Effect of abscisic acid and methyl jasmonate preharvest applications on fruit quality and cracking tolerance of sweet cherry

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ABSTRACT

Rain-induced cherry fruit cracking is one of the most important problems in the cherry industry, and its occurrence causes significant economic losses. Sweet cherry (*Prunus avium* [L.] L.) is a non-climacteric fruit affected by both abscisic acid (ABA) and methyl jasmonate (MeJA) during development. The objective of this study was to evaluate the effect of these phytohormones on cracking susceptibility and quality parameters of sweet cherry fruit ('Bing'), located in the central region of Chile. During two seasons, independent pre-harvest applications of ABA (0.1 mM) and MeJA (0.4 mM) or both combined, at fruit developmental stages of fruit set or fruit color change, significantly reduced the number of mature cracked fruit after 6 h of immersion in water (p < 0.05). In both seasons the combinations of ABA and MeJA applied at fruit set reducing cracking index in an 87% compared to the control without compromising the weight or the diameter of the fruits. Moreover, in the second season ABA and MeJA applications at fruit set increased fruit firmness (11% and 6% respectively) and fruit color parameters regardless of the fruit stage at application, although slight decreases in soluble solids content were observed in most of the treatments.

Key words: Abscisic acid, fruit cracking, methyl jasmonate, *Prunus avium*, sweet cherry.

INTRODUCTION

Sweet cherry (*Prunus avium* [L.] L.) is an economically important horticultural crop cultivated in temperate regions around the world. Rain-induced fruit cracking during the harvest period is one of the main sources of crop loss in the cherry industry. This disorder is characterized by cracks developed on the skin of the fruits after rain, sometimes penetrating deep into the flesh, affecting the stem end area, the calyx end, and the cheeks of the fruit (Balbontín et al., 2013).

The causes of this phenomenon seem to be related to a rapid increase in water absorption through the fruit surface and/or water uptake by the tree roots after rain events during the fruit ripening stage (Measham et al., 2009). There are several proposed factors contributing to this physiological disorder, such as cultivar, crop condition, irrigation management, rootstock, fruit size, osmotic potential of the pulp, skin cuticular characteristics and stage of fruit development (Simon, 2006). Recently, it has been suggested that a primary cause of fruit cracking could be the increase in fruit surface area during fruit development in the absence of cuticle membrane (CM) deposition (Alkio et al., 2012). In this sense, cracking results from localized water uptake, the bursting of individual cells and the spreading of the damage to neighboring cells, the release of malic acid into the apoplast, the resulting swelling of cell walls and the weakening of the fruit skin until the crack becomes macroscopically visible (Winkler et al., 2015).

Sweet cherry, like other *Prunus* species, presents a characteristic double-sigmoid pattern of fruit growth with three distinctive phases. The first phase is characterized by the rapid division of mesocarp cells, which implies a high expansion rate. The second phase involves embryo development and endocarp hardening, with slow fruit growth. In the third phase, fruit growth restarts, the color of the fruit changes, and the final fruit size is reached. In the first period, fruit growth is accompanied by a high production of CM and therefore the tension on the skin of the fruit is low. Conversely, during the second period of fruit expansion (third phase of fruit development), the amount of CM per unit area decreases, resulting in the formation of microscopic cracks in the cuticle, increasing the susceptibility to fruit cracking (Peschel and Knoche, 2005).

Plant hormones control many aspects of development in climacteric and non-climacteric fruits (Cherian et al., 2014; Kumar et al., 2014). Among these hormones, abscisic acid (ABA) and jasmonic acid seem to be involved in growth and ripening of sweet cherry fruits, which are non-climacteric. Various authors have reported that ABA promotes ripening in other non-climacteric fruits such as grapes, strawberries, and oranges, modulating anthocyanin biosynthesis and sugar accumulation (Kumar et al., 2014; Tijero et al., 2016). In sweet cherry fruit ABA levels have been shown to be high at the beginning of the first phase of growth, gradually decreasing during pit hardening, and increasing again during the final stage of fruit expansion (Ren et al., 2011; Luo et al., 2014). It is known that ABA plays a decisive role in the regulation of cuticle and cell wall biosynthesis, which consequently affects the structure and composition of the outer surface layers. Although a direct effect of ABA application on the fruit CM biosynthesis has not been reported, exogenous ABA application in Arabidopsis increases cuticle lipids biosynthesis, reducing cuticle permeability (Martin et al., 2017).

Jasmonates (JAs), such as jasmonic acid and methyl jasmonate (MeJA), influence physiological processes in plants, including biotic and abiotic stress tolerance, seed germination, leaf senescence, and fruit ripening (Cherian et al., 2014). Its possible influence on wax biosynthesis, and potentially on fruit cuticle properties, has been little studied (Mandaokar et al., 2006). The involvement of JAs in fruit ripening has been reported in several climacteric and non-climacteric fruit species. In apple, sweet cherry and peach, elevated levels of JA have been found during the early stages of fruit development, when cell division occurs, coinciding with the highest rates of cuticular membrane biosynthesis (Ziosi et al., 2008; Alkio et al., 2012). In sweet cherry fruits, Wang et al. (2015) reported that use of MeJA lowered fruit fungal infection, while Kucuker and Ozturk (2015) as well as Saracoglu et al. (2017) found that preharvest MeJA application during the last stage of fruit development increased fruit firmness in different sweet cherry varieties.

Until now, there have been no reports of the effects of pre-harvest ABA or MeJA applications on sweet cherry fruit cracking. However, we hypothesize that the use of these hormones would have effects on cuticle and cell wall properties, tending to increase cracking tolerance. In this paper, we evaluate the effects of MeJA and ABA in preharvest applications to prevent fruit cracking occurrence in sweet cherry fruit, as well as their effects on fruit quality.

MATERIALS AND METHODS

Plant material and treatments
Fruit samples were obtained from a commercial cherry (*Prunus avium* [L.] L.) orchard located in Chillán (36°31'07.4" S; 72°05'24.4" W), Chile. The cracking-susceptible sweet cherry 'Bing', grafted onto 'Colt' rootstock, was used for the study. Trees were planted at north-south direction with 5.0 m row spacing and 3.0 m on-row tree spacing and trained in central leader system under plastic shelter. All cultural practices were regularly implemented.

For each hormonal treatment, trees were sprayed with different hormone solutions: (1) 0.1 mM abscisic acid (ABA; Sigma-Aldrich, Darmstadt, Germany); (2) 0.4 mM methyl jasmonate (MeJA; Sigma-Aldrich); (3) a combination of both hormones (0.1 mM ABA + 0.4 mM MeJA); and (4) controls with distilled water. The concentrations used were in accordance with Luo et al. (2014) and Ren et al. (2011) for ABA, and with Ruiz et al. (2013) and Yao and Tian (2005) for MeJA.

Hormonal treatments (ABA, MeJA, or ABA+MeJA) were applied to three trees considering single applications at one of the two periods of maximum fruit growth, fruit set (FS; 20 d after full bloom [DAFB]) or initial fruit growth stage at fruit color change (FCC; 60 DAFB; final fruit growth stage). The trial was carried out over two seasons (2016 and 2017) with different trees. For both seasons, the effects of hormone applications on fruit cracking index, weight and size were measured. In the second season, solid soluble content (SSC), titratable acidity (TA), fruit firmness (FF), and color parameters were also assessed. Control fruit received applications of water at the same time.

In order to characterize growth evolution during fruit development, 25 fruits per tree were measured every week from anthesis to ripe stage (harvest) using a digital vernier caliper. The ripe stage was determined according to the grower's commercial standards (mainly mahogany red color and a minimum of 18 °Brix). At that point 50 ripe fruits of uniform size were collected from each tree and assessed for induced cracking and quality parameters.

Cracking tolerance and fruit quality assessments
To evaluate cracking tolerance, fruit of similar size from different treatments were sorted visually to remove any damaged fruit. A set of 25 stem-attached fruits from each biological sample (tree) was placed in distilled water at 20 °C for 6 h. Cracking index (CI) was calculated by the method used by Balbontín et al. (2014), based in the formula reported by Christensen (1972).

$$CI = ((6a + 5b + 4c + 3d + 2e + 1f) \, (MPV)\text{-}1) \, 100$$

where *a*, *b*, *c*, *d*, *e* and *f* represent the number of cracked fruit at 1, 2, 3, 4, 5 and 6 h respectively, *MPV* is maximum possible value (25 fruits × 6 h).

Seventy-five fruits from each treatment (25 fruits per tree) were used to characterize weight, size, skin color, FF, SSC, and TA. Fruit skin color was measured on two opposite sides of the mid-section of each fruit using a benchtop 45°/0° spectrophotometer (ColorFlex EZ, HunterLab, Reston, Virginia, USA) and the averages of these two measurements were recorded and expressed as CIE *L*a*b** coordinates together with the dimensions of color chroma (*C**) and hue angle (*h°*). Fruit firmness was determined nondestructively with a programmable texture analyzer (Cherrytech V5, developed at Universidad de Concepción, Chile) equipped with a 30 mm diameter probe mounted on a screw, using piezoelectric sensors to record the force (N) needed to produce 2 mm of cherry fruit deformation. Measurements were recorded on both cheek sides of the fruit, at the fruit's maximum width. SSC was determined using a digital temperature-compensated refractometer (96801, Hanna Instruments, Woonsocket, Rhode Island, USA) and the results were reported as °Brix. Titratable acidity was determined by diluting fruit juice in distilled water (1/10, v/v) and titrating with 20 mM NaOH to pH 8.2 using a continually immersed pH meter, and the results were given as percentage of malic acid. The results were also expressed as the SSC/TA ratio.

Statistical analysis
Experiments were conducted following a completely randomized design (CRD) two-way factorial ANOVA: the primary factor was hormone treatments of ABA, MeJA, and ABA + MeJA; and the secondary factor was the time of application (FS and FCC). The control group received water applications on the last schedule. Statistical analyses were performed using INFOSTAT/P 1.1 for Windows software (Grupo InfoStat Professional, Facultad de Ciencias Agropecuarias, Universidad Nacional de Córdoba, Córdoba, Argentina). Differences between treatments were considered significant at P ≤ 0.05 (Duncan's multiple range test).

RESULTS

Fruit cracking tolerance
Fruit cracking decreased significantly in all treatments compared to the control (Table 1). In the first season 74.89% of untreated fruits showed cracking after 6 h of distilled water immersion, while in the second season control fruits registered values of 54.22%. The application of ABA at FS stage reduced the number of cracked fruits to 14.89% and 16.67% in the first and second season respectively (P < 0.05). Spraying this hormone at FCC stage also produced lower values than the control in both seasons (32.22% and 23.33% for the first and second season).

Similarly, MeJA applications significantly decreased numbers of cracked fruits, averaging 28.89% in fruit treated at FS in the first season and 21.33% in the second season, while values for fruit treated at FCC stage showed lower effectiveness in both seasons (41.33% and 33.56%, respectively). Finally, the combined application of ABA + MeJA also significantly reduced fruit cracking levels in all treatments with respect to control fruits. Application of both hormones at FS reduced cracking to 9.33% in the first season and 6.89% in the second season, and the application in FCC stages showed values of cracking index of 26.44% and 18.67% in the first and second season respectively. The values of fruit

Table 1. Effect of abscisic acid (ABA) and/or methyl jasmonate (MeJA) pre-harvest applications on cracking, weight, and size of sweet cherry fruit.

Treatments		Cracking index		Fruit weight		Fruit diameter	
		2016	2017	2016	2017	2016	2017
		%		g		mm	
Control		74.89 ± 9.90d	54.22 ± 7.67d	9.56 ± 0.62ab	10.64 ± 1.15b	27.53 ± 0.31ab	28.61 ± 1.17ab
ABA	FS	14.89 ± 2.78a	16.67 ± 1.76b	9.55 ± 0.57ab	10.32 ± 1.20ab	27.37 ± 0.40ab	28.34 ± 1.20ab
	FCC	32.22 ± 3.67b	23.33 ± 1.33b	9.10 ± 0.14a	10.98 ± 0.99bc	26.84 ± 0.16a	29.31 ± 2.41bc
MeJA	FS	28.89 ± 2.78b	21.33 ± 1.76b	10,17 ± 0.28bc	11.51 ± 0.96c	28.19 ± 0.38bc	28.82 ± 3.50abc
	FCC	41.33 ± 1.76c	33.56 ± 1.92c	10.69 ± 0.64c	11.35 ± 1.20c	28.57 ± 0.55c	29.34 ± 1.26bc
ABA+MeJA	FS	9.33 ± 3.71a	6.89 ± 3.42a	9.87 ± 0.55abc	9.94 ± 1.62a	28.13 ± 0.50bc	28.03 ± 1.78a
	FCC	26.44 ± 3.15b	18.67 ± 2.40b	10.47 ± 0.46bc	11.63 ± 1.11c	28.25 ± 0.84bc	29.77 ± 0.95d

Data indicate the mean of three replicates; ± standard deviation.
Different letters indicate significant diferences between treatments in each parameter (Duncan, P ≤ 0.05).
FS: Fruit set; FCC: fruit color change.

cracking produced by the application of ABA+Meja at FS were significantly lower than the observed values for each independent hormone application. For each hormonal treatment, both independent and combined applications at FCC were the least effective (Table 1).

Fruit quality parameters

Untreated fruit showed a mean weight value of 9.56 g and 10.64 g for the first and second season, which was nonsignificant different from the weight values observed in ABA-treated fruit in both seasons (Table 1). High weight values were observed in the second season in MeJA or ABA+MeJA-treated fruit at FCC stage. Fruit diameters were affected by the treatments in a similar way as weight; but differences with respect to control fruit (27.53 and 28.61 mm for the first and second season respectively) were only observed in MeJA at FCC stage for the first season and ABA+MeJA-treated fruit at FCC stage in the second season (Table 1).

The effects of second season-pre-harvest ABA and MeJA sprays on fruit firmness, SSC, TA, and SSC/TA ratio are summarized in Table 2. Fruit firmness showed higher values (P < 0.05) with ABA and MeJA treatments than in the control fruit, while treatment with both hormones at any stage of application did not produce significant differences compared to the control. Most treatments lowered SSC values and significant differences were observed in ABA at FCC, MeJA at FS and FCC. Fruits treated with both hormones at FFC also showed lower values of SSC compared to the control fruit. Nonsignificant differences were observed between control fruits and the treatments with respect to fruit acidity (% malic acid). Values of SSC/TA ratio were only different from the control in the MeJA-treated fruit at FS and FCC stages.

Table 2. Effect of abscisic acid (ABA) and/or methyl jasmonate (MeJA) pre-harvest applications in second season (2017) on quality parameters of sweet cherry fruit.

Treatments		Fruit quality parameters			
		Fruit firmness	SSC	TA	SSC/TA
		N	°Brix	% Malic acid	
Control		3.76 ± 0.28a	28.01 ± 2.41de	0.61 ± 0.05a	46.18 ± 4.09b
ABA	FS	4.01 ± 0.23cd	27.32 ± 2.71cd	0.63 ± 0.04a	43.47 ± 1.64ab
	FCC	4.02 ± 0.20cd	25.26 ± 2.73ab	0.67 ± 0.04a	37.75 ± 1.25ab
MeJA	FS	4.17 ± 0.26d	25.01 ± 2.29a	0.69 ± 0.07a	36.50 ± 4.51a
	FCC	3.96 ± 0.26bc	25.55 ± 2.57ab	0.71 ± 0.05a	36.23 ± 3.86a
ABA+MeJA	FS	3.77 ± 0.21a	28.99 ± 3.16ef	0.65 ± 0.04a	44.94 ± 4.65ab
	FCC	3.82 ± 0.31ab	26.49 ± 1.82bc	0.61 ± 0.09a	43.88 ± 7.50ab

Data indicate the mean of three replicates; ± standard deviation.
Different letters indicate significant diferences between treatments in each parameter (Duncan, P ≤ 0.05).
SSC: Soluble solid content; TA: titratable acidity; FS: fruit set; FCC: fruit color change.

Treatments with ABA, MeJA or ABA + MeJA significantly affected the fruit skin color parameters depending on fruit development stage at application (Table 3). All ABA-treated fruit showed a greater L^* value than control fruit, while the MeJA treatment at FS did not affect significantly this parameter. ABA+MeJA-treated fruit showed greater values in FS and FCC stages than control fruit. All treated fruit presented higher values of a^* and C^* than the control fruits (9.91 and 10.53, respectively), although the treatment of ABA+Meja at FCC did not produce a significant increment of this last parameter. All treatments showed $h°$ values significantly lower than the control.

DISCUSSION

The results of this study indicate that pre-harvest treatment with ABA and/or MeJA can significantly increase sweet cherry fruit cracking tolerance and positively affect other fruit quality parameters (Table 1), such as fruit firmness and skin color, depending on both the hormone and fruit development stage when is applied. The effect of these phytohormones on cracking susceptibility could be associated with several mechanisms. For example, it is known that ABA plays an active role in wax metabolism through the activation of genes related to biosynthesis and transport of cutin and waxes (Kosma et al., 2009; Martin et al., 2017). Indeed, in Arabidopsis it has been shown that ABA induces the expression of *CER1* (Kosma et al., 2009), which encodes a regulation enzyme that promotes C29 alkane biosynthesis (Bourdenx et al., 2011). Although the relationship between ABA and cuticle membrane biosynthesis components has not been studied in sweet cherry fruits, it has been determined that a higher presence of cuticle C29-alkanes is related to higher cracking tolerance levels in different sweet cherry cultivars (Rios et al., 2015). Therefore, it is possible to speculate that the increase in cracking tolerance observed in this study may have been due to the activation of similar mechanisms.

Jasmonates also induce the upregulation of several wax biosynthesis-related genes (Mandaokar et al., 2006). However, to date, there are no reports that show a direct relationship between JA applications and fruit cuticle properties. On the other hand, the reduction in cracking levels found in MeJA-treated fruit could be related to the increase in firmness observed in the fruits treated with this hormone. In Prunus species such as plum (Martínez-Esplá et al., 2014; Kucuker et al., 2014) and sweet cherry (Saracoglu et al., 2017) it has been reported that MeJA applications can delay fruit softening during ripening. The underlying mechanism involved in this phenomenon seems to be related to the regulation of cell wall metabolism-associated genes; for example, in sweet cherry, MeJA application has induced the activity of phenylalanine ammonia lyase (PAL) and peroxidase (POD) enzymes, both involved in lignin biosynthesis (Yao and Tian, 2005), and in the increase of fruit firmness (Cai et al., 2006). In addition, in peach, MeJA applications can reduce the expression of polygalacturonase genes and their associated enzyme activity (Ziosi et al., 2008), delaying cell wall softening and therefore increasing resistance to mechanical damage (Reyes-Díaz et al., 2016). We observed that preharvest applications of MeJA, independent of application time, significantly increased sweet cherry flesh firmness, as was also seen by Kucuker

Table 3. Effect of abscisic acid (ABA) and/or methyl jasmonate (MeJA) pre harvest applications in second season (2017) on skin color parameters of sweet cherry fruit.

Treatments		Fruit color parameters			
		L^*	a^*	C^*	$h°$
Control		22.94 ± 1.48a	9.91 ± 3.12a	10.53 ± 3.32a	19.81 ± 2.06d
ABA	FS	24.84 ± 1.87c	12.42 ± 2.01bcd	12.87 ± 2.12bcd	15.08 ± 1.57a
	FCC	25.22 ± 1.80c	13.83 ± 2.25d	14.38 ± 2.41d	15.60 ± 1.79ab
MeJA	FS	23.73 ± 3.38ab	11.56 ± 3.01bc	12.06 ± 3.20b	16.26 ± 2.20bc
	FCC	24.64 ± 1.39bc	13.37 ± 2.88cd	13.95 ± 3.05cd	16.44 ± 1.33bc
ABA+MeJA	FS	24.15 ± 1.79bc	11.99 ± 3.45bc	12.55 ± 3.63bc	17.10 ± 1.62c
	FCC	24.98 ± 1.57c	11.44 ± 1.73b	11.96 ± 1.83ab	16.69 ± 2.22c

L^*: Lightness of a surface; a^*: green-red coordinates; C^*: color purity: $h°$: hue angle.
Data indicate the mean of three replicates; ± standard deviation.
Different letters indicate significant diferences between treatments in each parameter (Duncan, $P \leq 0.05$).
FS: Fruit set; FCC: fruit color change.

and Ozturk (2015). The possibility that increased firmness is associated with reduced cracking susceptibility has also been suggested by previous work on giberellins effects in sweet cherry fruit (Yildirim and Koyuncu, 2010). In a similar way, Erogul (2014) reported that Ca applications to cherry fruits increase their firmness, as well as their resistance to cracking. Elsewhere, Yamaguchi et al. (2002) observed that firmer cherry fruits can be more susceptible to cracking. Nevertheless, this seems to have been an effect of cultivar, as has been shown in blueberries, in which the relationship between the firmness of fruits and their cracking susceptibility depends on variety (Marshall et al., 2008).

Applications of hormones at different fruit developmental stages produced distinct levels of fruit cracking tolerance, where the applications were significantly less effective at FCC stage. Any explanation must consider that both MeJA and ABA present endogenous high concentrations in sweet cherry fruits during the first phase of fruit growth, while in the last stage, the levels are lower (Luo et al., 2014). In other studies, application time has been shown differentially effect parameters such as color, firmness, or fruit weight (Martínez-Esplá et al., 2014).

The effect of ABA on fruit weight has been shown to depend on timing, dose and fruit species; for example, in apples, ABA (1.13 mM) applied at fruit set increased fruit weight (Greene et al., 2011), while in grapes, ABA (1.35 mM) at fruit color change did not have significant effects on this parameter (Cantín et al., 2007). In sweet cherry fruit 'Satonishiki', Luo et al. (2014) reported an increase of fruit weight as a result of ABA applications (0.1 mM) towards the end of fruit ripening. However, in our study, using a different cultivar, similar doses did not produce significant differences from untreated fruit at any fruit growth stage.

In our study, MeJA treated fruit showed different weights depending on fruit developmental stage of application; the fruit that was sprayed during the phase of maximum fruit expansion had higher fruit mass. These results show that the effect of this hormone on fruit weight could depend on fruit developmental stage and its variability in different cultivars. Similarly, Kucuker and Ozturk (2015) reported an increase in sweet cherry ('North Wonder') fruit weight with the application of 10 mM MeJA 3 weeks before harvest. Nevertheless, Saracoglu et al. (2017), using the same dose in 'Regina', 'Sweet Heart' and '0900 Ziraat' did not show increases in fruit mass at the same stage of application. A possible explanation of these results can be found in the sensitive response to MeJA levels of cell growth and extension mechanisms, leading to varied effects, as reported by Ozturk et al. (2013).

Fruit diameter was not affected by the combined application of ABA and MeJA at FS, and the application of MeJA or both hormones combined at FCC resulted in an increase of fruit diameter only in the first and second season respectively. However, the magnitude of this variation was small and did not have an effect on the fruit commercial value.

Skin fruit color was altered in all treatments with ABA, MeJA or both combined (Table 3). ABA increases the color appearance of fruits and is used routinely in different grape cultivars (Cantín et al., 2007). Likewise, the application of 0.4 mM ABA at FCC stage has increased the anthocyanins content in sweet cherries (Ren et al., 2011).

In the CIELab system, fruit color is measured using different parameters, where $L*$ represents the lightness of a surface, while parameters such as $a*$ and $C*$ represent the green-red coordinates and color purity respectively. Hue angle ($h°$) indicates the proximity to specific colors, where the values closer to 0 or to 360 indicate a purer red. In the case of ABA treated fruit, the parameters of $L*$, $a*$ and $C*$ increased their values, while the values of $h°$ decreased significantly. The decrease observed in $h°$ could be attributed to an increase of anthocyanin content, as has been reported previously (Goncalves et al., 2007; Serrano et al., 2009). These authors found a direct negative correlation between the levels of anthocyanins (cyanidin-3-glucoside) and hue angle in sweet cherry fruits and related species.

Jasmonates affect the color of fruits in several species, through the induction of chlorophyll degradation and synthesis of anthocyanins. For example, preharvest applications of MeJA in apple and strawberry stimulate the accumulation of red pigments in the fruit skin (Rudell et al., 2005; Concha et al., 2013). However, the possible effect of this hormone in the induction of color in sweet cherry fruit is not well understood. Kondo (2006) reported that the preharvest application of 3 mM MeJA to cherry fruit 'Satohnishiki' did not increase the accumulation of anthocyanins, despite increasing the expression of anthocyanin biosynthesis-related genes. Similarly, Kucuker and Ozturk (2015) also showed that the application of 10 mM MeJA to cherry fruit 'North Wonder' did nonsignificantly affect fruit color. Nevertheless, Saracoglu et al. (2017) using similar doses and times of application, reported changes in fruit color parameters in different sweet cherry varieties. In our study, MeJA applications differentially affected the color parameters, particularly in lightness. The values of $a*$ and $C*$ were higher in all hormonal treatments compared to the control, while the value of $h°$ was smaller. These results indicate that MeJA and/or ABA applications affect fruit color properties in a manner that depend on the time of application.

The SSC is an important quality attribute in sweet cherry fruit; values over 20 °Brix are commonly acceptable for consumption of 'Bing' (Zhang and Whiting, 2011). Preharvest applications of 3.78 mM ABA at FCC stage in sweet cherry fruit increase the SSC (Kondo and Inoue, 1997). Our results show that treatments with ABA significantly decreased the SSC values (at FCC stage); however, all values remained above the threshold of acceptability. A similar outcome has been reported in grape, where a decrease in SSC was observed with ABA treatment (Cantín et al., 2007).

Regarding TA or SSC/TA ratio values, nonsignificant differences were observed between control and treated fruit, although the application of MeJA at FS or FCC stages decreased the SSC/TA ratio, which is in agreement with previous reports in peach and sweet cherry (Ziosi et al., 2008; Saracoglu et al., 2017). In peach, preharvest applications of MeJA affected expression of several fruit ripening-associated genes, delaying fruit ripening (Ruiz et al., 2013).

CONCLUSIONS

Preharvest applications of abscisic acid (ABA), methyl jasmonate (MeJA) or both combined can be performed at different stages of fruit development with the aim of reducing fruit cracking susceptibility in sweet cherry. However, some of these hormones/timing combinations could affect the quality parameters. For example, in the case of ABA or MeJA, the best reduction of the cracking index was achieved applying these hormones at the stage of fruit set, but slights reductions in solid soluble content were also observed.

The treatment that increased the most the fruit cracking tolerance was ABA+MeJA at fruit set. Thus, a single spray application could increase cracking tolerance without significantly compromising the quality of the fruit of and improving fruit color. This study provides new information about the effect of these hormones on fruit quality and the management of rain-induced cherry fruit cracking.

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