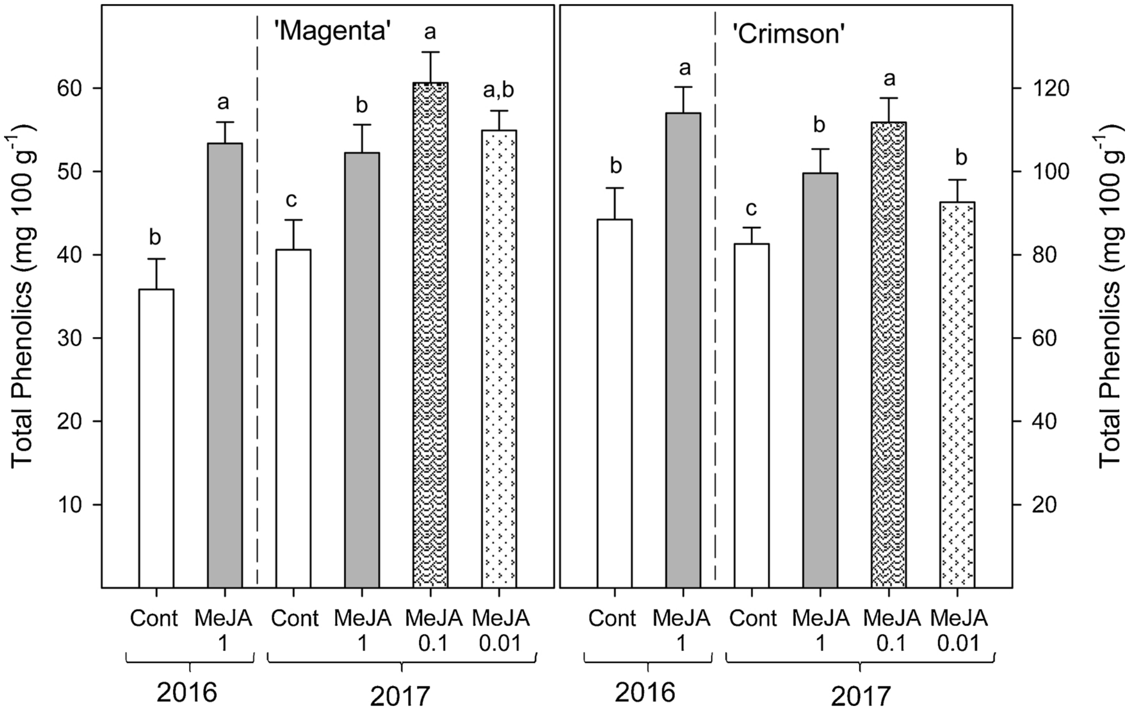


Fig. 6. Total phenolic concentration at harvest in control (Cont) and MeJA-treated (1, 0.1 and 0.01 mM) 'Magenta' and 'Crimson' table grapes. Data are the mean ± SE of three replicates of 20 berries from the first harvest date for both cultivars and all treatments. Different letters show significant differences ($P < 0.05$) among treatments.

affected in 'Crimson' cultivar while a significant reduction was found in 1 mM treated 'Magenta' berries. Thus, preharvest MeJA treatments led to increase table grape organoleptic quality parameters, such as size, weight, firmness and total soluble solids. Accordingly, the application of MeJA at 0.01 or 0.1 mM in blackberry and raspberry cultivars increased the content of TSS, the effect being proportional to the applied concentration (Wang and Zheng, 2005; Wang et al., 2008). In mango, preharvest MeJA treatment led to fruit with higher firmness levels at harvest as well as to increased concentration of glucose, fructose and sucrose (Muengkaew et al., 2016). The effect of MeJA treatments on enhancing fruit TSS and sugar content could be due to an increase of both the net photosynthetic rate of vine and the sink strength of berry cells which would lead to increase sugar accumulation, leading to enhance berry volume and weight. In this sense, it has been reported that MeJA at 1.0 mM stimulated dry matter accumulation in cauliflower seedlings by promoting synthesis of chlorophyll and increasing the net photosynthetic rate, stomatal conductance and intercellular CO_2 concentration (Wu et al., 2012). In turn, MeJA treatment would increase available photoassimilates to support fruit growth. From the agronomic and commercial point of view, the obtained results would have a great importance, since fruit with higher size and harvested earlier would reach higher prizes at markets and berries with higher firmness and TSS would be more appreciated by consumers.

3.3. *Phenolic and anthocyanin concentration*

Table grapes are rich in bioactive compounds, such as phenolics including anthocyanins, flavonoids and resveratrol, which have been reported to have health beneficial effects preventing cardiovascular diseases and having anti-inflammatory, anticancer and anti-diabetic

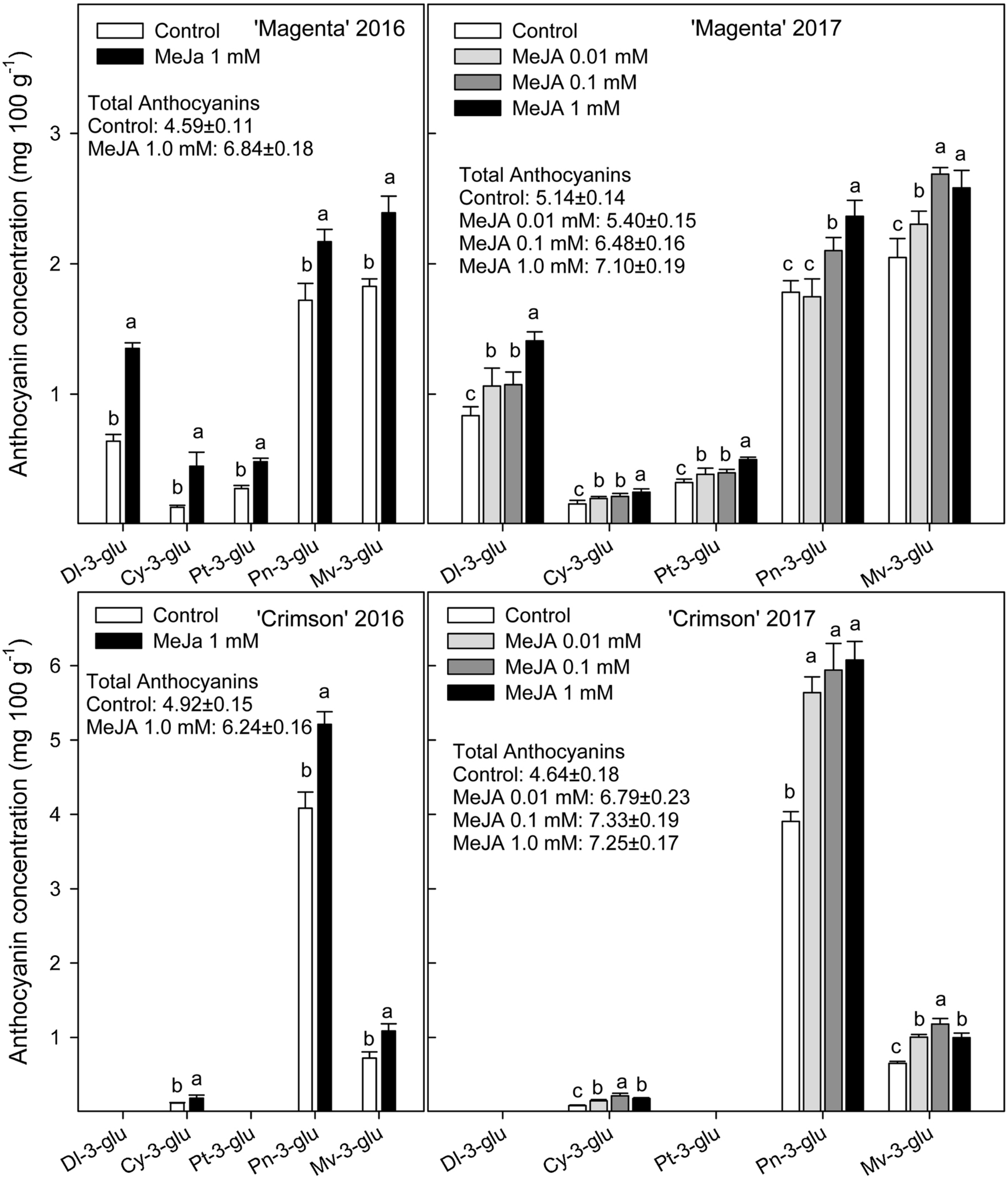


Fig. 7. Individual anthocyanin concentration at harvest in control (Cont) and MeJA-treated (1, 0.1 and 0.01 mM) 'Magenta' and 'Crimson' table grapes. Data are the mean ± SE of three replicates of 20 berries from the first harvest date for both cultivars and all treatments. Different letters show significant differences ($P < 0.05$) among treatments.

activities (Flamini et al., 2013; Doshi et al., 2015) which could depend on the gut microbiota composition (Espín et al., 2017). Previous reports have shown that quality of fruit and vegetable products could be greatly improved by MeJA treatment by inducing accumulation of biactive compounds, such as glucosinolates in broccoli and radish sprouts (Baenas et al., 2016), phenolics in artichoke (Martínez-Esplá et al., 2017), anthocyanins and other polyphenol compounds (hydrophilic antioxidants) in plums (Martínez-Esplá et al., 2014), black currants (Flores and Ruiz Del Castillo, 2016), raspsberries (Flores and Ruiz Del Castillo, 2015), mangos (Muengkaew et al., 2016) and apples (Ozturk et al., 2015), as well as in grapevine and wines (Ruiz-García et al., 2013; Portu et al., 2015, 2016; Gil-Muñoz et al., 2017), as a result of enhanced phenylalanine ammonialyase (PAL) activity. Accordingly, the present results show that total phenolic concentration at harvest was increased 1.3 and 1.5-fold by MeJA 1 mM treatments in 'Crimson' and 'Magenta' cultivars, respectively, in 2016 experiment. Similarly, in 2017 experiments, an increase in phenolic concentration was found as a consequence of MeJA treatments, the most effective concentration being 0.1 mM in both cultivars (Fig. 6).

On the other hand, five anthocyanins were identified and quantified in 'Magenta' cultivar for the first time, the main ones being peonidin 3-glucoside (Pn-3-glu) and malvidin 3-glucoside (Mv-3-glu), with concentrations of 1.7–2.0 mg 100 g^{-1}, in control berries of 2016 and 2017 experiments, respectively, followed by delphinidin 3-glucoside (Dl-3-glu, 0.6–0.8 mg 100 g^{-1}), while cyaniding 3-glusocide (Cy-3-glu) and petunidin 3-glucoside (Pt-3-glu) were found at lower concentrations

(Fig. 7). However, in 'Crimson' table grapes just three anthocyanins were found, the major one being Pn-3-glu with concentration ca. 4 mg 100 g^{-1} in control grapes followed by Mv-3-glu (0.6–0.7 mg 100 g^{-1} in control grapes) and just traces of Cy-3-glu were found (Fig. 7). Accordingly, Olivares et al. (2017) reported that Pn-3-glu accounted for 69% of 'Crimson' table grape anthocyanin content followed by Mv-3-glu with 15% and Cy-3-glu with 11%, although they also reported minor concentrations of Dl-3-glu and Pt-3-glu. However, Baiano and Terracone (2011) only found two anthocyanins in this cultivar, Pn-3-glu as major one and Cy-3-glu as minor one as well as Ferrara et al. (2015) who reported that Pn-3-glu composed around 85% and Cy-3-glu ca. 5% of total anthocyanins. Thus, total and individual anthocyanin concentration, as well as their profile, depend not only on genetic factors but also on environmental conditions and viticulture practices. In this sense, it has been recently reported that cluster thinning and girdling can influence profile and concentration of individual anthocyanins in 'Sugrathirteen' table grape (Basile et al., 2018). Nevertheless, it is worth noting that MeJA treatments increased total and individual anthocyanin concentration, in both cultivars and years, the higher effects being found for 1 and 0.1 mM MeJA treatments (Fig. 7). Taking into account that both cultivars were growth under similar environmental and agronomic conditions, these differences are due to MeJA treatments.

No previous reports are available in the literature regarding the effect of MeJA treatment on anthocyanin content in table grape although in grapevine the foliar application of MeJA increased anthocyanins in grape and wine, the magnitude of these effects being affected by growing season and variety (Portu et al., 2015, 2018a, 2018b; Gómez-Plaza et al., 2017). For instance, two applications of MeJA 10 mM, at veraison and one week later, or three applications, at veraison and three and six days later, increased total anthocyanin concentration in 'Garnacha' (Portu et al., 2017), 'Tempranillo' (Portu et al., 2015, 2016, 2018b), 'Monastrell' and 'Merlot' (Ruiz-García et al., 2013; Gómez-Plaza et al., 2017) but not effect was found in 'Graciano' (Portu et al., 2018a) or 'Syrah' (Gómez-Plaza et al., 2017). Accordingly, treatment with MeJA at 0.05 and 0.1 mM thirty days before harvest promoted anthocyanin biosynthesis in peach by increasing the expression of genes codifying enzymes involved in anthocyanin biosynthesis pathway (Wei et al., 2017). Moreover, in apple fruit this effect was dose-dependent since 1 and 0.1 MeJA mM postharvest treatments promoted anthocyanin accumulation by up-regulating these genes while 10 mM inhibited anthocyanin biosynthesis (Feng et al., 2017), which is in accordance with the present results (Figs. 1–3). In addition, it has been also reported that MeJA treatment increases some lipophilic antioxidant compounds such as carotenoids and vitamin E, which together with the hydrophilic ones previously commented would lead to improve quality and health properties of fresh fruit and vegetable consumption (Wang et al., 2008; Muengkaew et al., 2016; Reyes-Díaz et al., 2016; Serrano et al., 2018).

4. Conclusion

Taking into account that MeJA is already classified by the U.S. Food and Drug Administration (FDA) as "Generally Recognised as Safe" (GRAS, FDA-EPA, 2013), results from the present research show that it could be considered as a useful tool to increase economic profit of table grape growers. In fact, MeJA treatments at 0.1 mM applied at key points of berry development accelerated berry ripening, mainly colour evolution due to increased anthocyanin biosynthesis, leading to earlier harvest and increased vine yield in both table grape cultivars. In addition, berry quality parameters, such as size, weight, firmness and TSS, were also enhanced by these treatments. Finally, it is worth noting that higher concentrations of bioactive compounds with antioxidant activity, such as phenolics and individual anthocyanins, were found in grapes from treated vines than in controls, for both cultivars and years, leading to berries with increased health properties. Nevertheless, the possibility of reducing the number of MeJA treatments deserves further research.

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