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

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Summary
This study was carried out to evaluate the effects of pre-harvest benzyladenine (BA) and BA plus gibberellin (GA₄+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 + GA₄+7 (12.5, 25, and 50 mg·L⁻¹) when fruit was at its 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 + GA₄+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 + GA₄+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 + GA₄+7 and 50 and 150 mg·L⁻¹ BA were significantly firmer than the control. 50 mg·L⁻¹ BA + GA₄+7-treated fruit had higher SSC than untreated ones. In conclusion, fruit treated with the optimum dose of BA + GA₄+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 (BACVONKRALI et al., 2014; ROE 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, and also to delay maturity in high-cropping and self-fertile cherry varieties in North America and most other parts of the world (KAPPELL and MACDONALD, 2002), the effects of BA and BA + GA₄+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 + GA₄+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 Kayı (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 + GA₄+7 (Perlant 18 g·L⁻¹ GA₄+7 and 18 g·L⁻¹ BA), Fine Agrochemicals, Worcester, UK) using a handgun applicator when the fruit were at their straw

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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 Dev1) and the lowest Std Dev2 were within the acceptable limits (Std Dev1 - Std Dev2 = d, and d ≤ 4Std Dev2)], 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

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Concentration (mg·L⁻¹)</th>
<th>Fruit weight (g)ᵇ</th>
<th>Stone weight (g)ᵇ</th>
<th>Fruit weight / stone weight (g)ᵇ</th>
<th>Pedicel length (mm)ᵇ</th>
</tr>
</thead>
<tbody>
<tr>
<td>Control</td>
<td>0</td>
<td>7.71 b</td>
<td>2.24</td>
<td>3.44</td>
<td>4.82 b</td>
</tr>
<tr>
<td>BA + GA₁₄</td>
<td>12.5</td>
<td>8.36 ab</td>
<td>2.27</td>
<td>3.68</td>
<td>4.80 b</td>
</tr>
<tr>
<td>BA + GA₁₄</td>
<td>25</td>
<td>8.19 ab</td>
<td>2.20</td>
<td>3.72</td>
<td>4.97 ab</td>
</tr>
<tr>
<td>BA + GA₁₄</td>
<td>50</td>
<td>8.88 a</td>
<td>2.33</td>
<td>3.81</td>
<td>4.99 ab</td>
</tr>
<tr>
<td>BA</td>
<td>50</td>
<td>8.04 ab</td>
<td>2.62</td>
<td>3.06</td>
<td>5.00 ab</td>
</tr>
<tr>
<td>BA</td>
<td>100</td>
<td>7.62 b</td>
<td>2.48</td>
<td>3.07</td>
<td>4.95 ab</td>
</tr>
<tr>
<td>BA</td>
<td>150</td>
<td>8.35 ab</td>
<td>2.25</td>
<td>3.71</td>
<td>5.09 a</td>
</tr>
</tbody>
</table>

ᵃTrees were treated at straw-yellow color stage of the fruit. The control spray was composed of water and Tween-20.
ᵇMeans within a column followed by different letters are significantly different at P ≤ 0.05 by Tukey’s HSD test.

Tab. 1: Effects of pre-harvest benzyladenine (BA) and BA + gibberellin (GA₄₊₇) applications on fruit weight, stone weight and pedicel length of ‘0900 Ziraat’ sweet cherry (n=120)ᵃ.
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 benzyladene 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; LENEIHAN 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 fruit was 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 BIATTI, 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 and 150 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 (ONEY and LIDSTER, 1980). Uncertainty continues regarding the effects of GA\(_3\) 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; YEHA 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 im-

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**Tab. 2:** Effects of pre-harvest benzyladene (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.

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Concentration (mg·L(^{-1}))</th>
<th>Firmness (N)</th>
<th>SSC (%)</th>
<th>pH</th>
</tr>
</thead>
<tbody>
<tr>
<td>Control</td>
<td>0</td>
<td>9.30 c(^b)</td>
<td>17.22 c</td>
<td>3.75667</td>
</tr>
<tr>
<td>BA + GA(_{4+7})</td>
<td>12.5</td>
<td>9.96 ab</td>
<td>16.57 d</td>
<td>3.81267</td>
</tr>
<tr>
<td>BA + GA(_{4+7})</td>
<td>25</td>
<td>9.70 b</td>
<td>17.99 b</td>
<td>3.76455</td>
</tr>
<tr>
<td>BA + GA(_{4+7})</td>
<td>50</td>
<td>10.14 a</td>
<td>19.57 a</td>
<td>3.77467</td>
</tr>
<tr>
<td>BA</td>
<td>50</td>
<td>9.91 a</td>
<td>18.51 b</td>
<td>3.78800</td>
</tr>
<tr>
<td>BA</td>
<td>100</td>
<td>10.05 a</td>
<td>17.00 cd</td>
<td>3.74933</td>
</tr>
<tr>
<td>BA</td>
<td>150</td>
<td>10.05 a</td>
<td>18.35 b</td>
<td>3.75000</td>
</tr>
</tbody>
</table>

*aTrees were treated at straw-yellow color stage of the fruit. The control spray was composed of water and Tween-20.

*bMeans within a column followed by different letters are significantly different at P ≤ 0.05 by the Tukey’s HSD test.

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**Tab. 3:** Effects of benzyladene (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.

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Concentration (mg·L(^{-1}))</th>
<th>Firmness (Bf(^{13}))</th>
<th>SSC (%)</th>
<th>Surface pitting (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Control</td>
<td>0</td>
<td>1.54 d b</td>
<td>17.04 bc</td>
<td>17.29 ab</td>
</tr>
<tr>
<td>BA + GA(_{4+7})</td>
<td>12.5</td>
<td>1.59 cd</td>
<td>16.28 d</td>
<td>24.25 a</td>
</tr>
<tr>
<td>BA + GA(_{4+7})</td>
<td>25</td>
<td>1.74 a</td>
<td>17.17 b</td>
<td>21.86 bc</td>
</tr>
<tr>
<td>BA + GA(_{4+7})</td>
<td>50</td>
<td>1.70 ab</td>
<td>18.53 a</td>
<td>24.52 a</td>
</tr>
<tr>
<td>BA</td>
<td>50</td>
<td>1.68 abc</td>
<td>17.62 b</td>
<td>23.56 a</td>
</tr>
<tr>
<td>BA</td>
<td>100</td>
<td>1.63 bcd</td>
<td>16.68 cd</td>
<td>12.20 b</td>
</tr>
<tr>
<td>BA</td>
<td>150</td>
<td>1.75 a</td>
<td>16.92 c</td>
<td>15.96 b</td>
</tr>
</tbody>
</table>

*aTrees were treated at straw-yellow color stage of the fruit. The control spray was composed of water and Tween-20.

*bMeans within a column followed by different letters are significantly different at P ≤ 0.05 by the Tukey’s HSD test.

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proving 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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