Effects of BA, GA$_{4+7}$, and Daminozide on Fruit Set, Fruit Quality, Vegetative Growth, Flower Initiation, and Flower Quality of ‘Golden Delicious’ Apple

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Abstract. Five repeat spray applications at full bloom (FB) + 11 days through FB + 61 days of 50 ppm 6-benzylamino purine (BA) and/or gibberellins A$_{4+7}$ (GA$_{4+7}$) were made on limbs receiving 0 or 2000 ppm butanedioic mono-(2,2-dimethylhydrazide) (daminozide) at FB + 11 days. Similar repeat applications of BA and GA$_{4+7}$ were made at FB + 4 through FB + 57 days on limbs where all blossom clusters were removed at FB or all blossom clusters were retained. GA$_{4+7}$ depressed flower bud formation, whereas BA not only increased bloom but also overcame some of the inhibitory effects of GA$_{4+7}$ on flowering. The daminozide and BA combination increased flowering more than when each was applied separately. BA increased lateral flower development in the blossom cluster and increased the number of ”king” flowers surviving several mid-April freezes. Russeting was increased by BA, decreased by GA$_{4+7}$, and unaffected when BA and GA$_{4+7}$ were combined. BA increased fruit weight, length, and diameter when treatments were started at FB + 4 days. GA$_{4+7}$ increased fruit length but fruit weight was increased only when treatments were started at FB + 11 days. GA$_{4+7}$ decreased seed number, and when combined with BA, seed number was reduced even further.

Seeds may be a dominant factor in suppressing flowering and initiating the alternate bearing cycle characteristic of many apple cultivars (1). Seeds are also a major source of gibberellins (2). It is thought that gibberellins originating from developing seeds migrate to the subtending bud and inhibit flower bud formation (8, 15, 17). The importance of gibberellins in regulating flowering has been questioned recently since the peak in gibberellin-cultivars (1). Seeds are also a major source of gibberellins (2). Nevertheless, diffusion of relatively low levels of gibberellins at the specific time when seeds inhibited flower bud formation (19). It is thought that gibberellins originating from developing seeds migrate to the subtending bud and inhibit flower bud formation (19). Nevertheless, diffusion of relatively low levels of gibberellins from developing fruit prior to ”June drop”, and perhaps even from flowers, may be sufficient to inhibit flowering (2, 19).

Removal of spur leaves soon after bloom can inhibit flowering (11). Leaves as well as roots are sites of cytokinin biosynthesis (3). Over 2% of the cytokinins in young apple trees were found in the leaves and shoot tips (7). The promotive effects of leaves on flowering may be due to cytokinins supplied directly by the leaves or due to cytokinins being redistributed to the bud through the leaves (9, 16). The inhibitory effects of leaf removal on flowering can be reversed by a petiole application of cytokinins (9, 21).

The growth retardant daminozide can increase flower bud formation (15). It may be acting in part by reducing gibberellin levels diffusing to the spur bud. Hoad and Monselise (10) reported a reduction in the extractable GA-like substances from Malling (M) 26 rootstocks 5 days after daminozide treatment. Gibberellin levels in ‘Cox’s Orange Pippin’ were uninfluenced when a postbloom spray of daminozide was applied, although cytokinin levels were increased (22). Flowering of defoliated spurs was greatest when treatments of daminozide and cytokinins were combined (22).

Daminozide, gibberellins, and cytokinins can influence flower bud formation in apple but the interrelationships are not well understood. This investigation was undertaken to determine the individual and interrelated effects of daminozide, GA$_{4+7}$, and BA on flower bud formation, and to establish their influence on fruit set, growth, and fruit characteristics. ‘Golden Delicious’ was selected because of its biennial bearing tendency.

Materials and Methods

Uniform, 16-year-old ‘Golden Delicious’ trees on M 7 rootstocks growing at the Horticultural Research Center, Belchertown, Mass. were selected. In 1980, when all treatments were applied, the bloom was very heavy on all trees, averaging 18 blossom clusters/cm of limb circumference.

Exp. 1. Prior to bloom, 4 uniform limbs 12-15 cm in diameter were selected on 18 trees, their diameter was measured, and the total number of blossom clusters on each was counted. Trees were then grouped into 9 pairs according to their bloom density; at FB + 11 days, one of each pair of trees was sprayed to the drip point with 2000 ppm daminozide. Four limbs on each of the 18 trees were assigned randomly to one of the following 4 treatments. One limb was sprayed to the drip point with 50 ppm BA, a 2nd with 25 ppm GA$_{4+7}$, and a 3rd limb received both 50 ppm BA and 25 ppm GA$_{4+7}$. A 4th, tagged limb on each tree was not treated and served as the check. The BA and GA$_{4+7}$ treatments were applied at FB + 11, 20, 33, 45, and 61 days. Treatments were arranged in a randomized block design with a split for the daminozide treatments with 9 replications.

Fruit set was determined after the “June drop” period in July by counting the total number of persisting fruit on each tagged limb. Thirty fruit from each tagged limb were sampled at the normal harvest date. Fruit weight, length, diameter, and the
number of aborted and apparently viable seeds were determined. Samples were evaluated at the same time for the severity of russetting based on a visual scale of 1–5 (over 50% of the fruit surface russeted = 5, 40–50% = 4, 25–40% = 3, 10–25% = 2, and less than 10% = 1). After harvest, all of the leaves on each tagged limb were removed and the total leaf area was determined by a LI-COR Model 3100 Area Meter. Terminal growth was measured on 5 shoots per limb. Return bloom and fruit set were determined on the same tagged limbs in 1981.

Expt. 2 and 3. Four limbs, 12–15 cm in diameter, were selected on each of 2 sets of 8 trees prior to bloom and one of the following 4 treatments was assigned randomly to each limb: 1) all flower clusters retained (+ flowers), no plant growth regulator (PGR) treatment; 2) all flower clusters removed (− flowers), no PGR treatment; 3) − flowers, + PGR treatment; and 4) + flowers, + PGR treatment. BA was applied as a dilute spray at 50 ppm at FB + 4, 12, 27, 42, and 57 days in expt. 2. Expt. 3 was designed the same as expt. 2 except that 25 ppm GA4 + 7 was applied instead of BA. Treatments were arranged in a randomized complete block design with 8 tree replications. Thirty fruit were sampled at the normal harvest date from each tagged limb. Flower weight, length, diameter, the number of aborted and apparently viable seeds, fruit russeting, terminal growth, return bloom, and fruit set were determined as described in expt. 1. Twenty flowering spurs per tagged limb were selected at full bloom in 1981 in addition. The number of flowers in spur blossom clusters were counted, including cold-damaged “king” flowers. The percentage of clusters with “king” flowers not damaged by cold temperatures (viable) was determined also. In expt. 3, flower numbers in 1981 were evaluated only for treatments deflowered in 1980 since the + flower treatments had little or no return bloom in 1981.

Bartlett’s test for homogeneity of variance was performed on each variable in all 3 experiments to determine if transformation of the data were necessary. Logarithmic or arc sin transformations were utilized and the analysis of variance and mean separation procedures were repeated with the transformed data. Treatment means within the split plot of daminozide were separated by Duncan’s multiple range test at the 5% level using the whole plot error term in expt. 1. Comparisons of daminozide and nondaminozide treatments were made with single degree of freedom t-tests using a pooled split and whole plot error term with a tabulated t-value. In expt. 2 and 3, comparisons were made with single degree of freedom F tests.

### Results

Fruit set following application of GA4 + 7, BA, or GA4 + 7 + BA was similar to the control although limbs sprayed with GA4 + 7 alone had a greater initial bloom (Table 1). On daminozide-treated limbs, BA caused some fruit thinning and GA4 + 7 increased fruit set, but in combination they were equivalent to daminozide alone. Neither GA4 + 7 nor BA alone influenced leaf area although the combination on both untreated and daminozide-treated limbs did increase leaf size. No treatment influenced terminal growth when compared with untreated or daminozide-treated limbs. GA4 + 7 alone or in combination with daminozide essentially eliminated flowering in 1981. This underestimated the error terms in the statistical analysis, so the two GA4 + 7 treatments with and without daminozide were omitted for return bloom and fruit set in 1981, which then showed that bloom was greater on BA-treated limbs than on the check or BA + GA4 + 7-treated limbs. When BA or BA + GA4 + 7 were combined with daminozide there was greater flowering than on the corresponding nondaminozide PGR treatments or daminozide alone. BA reversed, but did not completely overcome, GA4 + 7-induced inhibition of flowering on daminozide-treated limbs. Return bloom on spurs was increased only when daminozide and BA were

**Table 1. Effects of 6-benzylamino purine (BA), gibberellins A4 + 7 (GA), and daminozide (D) on bloom, fruit set, and vegetative characteristics in 1980 and 1981.**

<table>
<thead>
<tr>
<th>Treatments</th>
<th>No. blossom clusters/cm limb circum.</th>
<th>No. fruit/100 blossom clusters</th>
<th>No. fruit/cm limb circum.</th>
<th>Mean leaf area (cm²)</th>
<th>Terminal growth (cm)</th>
<th>No. blossom clusters/cm limb circum.</th>
<th>No. fruit/100 blossom clusters</th>
<th>Terminal growth (cm)</th>
<th>No. fruit/cm limb circum.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Control</td>
<td>16.0 a</td>
<td>75.2 a</td>
<td>11.9 a</td>
<td>14.9 a</td>
<td>13.5 ab</td>
<td>0.59 a</td>
<td>4.7 a</td>
<td>51.0 a</td>
<td>0.51 a</td>
</tr>
<tr>
<td>BA 50</td>
<td>16.8 a</td>
<td>64.3 a</td>
<td>10.3 a</td>
<td>15.5 a</td>
<td>12.9 a</td>
<td>1.35 b</td>
<td>8.3 a</td>
<td>110.0 b</td>
<td>1.62 b</td>
</tr>
<tr>
<td>BA 25</td>
<td>21.0 b</td>
<td>64.0 a</td>
<td>13.2 a</td>
<td>15.3 a</td>
<td>18.4 b</td>
<td>0.04 b</td>
<td>0.3</td>
<td>14.8 b</td>
<td>0.04 b</td>
</tr>
<tr>
<td>BA 50 + GA 25</td>
<td>18.1 a</td>
<td>75.9 a</td>
<td>13.5 a</td>
<td>17.5 b</td>
<td>15.5 ab</td>
<td>0.38 a</td>
<td>2.8 a</td>
<td>11.5 b</td>
<td>0.58 a</td>
</tr>
<tr>
<td>D 2000</td>
<td>17.3 a</td>
<td>76.9 bc</td>
<td>13.1 b</td>
<td>15.9 a</td>
<td>15.9 a</td>
<td>1.17 a</td>
<td>8.5 a</td>
<td>96.4 a</td>
<td>0.94 a</td>
</tr>
<tr>
<td>BA 50 + D 2000</td>
<td>16.5 a</td>
<td>58.3 a</td>
<td>9.6 a</td>
<td>17.1 ab</td>
<td>15.1 a</td>
<td>4.46 c</td>
<td>27.4 b</td>
<td>95.3 a</td>
<td>3.25 c</td>
</tr>
<tr>
<td>GA 25 + D 2000</td>
<td>19.7 a</td>
<td>86.7 c</td>
<td>16.9 c</td>
<td>16.5 bc</td>
<td>15.3 a</td>
<td>0.08 b</td>
<td>1.1</td>
<td>39.7</td>
<td>0.15</td>
</tr>
<tr>
<td>BA 50 + GA 25 + D 2000</td>
<td>17.4 a</td>
<td>66.1 ab</td>
<td>11.3 ab</td>
<td>18.0 b</td>
<td>14.8 a</td>
<td>2.31 b</td>
<td>12.4 a</td>
<td>110.5 a</td>
<td>1.93 b</td>
</tr>
</tbody>
</table>

**Analysis of variance**

| Daminiozide | NS | NS | NS | NS | NS | ** | ** | NS | ** | ** |
| BA, GA      | *  | *  | ** | *  | NS | ** | ** | NS | ** | ** |
| D, BA, GA interaction | NS | * | NS | NS | NS | NS | * | NS | NS | NS |

| Significance | Trt 1 vs. Trt 5 | NS | NS | NS | NS | NS | NS | NS | NS | NS |
| Trt 2 vs. Trt 6 | NS | NS | NS | NS | NS | NS | NS | NS | NS | NS |
| Trt 3 vs. Trt 7 | NS | NS | NS | NS | NS | NS | NS | NS | NS | NS |
| Trt 4 vs. Trt 8 | NS | NS | NS | NS | NS | NS | NS | NS | NS | NS |

³BA and GA were applied at full bloom (FB) + 11, + 20, + 33, + 47, and + 61 days in 1980. D was applied at FB + 11 days in 1980.

³Analysis of variance and mean separation performed on transformed data via equations FSLC80 = LN (FSLC80), BCLC81 = LN (BCLC81 + 0.5), % bloom = ARC SIN (SQRT % bloom/54), FSLC81 = LN (FSLC81 + 0.5). Treatments 3 and 7 were not included. Mean separation within split plot, (---), by Duncan’s multiple range test, 5% level.

NS...**Non-significant (ns) or significant at 5% (*) or 1% (**) level.
Table 2. Effects of BA on terminal growth, bloom, fruit set, and blossom quality of fruiting and nonfruiting limbs.

<table>
<thead>
<tr>
<th>Treatments (ppm)</th>
<th>Terminal growth (cm)</th>
<th>No. blossom clusters/cm limb circum.</th>
<th>Flowering flowers/spur</th>
<th>No. flowers/spur cluster</th>
<th>Viable &quot;King&quot; flowers (%)</th>
<th>No. fruit/100 blossom clusters</th>
<th>No. fruit/cm limb circum.</th>
</tr>
</thead>
<tbody>
<tr>
<td>+ Flowers 26.0</td>
<td>0.9</td>
<td>3.6</td>
<td>2.9</td>
<td>21.8</td>
<td>5.6</td>
<td>0.1</td>
<td></td>
</tr>
<tr>
<td>- Flowers 32.0</td>
<td>13.4</td>
<td>52.0</td>
<td>3.2</td>
<td>39.1</td>
<td>40.7</td>
<td>5.6</td>
<td></td>
</tr>
<tr>
<td>+ BA 50 35.0</td>
<td>13.6</td>
<td>59.3</td>
<td>4.0</td>
<td>58.1</td>
<td>50.7</td>
<td>6.0</td>
<td></td>
</tr>
<tr>
<td>+ BA 50 31.2</td>
<td>3.8</td>
<td>19.6</td>
<td>3.3</td>
<td>55.0</td>
<td>33.6</td>
<td>1.2</td>
<td></td>
</tr>
</tbody>
</table>

Significance:

- Trt 1 vs. Trt 4: NS, **, **, **, **
- Trt 1 vs. Trt 2: *, **, **, NS, *
- Trt 2 vs. Trt 3: NS, NS, NS, **, *
- Trt 2 vs. Trt 4: NS, **, **, **, *
- Trt 3 vs. Trt 4: NS, **, **, NS, *
- Trt 1 and 2 vs. Trt 3 and 4: NS, **, **, **, **
- Trt 1 and 2 vs. Trt 3 and 4, Trt 1 and 4 vs. Trt 2 and 3: * , **, **, NS, NS, NS, NS, NS

Combined. Treatments that increased bloom correspondingly increased fruit set.

Crop load reduced terminal growth but BA had no influence in the year of application (Table 2). BA increased return bloom and fruit set regardless of BA treatment. The number of flowers in a blossom cluster was increased on both deflowered and flowering limbs treated with BA, but the largest number of flowers per cluster was on limbs that were deflowered and received BA. Crop load did not influence the number of flowers per cluster. On 15, 20, and 21 Apr., 1981 temperatures

Table 3. Effect of BA, GA, and daminozide (D) on fruit weight, russetting, L/D ratio, fruit length, and fruit diameter in 1980.

<table>
<thead>
<tr>
<th>Treatments (ppm)</th>
<th>Fruit weight (g)</th>
<th>Russetting rating</th>
<th>Length/diam (L/D ratio)</th>
<th>Fruit length (cm)</th>
<th>Fruit diam (cm)</th>
<th>No. aborted seeds/ viable seeds/ fruit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Control 97 a</td>
<td>2.7 b</td>
<td>0.93 c</td>
<td>5.75 a</td>
<td>6.21 b</td>
<td>0.4 a</td>
<td>8.1 c</td>
</tr>
<tr>
<td>BA 50 112 b</td>
<td>3.4 c</td>
<td>0.93 c</td>
<td>5.87 ab</td>
<td>6.31 b</td>
<td>0.8 b</td>
<td>8.0 c</td>
</tr>
<tr>
<td>GA 25 109 b</td>
<td>2.0 a</td>
<td>0.97 b</td>
<td>5.99 b</td>
<td>6.21 b</td>
<td>2.0 c</td>
<td>6.4 b</td>
</tr>
<tr>
<td>BA 50 + GA 25</td>
<td>105 b</td>
<td>2.5 b</td>
<td>0.98 a</td>
<td>5.93 b</td>
<td>6.05 a</td>
<td>4.0 d</td>
</tr>
<tr>
<td>BA 50 + GA 25 + D 2000</td>
<td>94 a</td>
<td>3.1 c</td>
<td>0.93 a</td>
<td>5.47 a</td>
<td>5.88 a</td>
<td>0.3 a</td>
</tr>
<tr>
<td>BA 50 + D 2000</td>
<td>105 b</td>
<td>3.5 d</td>
<td>0.94 a</td>
<td>5.66 b</td>
<td>6.05 b</td>
<td>0.6 a</td>
</tr>
<tr>
<td>GA 25 + D 2000</td>
<td>95 a</td>
<td>1.9 a</td>
<td>0.96 b</td>
<td>5.65 b</td>
<td>5.88 a</td>
<td>1.6 b</td>
</tr>
<tr>
<td>D 2000 103 ab</td>
<td>2.3 b</td>
<td>0.97 b</td>
<td>5.82 b</td>
<td>5.99 ab</td>
<td>3.6 c</td>
<td>4.8 a</td>
</tr>
</tbody>
</table>

Analysis of variance:

- Daminozide: NS, NS, NS, NS, * NS, NS
- BA, GA: ** NS, NS, NS, NS
- D, BA, GA: NS, NS, NS, NS, NS, NS

Significance:

- Trt 1 vs. Trt 5: NS, * NS, NS, ** NS, NS
- Trt 2 vs. Trt 6: NS, NS, NS, NS, NS, NS
- Trt 3 vs. Trt 7: NS, NS, NS, NS, NS, NS
- Trt 4 vs. Trt 8: NS, NS, NS, NS, NS, NS

Notes:

- Flowers removed at full bloom (FB). BA was applied at FB + 4, + 12, + 27, + 42, and 57 days in 1980.
- Analysis of variance and mean separation performed on transformed data via equations: \( BCLC81 = \ln (BCLC81 + 0.5) \), % bloom = \( \text{ARC SIN} (\text{SORT} \% \text{ bloom}/90) \), \( \text{FSLC81} = \ln (\text{FSLC81} + 0.5) \).
- Ns. * NS or significant at 5% (*) or 1% (**) level.

of $-2.8^\circ$C, $-2.8^\circ$ and $-2.2^\circ$, respectively, were recorded near the plots following a period of above-average temperatures. BA treatments on deflowered and flowering limbs the previous year increased the percentage of ‘king’ flowers surviving the cold temperature. More ‘king’ flowers survived on branches that were deflowered the previous year.

GA$_4$ + 7 treatments did not influence terminal growth, return bloom, fruit set, the number of flowers per cluster, or the percentage of viable (surviving cold temperatures) “king” flowers (data not shown).

BA or GA$_4$ + 7 alone or in combination and BA + daminozide increased fruit weight (Table 3). Russetting was increased by BA and decreased by GA$_4$ + 7 but when the 2 were combined russetting was not different from the control fruit. Daminozide increased russetting slightly. The L/D ratio was increased by GA$_4$ + 7 treatments, and when combined with BA there was a further increase. There was a comparable increase in the L/D ratio on the GA$_4$ + 7 and GA$_4$ + 7 + BA-treated fruit when daminozide was added. GA$_4$ + 7 alone or when combined with BA increased fruit length whereas BA increased fruit length only when combined with daminozide and only in comparison to daminozide-treated fruit. Fruit diameter was reduced when BA and GA$_4$ + 7 were combined and by all daminozide treatments except that in combination with BA + GA$_4$ + 7. GA$_4$ + 7 alone or with daminozide increased the number of aborted seeds and reduced the number of viable seeds. BA had no influence on the number of aborted or viable seeds, except when it was combined with GA$_4$ + 7, there was a synergistic increase in aborted seeds and a corresponding decrease in viable seeds. Daminozide did not influence seed number.

BA increased fruit weight, L/D ratio, fruit length, fruit diameter, and russetting but had no influence on seed number (Table 4). GA$_4$ + 7 increased the L/D ratio, fruit length, the number of aborted seeds, and decreased russetting (Table 4).

**Discussion**

Cytokinins in sap reach a peak at full bloom and the concentration drops to unmeasurable levels by mid- to late summer (18). Luckwill (15) proposed that flowering may be controlled by a balance between gibberellins and cytokinins. He suggested that gibberellin production in shoots must be reduced substantially while cytokinin levels are still sufficiently high to stimulate partially the development of lateral buds into flowers. An interaction between gibberellins and cytokinins was demonstrated clearly in this investigation. GA$_4$ + 7 reduced and BA increased flowering, but when they were combined these effects were nullified (Table 1). If one assumes that the inhibition of flowering on spurs is due to gibberellins diffusing from flowers and/or young fruit, then the application of cytokinins can overcome this inhibition imposed by the seeds. It thus appears that the major effect of cytokinins on flowering may be overcoming GA-induced flower bud inhibition. BA increased flowering on limbs that carried fruit, whereas BA applied to limbs lacking fruit had no effect on flowering (Table 2), similar to the earlier findings of Ramirez and Hoad (21).

It has been suggested that daminozide may be influencing flowering and vegetative growth by reducing gibberellin levels since an application of 2000 ppm of daminozide on M 26 rootstocks caused growth retardation and a reduction in the gibberellin content of shoot tips (10). However, in a later investigation on ‘Cox’s Orange Pippin’, 2000 ppm of daminozide reduced shoot growth and increased flower bud formation without a reduction in gibberellin levels in either shoot tips or developing seeds (22). Alternatively, daminozide might increase bloom, not by directly influencing gibberellin levels, but by antagonizing the action of gibberellins or by increasing the cytokinin content. Daminozide-induced bloom increases were comparable to that caused by the BA treatments (Table 1) and daminozide can increase the cytokinin content of seeds (22). Thus, bloom could be increased by a greater amount of cytokinins in the seeds and/or leaves moving into the spur bud. We have confirmed the promotive effects of cytokinins on flowering and the additive interaction with daminozide by Ramirez and Hoad (21) when cytokinins were applied as micro-droplets to cut apple leaf petioles. It has been further established that increased flowering can be accomplished by spray applications of BA. Daminozide sometimes is included in the chemical thinning program on biennial bearing trees having a “snowball” bloom (24). Thinning activity and increased fruit length, diameter, and weight the year of application and increased bloom, improved blossom cluster quality, and increased resistance to cold damage the year following treatment (Tables 1, 2, and 3) may justify inclusion of BA in the spray program especially on cultivars that may be difficult to thin and tend to be biennial.

Early application of growth regulators on bearing trees may be necessary since inhibition of flowering may occur prior to, at, or soon following bloom (19). Treatments of limbs with BA at FB + 4, 12, 27, 42, and 57 days in 1980 stimulated flower bud formation on bearing trees in 1981 (Table 2) whereas an identical treatment initiated one week later failed to stimulate flowering on bearing spurs (Table 1). Presumably, it is the gibberellins diffusing from flowers or very young fruit that inhibit flowering. Some inhibition of flowering occurred prior to FB + 11 days. Several applications of BA at 9–14 day intervals were made in this study. Since some flower bud inhibition can and did occur early it is likely that the later BA treatments had little or no effect on influencing flower initiation and thus, may be unnecessary.

**Table 4. Effects of BA and GA on fruit characteristics in 1980.**

<table>
<thead>
<tr>
<th>Treatments (ppm)</th>
<th>Fruit wt (g)</th>
<th>Length/diam (L/D ratio)</th>
<th>Fruit length (cm)</th>
<th>Fruit diam (cm)</th>
<th>Russetting rating</th>
<th>No. aborted seeds/ fruit</th>
<th>No. viable seeds/ fruit</th>
</tr>
</thead>
<tbody>
<tr>
<td>+ Flowers - BA 50</td>
<td>117</td>
<td>0.94</td>
<td>6.04</td>
<td>6.45</td>
<td>2.7</td>
<td>0.4</td>
<td>8.2</td>
</tr>
<tr>
<td>+ Flowers + BA 50</td>
<td>136**</td>
<td>0.97**</td>
<td>6.57**</td>
<td>6.75**</td>
<td>3.4**</td>
<td>0.5 NS</td>
<td>7.5 NS</td>
</tr>
<tr>
<td>+ Flowers - GA 25</td>
<td>119</td>
<td>0.93</td>
<td>5.93</td>
<td>6.42</td>
<td>2.6</td>
<td>0.4</td>
<td>8.3</td>
</tr>
<tr>
<td>+ Flowers + GA 25</td>
<td>121 NS</td>
<td>0.96**</td>
<td>6.24*</td>
<td>6.48 NS</td>
<td>2.0**</td>
<td>1.3**</td>
<td>7.0 NS</td>
</tr>
</tbody>
</table>

1BA, GA were applied at full bloom (FB) + 4, + 12, + 27, + 42, and + 57 days in 1980.
2Scale 5 = over 50%; 4 = 40% to 50%; 3 = 25% to 40%; 2 = 10% to 25%; 1 = less than 10%.
3NS,***Nonsignificant (ns) or significant at 5% (*) or 1% (**) levels for paired data.
Fruit weight was increased in the absence of thinning when either GA$_{4+7}$ or BA were applied starting at FB + 11 days but not when used in combination (Table 3). Sprays of GA$_{4+7}$ and BA can increase fruit weight of ‘Delicious’ primarily by elongation of the calyx end, and maximum response appears to be when applied during the bloom period (23). However, Looney (14) has reported that treatments with GA$_{4+7}$ and BA increased the L/D ratio and especially fruit weight for at least 5 weeks after bloom. The increase in fruit weight with GA$_{4+7}$ can be attributed to an increase in fruit length, whereas neither length nor diameter were influenced by BA (Table 3). Letham and Williams (13) reported increases in fruit weight on ‘Jonathan’ when there was no effect on the L/D ratio. The increase was attributed to an increase in cell density in the cortex area of the fruit. Although BA increased fruit weight in expt. 2, (Table 4) we can not be certain whether the increase may have been due to either thinning or to the BA itself, since fruit set was not taken on these trees.

The number of flowers in each spur was increased on both fruiting and nonfruiting limbs by BA application (Table 2). The increase in flowers within each blossom cluster on nonfruiting limbs treated with BA was particularly striking since there was no accompanying effect on the total number of flowering spurs (Table 2). Differentiation of the floral primordia is actually thought to begin in the lateral meristems of the inflorescence, but the terminal or “king” flower soon begins to develop faster and overtakes the lateral flowers (5). Therefore, BA probably increased the number of flowers most likely by enhancing lateral flower development. Kender and Carpenter (12) and Williams and Stahly (25) have reported stimulation of lateral buds into vegetative shoots by BA but there have been no reports of BA promotion of flower primordia development from a lateral bud within a spur. The presence of fruit the previous year reduced the numbers of flowers developing per spur. BA application could reverse partially this inhibition and cause flower numbers per spur to be increased to the levels on limbs lacking fruit but not receiving BA.

When cold temperatures occurred in 1981 (15–21 Apr.), flower buds were at the tight cluster stage. Proebsting and Mills (20) reported that some cold damage to apple buds can occur when apple flower buds in the tight cluster stage are exposed to a temperature of −3.9°C. A temperature as low as −4.0°C probably occurred in the block of trees since temperatures of −2.8°C to −2.3°C were recorded in a protected and elevated section of the orchard nearby. Consequently, we feel that the death of “king” flowers was due to freeze damage and the reduced damage on BA-treated limbs was due to a BA-induced increase in cold hardness. One can speculate that increased resistance to cold damage caused by BA is due to a larger, more vigorous bud. Limbs receiving BA had more flower buds (Table 2). However, there is no clear evidence in the literature that relates bud vigor with an ability to withstand cold temperatures. Alternatively, the BA treatment could have slowed the development of the “king” flower buds, thus making them more resistant to the cold, although no visual differences at this early stage of development could be seen. Flowers in a less advanced stage of development are more resistant to cold damage than more advanced flowers (20). This is true not only between flower clusters but also within flower clusters since it was observed that only the more advanced “king” flowers appeared damaged whereas the less advanced lateral flowers were uninjured (Table 2). The heavy crop load the previous year (12–13 fruit/cm limb circumference) with the associated reduction in spur leaf area (Table 1) undoubtedly weakened trees, caused smaller flower buds, and ultimately made flowers more susceptible to freeze damage. A heavy crop load can decrease the cold hardiness of peach buds (4) and in some instances this is also true with apple buds (6).

**Literature Cited**

Shoot extension in bearing pistachio trees begins during the latter part of March and terminates in early May. Normally, the terminal and subapical one or 2 buds on the new growth remain vegetative (7). The remaining axillary buds on current shoots differentiate into inflorescence buds early in April (16). Some of these inflorescence buds subsequently abscise during July and August when seed growth and development are progressing rapidly. The abscission of inflorescence buds results in alternate or biennial bearing in pistachio (7).

Application of GA₃ has been reported to inhibit the development of flower buds in fruit trees such as Prunus (5, 8) and apples (9). Gibberellins also have been implicated in the abscission process of several explants (17). These observations lead one to speculate that gibberellins may be involved in inflorescence bud abscission in pistachio. The work reported here was undertaken to test this idea by comparing the response of lateral inflorescence buds to exogenous GA₃ with that of terminal vegetative buds.

Materials and Methods

Ten-year-old ‘Kerman’ pistachio trees in the Wolfskill Experimental Orchard, Winters, Calif., were used in this study.

Expt. 1. Absorption of GA₃ through the rachis. On 6 May, all fruit clusters except one were removed from one-year-old wood of 4 branches on each of 8 trees. The young fruits and their subtending lateral branchlets of the remaining cluster (panicle) were removed also, leaving the central axis (rachis) with one fruit attached near the base. Previously it was found that a single, developing fruit on the rachis was sufficient to prevent its abscission. The tip of the rachis beyond the single fruit was removed by an oblique cut and the cut end wrapped in a ball of cotton moistened with 5 ml of 50, 500, or 5000 μM GA₃. The cotton balls were then covered with aluminum foil to prevent desiccation. The control treatment consisted of a cotton ball containing water with a volume of ethanol (0.3–0.6 ml) equal to that used for dissolving GA₃. The cotton balls were rewetted every 3 days until termination of the experiment. The same treatments were applied to different rachises on June 16. Eight inflorescence buds with part of the adjacent shoots were collected at 7-day intervals after treatment for anatomical study. The others were left intact for observation, particularly with regard to abscission.

Expt. 2. Injection of GA₃ into inflorescence buds. On 6 June, 6 nonfruiting branches, each having 5 to 8 inflorescence buds, on each of 6 trees were selected. All buds on each branch were injected with 6 μl of a solution containing 1, 10, 100, or 1000 μM GA₃. Control buds were injected with 6 μl of water containing a volume of ethanol equal to that used for dissolving GA₃. An additional control consisted of buds that were not injected. The number of buds retained on each shoot was determined and recorded periodically so that percentage of bud retention could be calculated.

Expt. 3. Spraying of nonfruiting branches with GA₃. On 7 Aug., 4 nonfruiting branches on each of 6 trees were chosen and sprayed with 72, 720, and 2880 μl GA₃. Control branches were sprayed with water containing a volume of ethanol equal to that used for dissolving GA₃. The number of buds retained on each shoot was determined 2 months after treatment.

Expt. 4. Injection of GA₃ into terminal vegetative buds. Terminal vegetative buds on 4 branches on each of 6 trees were injected with 6 μl of 10, 100, or 1000 μM GA₃ solution on 21 July, more than 2 months after shoot elongation had ceased. Control buds were injected with water containing a volume of ethanol equal to that used for dissolving GA₃. These treatments were applied again to different buds on 6 Aug. Three buds of each treatment were collected 7 days after injection for anatomical studies. The other buds were left intact for observation.

Terminal vegetative and lateral inflorescence buds sampled periodically were fixed in 1 formalin : 1 propionic acid : 18 70% ethanol (by volume) solution and dehydrated in a tertiary butyl alcohol series. After embedding in paraffin, they were sectioned at 8 μm and the median sections were stained with safranin-fast green; sections then were examined under a light microscope.