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[1]Department of Biotechnology, Suleyman Demirel University, Isparta, Turkey
[2]Department of Horticulture, Ataturk University, Erzurum, Turkey
[3]West Mediterranean Development Agency, Isparta, Turkey

Harvest and postharvest quality of sweet cherry are improved by pre-harvest benzyladenine and benzyladenine plus gibberellin applications

Fatih Ali Canli[1], Murat Sahin[1], Sezai Ercisli[2*], Ozgur Yilmaz[1], Nurettin Temurtas[1], Mustafa Pektas[3]

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Summary

This study was carried out to evaluate the effects of pre-harvest benzyladenine (BA) and BA plus gibberellin (GA_{4+7}) treatments on fruit quality attributes of '0900 Ziraat' cherry at harvest and after cold storage. '0900 Ziraat' cherry trees were sprayed with BA (50, 100, and 150 mg·L^{-1}) and BA + GA_{4+7} (12.5, 25, and 50 mg·L^{-1}) when fruit was at their straw-yellow color stage. All of the treated fruit were significantly firmer than control fruit. Fruit treated with 25 and 50 mg·L^{-1} BA + GA_{4+7} and 50 and 150 mg·L^{-1} BA had significantly higher soluble solids content (SSC) than untreated fruit. Sweet cherry trees treated with the optimum concentration of BA + GA_{4+7} (50 mg·L^{-1}) yielded fruit with 15.17% greater weight, 9.0% higher firmness and 13.6% higher SSC. Additional samples were harvested, placed in plastic bags, and stored at 4 °C for 30 days. At the end of the cold storage period, fruit treated with 25 and 50 mg·L^{-1} BA + GA_{4+7} and 50 and 150 mg·L^{-1} BA were significantly firmer than the control. 50 mg·L^{-1} BA + GA_{4+7} -treated fruit had higher SSC than untreated ones. In conclusion, fruit treated with the optimum dose of BA + GA_{4+7} (50 mg·L^{-1}) were larger and firmer than untreated fruit at harvest and this concentration had the best effects. Most of the treated fruit maintained a superior firmness and quality to control fruit during cold storage.

Introduction

Horticultural plants including fruits, vegetables and grapes have long been valued as part of a nutritious and tasty diet and there is increasing scientific awareness that fruits including sweet cherry plays important role for human nutrition and health (Bacvonkralj et al., 2014; Rop et al., 2014).

Large and firm sweet cherry fruits are preferred by both consumers and producers (Whiting and Ophardt, 2005). Producers always seek for solutions to avoid lower returns associated with cherries harvested during the peak period when cherry supplies are overly abundant. PGRs can be used to increase fruit size and firmness, to delay maturity (Canli and Orhan, 2009) and to improve after storage quality of fruit crops (Canli et al., 2009).

The effects of gibberellic acid (GA_3) on fruit quality of cherry fruit are well documented. GA_3-treated sweet cherry fruit were larger, heavier (Clayton et al., 2006; Canli and Orhan, 2009; Zhang and Whiting, 2011a) and firmer than untreated fruit (Kappel and MacDonald, 2002; Canli and Orhan, 2009).

Pre-harvest GA_3 applications were also effective in delaying maturity (Kappel and MacDonald, 2002; Webster et al., 2006) and improving cold storage quality and shelf life (Einhorn et al., 2013) of sweet cherry fruit. GA_3 reduced pedicel browning (Einhorn et al., 2013) and improved resistance to surface pitting disorder (Einhorn et al., 2013) during the storage period. GA_3-treated fruit were also firmer than the untreated fruit at the end of the cold storage period (Ozkaya et al., 2006; Zhang and Whiting, 2011b).

* Corresponding author

GA_3 treatments resulted in variable responses in some of the fruit quality attributes such as pedicel length, SSC, and fruit cracking. In contrast to results of Canli and Orhan (2009), few researchers have reported that it also increased the pedicel length of the cherry fruit (Horvitz et al., 2003). An increase in SSC, as a response to GA_3 application was reported by some researchers (Lenehan et al., 2006; Canli and Orhan, 2009), but contrary to these results, there were not always changes in SSC (Kappel and MacDonald, 2002). As in the examples of pedicel length and SSC, the response of fruit cracking to GA_3 treatment was also irregular and complex (Looney, 1996; Usenik et al., 2005). The variable responses of sweet cherry fruit to GA_3 applications are possibly caused by ecological and environmental factors such as location (Canli and Orhan, 2009), humidity, temperature, precipitation, water status, light, and nutrition (Facteau et al., 1985) or by the utilization of different cultivars (Usenik et al., 2005) and by application time and application doses (Kappel and MacDonald, 2002).

The final fruit size is mostly determined by the cell division and enlargement in the early phases of fruit development (Bohner and Bangerth, 1988). While the cell expansion is stimulated mainly by endogenous GAs, the cell division in a young fruit is promoted primarily by endogenous cytokinins. BA is the first discovered synthetic compound with cytokinin activity and it is very efficient in promoting cell division (Buban, 2000).

'0900 Ziraat' is a self-incompatible, low-cropping, and a late maturing sweet cherry variety, which constitutes about 12% of the world cherry trade. Although GA_3 is currently used to improve the fruit size and quality, and also to delay maturity in high-cropping and self-fertile cherry varieties in North America and most other parts of the world (Kappel and MacDonald, 2002), the effects of BA and BA + GA_{4+7} on fruit quality attributes of cherry at harvest and after a cold storage period have not been studied yet. Therefore, the objective of this study was to determine if a single pre-harvest application of BA or BA + GA_{4+7} will improve the fruit quality and the cold storage quality of '0900 Ziraat' cherry, which constitutes an important portion of the cherry trade in the world.

Materials and methods

Plant material and experimental site

The experiments were carried out in two consecutive years using 9-year-old '0900 Ziraat' cherry trees planted at 7 × 7 m and grown on Mazzard rootstocks in Kayi (lat. 37°49'12.59"N, long. 30°29'51.65"E, altitude 1097 m), Isparta, Turkey.

Plant growth regulator (PGR) applications

'0900 Ziraat' cherry trees were treated with a single application of 50, 100 or 150 mg·L^{-1} BA [Exilis (20 g·L^{-1} BA); Fine Agrochemicals, Worcester, UK] and 12.5, 25, or 50 mg·L^{-1} BA+GA_{4+7} [Perlan (18 g·L^{-1} GA_{4+7} and 18 g·L^{-1} BA), Fine Agrochemicals, Worcester, UK] using a handgun applicator when the fruit were at their straw yellow color stage of development on a non-windy day in the afternoon. All treatments also had a surfactant [Tween-20 (Polyethylene glycol sorbitan monolaurate); Sigma-Aldrich, St. Louis, MO]. The experiments were conducted in the same trees each year.

Harvest and data collection

When fruit reached their maturity [determined by hedonic taste analysis of local farmers, size, color (at ideal harvest color of the variety determined by the naked eye of the experienced local farmers), SSC and firmness], samples of 120 fruit/tree for each application were harvested and fruit quality parameters were evaluated in terms of: fruit weight, stone weight, pedicel length, SSC, firmness and pH.

Fruit weight

Fruit weight measurements were taken in groups of ten fruit using a digital balance (model SBA 51, sensitivity 0.01 g; Scaltec Instruments, Goettingen, Germany), then weights of all 12 groups were added together to find the total weight of each replication. The total weight of each replication was divided by 120 to find the mean fruit weight for each replication.

Pedicel length

The pedicel length of each of 120 fruit/tree was determined using a digital caliper (Absolute 500-196-20; Mitutoyo, Aurora, IL).

Fruit firmness

Fruit firmness of each of 120 fruits per tree samples was measured on two sides of the equatorial region at the fruit's maximum width using a fruit texture analyzer (model FT 001; Gullimex, Alfonsine, Italy) equipped with a 4.94 mm diameter probe.

Seed weight

After fruit weight, pedicel length and fruit firmness data were collected, stone of each fruit was taken out. Stone weight measurements were taken in groups of ten seeds using the digital balance described above. Then, weights of all 12 groups were added together to find the total weight of each replication. The total weight of each replication was divided by 120 to find the mean stone weight for each replication.

SSC and fruit pH

After fruit weight, pedicel length, fruit firmness and stone weight data were collected, fruits of each replication were divided in to 12 groups (each group containing 10 fruits). Each of these groups was mashed to obtain fruit juice, then SSC and fruit pH measurements were taken for each of 12 groups for all replications. The values of all 12 groups were added together to find a total value for each replication. The total value of each replication was divided by 12 to find the mean SSC and fruit pH values for each replication. The fruit pH was determined with a digital pH meter (model pH 330; WTW, Weilheim, Germany). Fruit soluble solids concentration was measured using a refractometer (model N.O.W. 507-1; Brix scale of 0 to 32; Nippon Optical Works, Tokyo).

Cold storage experiment

In the second year of the experiment, additional samples of 120 fruit/tree were harvested, placed in 1.5 kg capacity polyethylene bags with perforation. Each bag had four holes (1 cm in diameter) at the mid-sections of each side. Cherries were stored at 4 °C for 30 days. The gaseous composition and the relative humidity inside the bags were not measured in this study. Firmness, SSC and surface pitting rate of fruit were evaluated after 4 weeks of cold storage.

Experimental design and statistical analysis

The experimental design was a completely randomized design with three single-tree replicates for each treatment since the soil type and the trees were uniform throughout the orchard. Homogeneity tests were performed to see if the data from two separate years could be combined. The data were homogeneous over two years for each parameter tested [the differences (d) between the highest standard deviation (Std Dev_1) and the lowest Std Dev_2 were within the acceptable limits (Std Dev_1- Std Dev_2 = d, and d ≤ 4Std Dev_2)], thus the data of 2 years were combined and subjected to analyses of variance (ANOVA). The means were separated using Tukey range test (version 9.0; SAS Institute, Cary, NC). Data from cold storage experiment were also subjected to analyses of variance (ANOVA), and then the means were separated using Tukey range test.

Results and discussion

The effects of pre-harvest Plant growth regulator (PGR) applications on quality of '0900 Ziraat' cherry fruit at harvest and after cold storage were evaluated. The effects of PGR applications on fruit weight, pedicel length (Tab. 1), fruit firmness and SSC (Tab. 2) were significant, but stone weight, fruit weight/stone weight (Tab. 1) and fruit pH (Tab. 2) were not affected by the applications. Some of these

Tab. 1: Effects of pre-harvest benzyladenine (BA) and BA + gibberellin (GA_{4+7}) applications on fruit weight, stone weight and pedicel length of '0900 Ziraat' sweet cherry (n=120)[a].

Treatment	Concentration ($mg \cdot L^{-1}$)	Fruit weight (g)[b]	Stone weight (g)[b]	Fruit weight / stone weight (g)[b]	Pedicel length (mm)[b]
Control	0	7.71 b[y]	2.24	3.44	4.82 b
BA + GA_{4+7}	12.5	8.36 ab	2.27	3.68	4.80 b
BA + GA_{4+7}	25	8.19 ab	2.20	3.72	4.97 ab
BA + GA_{4+7}	50	8.88 a	2.33	3.81	4.99 ab
BA	50	8.04 ab	2.62	3.06	5.00 ab
BA	100	7.62 b	2.48	3.07	4.95 ab
BA	150	8.35 ab	2.25	3.71	5.09 a

[a]Trees were treated at straw-yellow color stage of the fruit. The control spray was composed of water and Tween-20.

[b]Means within a column followed by different letters are significantly different at $P \leq 0.05$ by Tukey's HSD test.

Tab. 2: Effects of pre-harvest benzyladenine (BA) and BA + gibberellin (GA_{4+7}) applications on firmness, soluble solids concentration (SSC) and pH of '0900 Ziraat' sweet cherry fruit (n=120)[a].

Treatment	Concentration ($mg·L^{-1}$)	Firmness (N)	SSC (%)	pH
Control	0	9.30 c[b]	17.22 c	3.75667
BA + GA_{4+7}	12.5	9.96 ab	16.57 d	3.81267
BA + GA_{4+7}	25	9.70 b	17.99 b	3.76455
BA + GA_{4+7}	50	10.14 a	19.57 a	3.77467
BA	50	9.91 a	18.51 b	3.78800
BA	100	10.05 a	17.00 cd	3.74933
BA	150	10.05 a	18.35 b	3.75000

[a]Trees were treated at straw-yellow color stage of the fruit. The control spray was composed of water and Tween-20.
[b]Means within a column followed by different letters are significantly different at $P \leq 0.05$ by the Tukey's HSD test.

Tab. 3: Effects of benzyladenine (BA) and BA + gibberellins (GA_{4+7}) applications on firmness, soluble solids content (SSC), and surface pitting of '0900 Ziraat' sweet cherry fruit after cold storage (n=120)[a].

Treatment	Concentration (mg·L–1)	Firmness (lbf)[13]	SSC (%)	Surface pitting (%)
Control	0	1.54 d b	17.04 bc	17.29 ab
BA + GA4+7	12.5	1.59 cd	16.28 d	24.25 a
BA + GA4+7	25	1.74 a	17.17 bc	21.86 ab
BA + GA4+7	50	1.70 ab	18.53 a	24.52 a
BA	50	1.68 abc	17.62 b	23.56 a
BA	100	1.63 bcd	16.68 cd	12.20 b
BA	150	1.75 a	16.92 c	15.96 b

[a]Trees were treated at straw-yellow color stage of the fruit. The control spray was composed of water and Tween-20.
[b]Means within a column followed by different letters are significantly different at $P \leq 0.05$ by the Tukey's HSD test.

differences were also maintained during the 30 days of cold storage when most of the treated fruit retained a superior quality to untreated fruit. Pre-harvest PGR applications significantly affected fruit firmness, SSC and surface pitting during cold storage (Tab. 3).

Fruit size data were summarized in Tab. 1. Fruit treated with 50 $mg·L^{-1}$ BA + GA_{4+7} were significantly heavier than the control fruit and the heaviest fruits were obtained from 50 $mg·L^{-1}$ BA + GA_{4+7} application. Although the differences were not statistically different, most of the other BA and BA + GA_{4+7} applications yielded heavier fruits than the control (Tab. 2). When compared to untreated '0900 Ziraat' cherry trees, 50 $mg·L^{-1}$ BA + GA_{4+7} treated trees yielded fruit with 15.17% greater weight. Similarly, GA_3 treatments increased fruit size of cherries about 10% to 15% (KAPPEL and MACDONALD, 2002; USENIK et al., 2005; LENEHAN et al., 2006; CANLI and ORHAN, 2009). A significant increase of fruit size in fruit crops is one of the most common and important effects of pre-harvest GA_3 applications (CANLI and ORHAN, 2009) and gibberellins plus benzyladenine treatments (USENIK et al., 2005; STERN et al., 2007).

When compared to untreated control fruit, only 150 $mg·L^{-1}$ BA treatment significantly increased fruit pedicel length (Tab. 2). Sweet cherry fruits with long pedicels are preferred by consumers (CANLI and ORHAN, 2009). This is the first report that benzyladenine treatments can be used to increase the pedicel length of cherry fruit. Lower concentrations of BA or BA + GA_{4+7} applications did not affect pedicel length. HORVITZ et al. (2003) reported an increase in pedicel length of cherry fruit as a response to pre-harvest GA_3 applications. However, there are other reports that pedicel length is not always increased by GA_3 applications and the responses to GA_3 application were variable (CANLI and ORHAN, 2009).

No significant differences were observed between untreated fruit and PGR treated fruit with respect to fruit pH (Tab. 2).

All BA and BA + GA_{4+7} treatments significantly increased fruit firmness when compared with untreated fruit (Tab. 2). In agreement with our results, pre-harvest sprays of BA also increased fruit firmness in pear (STERN et al., 2007; CANLI et al., 2009). One of the most consistent effects of BA, GA, and BA plus GA combinations is also to increase firmness in fruit crops (USENIK et al., 2005; STERN et al., 2007; CANLI and ORHAN, 2009). The pre-harvest treatments of GA_3 increased fruit firmness in cherry (KAPPEL and MACDONALD, 2002; USENIK et al., 2005; CANLI and ORHAN, 2009).

When compared with untreated control fruit, most of the BA and BA + GA_{4+7} treatments increased the SSC of fruit except the 12.5 $mg·L^{-1}$ BA + GA_{4+7} and 100 $mg·L^{-1}$ BA treatments (Tab. 2). An increase in SSC as a response to GA application was also reported by other researchers (BASAK et al., 1998; LENEHAN et al., 2006). However, the responses to GA application were complex and variable and there were not always changes in SSC (FACTEAU et al., 1985b; KAPPEL and MACDONALD, 2002; HORVITZ et al., 2003).

When fruits were evaluated for quality parameters after the cold storage period, the firmness of the fruits treated with 25 and 50 $mg·L^{-1}$ BA + GA_{4+7} and 50 and 150 $mg·L^{-1}$ BA were still significantly higher than the untreated control fruit. Similarly, GA_3 treated cherry fruit maintained a superior firmness to control fruit during cold storage (CLAYTON et al., 2006; OZKAYA et al., 2006). GA_3 sprays also reduced pedicels browning in cold stored cherries (OZKAYA et al., 2006). Surface pitting devaluated the appearance of the cherry fruit, reflecting irregular formed sunken areas (CLAYTON and BIASI, 2003). No significant differences were observed between control and PGR treated fruit with respect to surface pitting (Tab. 3). On the other hand, cherries treated with 100 and 150 $mg·L^{-1}$ BA were significantly less susceptible to pitting than 12.5 and 50 $mg·L^{-1}$ BA + GA_{4+7} and 50 $mg·L^{-1}$ BA treatments. In addition, when compared to untreated control fruit, the pre-harvest application of 100 $mg·L^{-1}$ BA reduced surface pitting disorder of '0900 Ziraat' cherry about 5% after 4 weeks of cold storage; but the difference was not statistically significant (Tab. 3). GA_3 treatments improved resistance to surface pitting disorder in cherry (EINHORN et al., 2013). Similarly, pre-harvest GA_3 applications reduced the pitting in cold-stored 'Van', but had no effects on surface pitting in 'Lambert' cherries (LONEY and LIDSTER, 1980). Uncertainty continues regarding the effects of GAs on pitting of cherries. To the best of our knowledge, this is the first report on the effects of BA on postharvest surface pitting of cherries. At the end of the cold storage period, SSC content of 50 $mg·L^{-1}$ BA + GA_{4+7} -treated fruit was still significantly higher than that of control fruit. In general, most of the treated fruit had superior firmness and quality than control fruit at the end of the cold storage period. Similarly, pear fruits with high pre-cold storage period firmness were confirmed to have longer postharvest life and higher postharvest quality (CALVO and SOZZI, 2004; YEHIA and HASSAN, 2005).

Conclusion

A single pre-harvest application of 50 $mg·L^{-1}$ BA + GA_{4+7} increased the size and firmness of '0900 Ziraat' cherry. The BA alone or in combination with GA_{4+7} treatments showed a good potential for improving sweet cherry fruit storability by maintaining fruit firmness during the cold storage. These results are the first report on the effects of BA and BA + GA_{4+7} on fruit quality and shelf life of cherry and particularly useful for sweet cherry due to the relatively low application costs of the pre-harvest PGR treatments. Applications that led to high level of fruit firmness demonstrated to be more promising to improve postharvest life and quality.

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Address of the corresponding author:
E-mail: sercisli@gmail.com