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# Effects of Prohexadione-Ca and $GA_{4+7}$ on Scarf Skin and Fruit Maturity in Apple

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***Abstract.*** **A series of experiments were undertaken to compare the effects of individual and combined applications of $GA_{4+7}$ and prohexadione-Ca (P-Ca) on scarf skin and fruit quality parameters on red strains of 'Rome Beauty' and 'Gala' apples. Three applications of $GA_{4+7}$ at 10-day intervals beginning at petal fall (PF) significantly reduced scarf skin severity in all experiments. A single application of P-Ca at PF had no effect on scarf skin in one experiment but reduced scarf skin severity in two further experiments. Combining P-Ca with the first of three $GA_{4+7}$ sprays as a tank mix reduced the severity of scarf skin more effectively than either material alone in two of three experiments at $P < 0.05$ and in all three experiments at $P < 0.10$. Combining P-Ca with the first application of $GA_{4+7}$ as a tank mix generally reduced scarf skin as effectively as applying P-Ca and the first $GA_{4+7}$ spray two days apart, although in one experiment, greater scarf skin control was achieved when P-Ca was applied 2 days after the first $GA_{4+7}$ spray. A single application of P-Ca at PF consistently reduced, and three applications of $GA_{4+7}$ consistently increased, mean fruit weight at harvest compared with the control. The economic benefits as a result of reducing scarf skin severity with P-Ca and $GA_{4+7}$ sprays will need to be balanced against the negative effect of P-Ca on mean fruit weight. There is no antagonism between early season P-Ca and $GA_{4+7}$ sprays for scarf skin control, and P-Ca may increase the efficacy of $GA_{4+7}$ sprays for scarf skin control in apple.**

Scarf skin is a cosmetic defect of apples (*Malus ×domestica* Borkh.) in which the fruit surface is milky or opaque in appearance. The milky appearance is the result of light being reflected from heavily pigmented hypodermal cells into intercellular air spaces that arise several cell layers below the fruit epidermis (Dayton, 1959; Ferree et al., 1984a). The disorder was first described in 'Sweet Winesap' and 'Black Gilliflower' by Beach et al. (1905) but is frequently observed in red strains of modern cultivars such as 'Rome' (Ferree, 1994) and 'Gala'. Scarf skin is initiated during the first 60 d after bloom (Ferree et al., 1984b); its severity is modified by the microclimate around the fruit and is increased by some fungicide sprays (Ferree et al., 1984a) and reduced by gibberellic acid ($GA_{4+7}$) sprays during this period (Ferree et al., 1984b). Byers (1977) emphasized the potential significance of the disorder when the U.S. Federal State Inspection Service lowered the fruit grade if an area greater than 15% of the skin surface was affected. Although there are currently no national grade standards for scarf skin for fresh market apples in the United States, there have been several instances in Ohio when packed apples have been rejected by the retailer as a result of excessive scarf skin. Most packing houses in the United States would adopt a grade standard for scarf skin similar to that for russet for U.S. No. 1 grade fruit, i.e., the aggregate area of the apple covered by the defect should not be greater than 25%.

Prohexadione-Ca (P-Ca) is a gibberellin biosynthesis inhibitor that is being used in apple production systems to reduce vegetative growth, improve fruit set, and reduce the incidence of fire blight and other diseases (Rademacher and Kober, 2003). Because the effects of P-Ca on shoot growth are short-lived (Byers and Yoder, 1999), multiple applications are required for season-long control of shoot growth in most growing environments. P-Ca frequently results in increased fruit set (Byers et al., 2004; Glenn and Miller, 2005; Greene, 1999; Unrath, 1999) and may reduce the efficacy of some postbloom chemical thinning sprays (Greene, 1999). The initial application of P-Ca is normally made when new shoot growth is approx. 2.5 to 5 cm in length, corresponding in most seasons to about the time of PF. This is also when the first of three or four $GA_{4+7}$ applications is made for russet or scarf skin control. Miller (1998) reported that $GA_{4+7}$ applications to reduce russet in 'Golden Delicious' reduced the level of shoot growth control normally obtained with P-Ca, and that high rates of P-Ca (above 188 ppm) had some positive effects on reducing the level of fruit russet. However, P-Ca also reduced the efficacy of $GA_{4+7}$ applications for reducing fruit cracking in 'Stayman'. It is not known at this time if application of the gibberellin biosynthesis inhibitor P-Ca will interfere with the efficacy of $GA_{4+7}$ sprays for scarf skin control in apple.

The objectives of the present studies were to compare the effects of P-Ca and $GA_{4+7}$, alone or in combination, on scarf skin and other fruit quality parameters at harvest in red strains of 'Gala' and 'Rome' apples.

## Materials and Methods

*Expt. 1: 2003, OARDC, Wooster, Ohio.* Thirty-six uniform 'Buckeye Gala' trees on B.9 rootstock were selected in 2003 from within a group of trees planted in 1998 at a spacing of 4.0 m × 2.5 m on the OARDC research farm in Wooster, Ohio. Six treatments described subsequently were applied to fully guarded single-tree plots arranged in a randomized complete block design with six replications. The six treatments were 1) an unsprayed control; 2) 20 ppm $GA_{4+7}$ (ProVide 50W; Valent BioSciences Corporation, Libertyville, Ill.) applied 0, 10, and 20 d after PF (PF, 6 May); 3) 250 ppm P-Ca (90 g Apogee per 100 L, Apogee; BASF Corporation, Research Triangle Park, N.C.) applied at PF; 4) 20 ppm $GA_{4+7}$ and 250 ppm P-Ca applied at PF as a tank mix followed by applications of 20 ppm $GA_{4+7}$ 10 and 20 d after PF; 5) 250 ppm P-Ca applied at PF followed by 20 ppm $GA_{4+7}$ applied 2, 10, and

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20 d after PF; and 6) 20 ppm $GA_{4+7}$ applied at 0, 10, and 20 d after PF and 250 ppm P-Ca applied two d after PF. P-Ca was applied without a surfactant or a water conditioner. Spray treatments were applied to individual trees to runoff with a high-pressure hand gun. Fruit set was calculated from counts of total cluster number per tree at bloom and total fruit number per tree in July after the completion of fruit drop. A random sample of 20 fruit per tree was removed at harvest and rated for scarf skin severity (rating of 1 = no scarf skin, 5 = severe milk color blocking red) and the percentage of fruit surface covered with scarf skin. The length of 10 random shoots per tree and total fruit yield per tree were also recorded at harvest.

*Expt. 2: 2004, Henderson County, N.C.* $GA_{4+7}$ (20 ppm) was applied to mature 'Red Rome'/M.7 apple trees in a commercial orchard in Henderson County, N.C., at PF in 2004, followed by 250 ppm P-Ca two d after PF. In a second treatment, 20 ppm $GA_{4+7}$ was applied as a tank mixture with 250 ppm P-Ca at PF. Both treatments received repeat applications of 20 ppm $GA_{4+7}$ 10 and 20 d after PF. The spray treatments were applied with an air-blast sprayer calibrated to deliver 1400 L per hectare, 80% of the calculated tree row volume at full canopy development. In addition to the two spray treatments, there was an unsprayed control. The treatments were applied to 20 tree plots arranged in a randomized complete block design with four replications, each replicate on an alternate row within the orchard. Because there were significant infections of fire blight within the orchard in 2004, the number of shoot infections was counted on 10 trees per plot in mid-June. At harvest, a random sample of 60 fruit was removed from each of two canopy zones (upper half and lower half) per plot, the 60 fruit per zone representing a pooled sample of 10 fruit from each of six trees per plot. The severity of scarf skin, determined as the percent of total surface area affected in increments of 10%, was rated on each fruit.

*Expts. 3 and 4: 2005, Henderson County, N.C.* Two studies with identical experimental designs were conducted on separate commercial orchards in Henderson County, N.C., in 2005 to evaluate the individual and combined effects of $GA_{4+7}$ and P-Ca on scarf skin, one on 'Red Rome'/M.7 and the other on 'Buckeye Gala'/M.7. Each study included the following four treatments: an untreated control; a single application of 138 ppm P-Ca at PF; applications of 15 ppm $GA_{4+7}$ (Provide 10 SG, Valent USA) at 0, 10, and 20 d after PF; and a combined treatment where the PF spray of 15 ppm $GA_{4+7}$ was tank mixed with 138 ppm P-Ca. The spray treatments were applied to six-tree plots with an air-blast sprayer calibrated to deliver 1680 L per hectare in each orchard, 80% of the calculated tree row volume at full canopy development. The treatments were arranged in a randomized complete block design experiment with six replications. A random sample of 100 fruit was removed from each plot at harvest, 25 fruit from each of the middle four trees per plot. The percent of surface area affected by scarf skin was rated on each of the sample fruit in increments of 10%. Mean fruit weight was calculated from the total weight of the 100 fruit sample per plot. An additional sample of 20 fruit per plot was removed for assessment of treatment effects on fruit maturity parameters: flesh firmness, soluble solids content, and starch index (SI). Firmness was determined at two locations on each apple with an Effegi pressure tester equipped with an 11.1-mm probe. SI was determined using the Cornell University generic starch–iodine index chart for apples (rating scale of 1–8).

*Statistical analysis.* The general linear models procedure of the Statistical Analysis System (SAS Institute, Cary, N.C.) was used to test for treatment effects. Means separations were determined using Duncan multiple range test (DMRT) at the 5% significance level. Single df contrasts were used to test for effects where appropriate.

## Results

*Expt. 1.* Although there were large differences in fruit set between treatments, these were not significantly different from the control at $P < 0.05$ (Table 1), indicating considerable variability in the data. $GA_{4+7}$ increased mean fruit weight of 'Buckeye Gala' at harvest by 13 g compared with the control treatment, whereas P-Ca reduced mean fruit weight by 14 g compared with the control. When $GA_{4+7}$ and P-Ca were both applied, mean fruit weight was reduced by 12 to 24 g compared with the control. The effects of treatment on yield were not significant, although there was a trend for higher yields on trees that received P-Ca. A single application of P-Ca at PF reduced mean shoot length at harvest to the same extent on trees that did not receive $GA_{4+7}$ compared with trees that did, indicating that $GA_{4+7}$ sprays did not reduce the effects of a single application of P-Ca at PF on shoot growth.

All treatments resulted in a significant reduction in both the scarf skin rating and the percentage of the fruit surface covered with scarf skin compared with the control. Three applications of $GA_{4+7}$ or a single application of P-Ca at PF reduced the proportion of the fruit surface covered with scarf skin to 17% and 21%, respectively, compared with 31% of the surface area covered on fruit from control trees (Table 1). $GA_{4+7}$ reduced scarf skin more effectively than P-Ca. Scarf skin was less severe on trees that received sprays of both $GA_{4+7}$ and P-Ca compared with trees that were only sprayed with either $GA_{4+7}$ or P-Ca. In addition, combining P-Ca with the first application of $GA_{4+7}$ as a tank mixture was less effective than when the applications were made 2 d apart.

*Expt. 2.* P-Ca or $GA_{4+7}$ increased the proportion of fruit with a low severity of scarf skin (<10% of the fruit surface covered) and reduced the proportion of fruit with a high severity of scarf skin (>20% of the fruit surface covered) compared with the untreated control (Table 2). The reduction in scarf skin severity was the same if the initial applications were made 2 d apart or as a tank mixture. There was a significant interaction between treatment and canopy position for two of the scarf skin severity categories (0–10% coverage and 21–30% coverage). Scarf skin was more severe in the lower canopy than in the upper canopy on control trees, whereas this trend was reversed in the treated trees. Only 11% of fruit from the lower canopy of control trees had 0% to 10% coverage with scarf skin, whereas ≈54% of the fruit from the upper canopy had 0% to 10% scarf skin coverage at the same position in the canopy of treated trees. In addition to reducing the severity of scarf skin, both of the P-Ca and $GA_{4+7}$ treatments reduced the number of fire blight shoot strikes per tree in June ($P \leq 0.005$), from an average of 8.2 strikes per tree in the control to 2.6 and 2.9 shoot strikes per tree in the tank mix and separate spray treatments, respectively (data not shown).

*Expts. 3 and 4.* Fruit in the 'Red Rome' study were relatively free from scarf skin with 71% of the fruit from control trees having 10% or less of their surface covered with scarf skin (Table 3). The incidence of scarf skin was much higher in the 'Buckeye Gala' study, with only 22% of the fruit on control trees having 10% or less of the fruit surface covered with scarf skin. Either a single application of 138 ppm P-Ca at PF or three applications of 15 ppm $GA_{4+7}$ at

Table 1. Effects of $GA_{4+7}$ and prohexadione-Ca (P-Ca), alone or in combination, on fruit set, shoot length, yield per tree, mean fruit weight, and scarf skin of 'Buckeye Gala'/B.9 apple trees in Wooster, Ohio, in 2003 (Expt. 1).

| Treatment | Fruit set (%) | Fruit wt (g) | Yield (kg) | Shoot length (cm) | Scarf skin Rating[w] | Scarf skin Coverage (%) |
|---|---|---|---|---|---|---|
| Control | 57 ab[v] | 160 b | 11.9 | 30.6 a | 3.9 a | 31 a |
| $GA_{4+7}$[z,x] | 67 ab | 173 a | 11.7 | 22.9 ab | 2.9 c | 17 c |
| P-Ca[z] | 56 ab | 146 c | 13.5 | 15.1 b | 3.4 b | 21 b |
| $GA_{4+7}$[z,x] + P-Ca[z] | 54 b | 148 c | 13.0 | 21.4 b | 2.1 d | 10 d |
| P-Ca[z], $GA_{4+7}$[y,x] | 94 ab | 136 d | 13.5 | 19.7 b | 2.0 d | 7 e |
| $GA_{4+7}$[z,x], P-Ca[y] | 104 a | 147 c | 13.2 | 19.5 b | 1.7 e | 4 e |

[z]Applications made on 6 May.
[y]Applications made on 8 May.
[x]Additional $GA_{4+7}$ applications made on 14 May and 27 May.
[w]Rating: 1 = no scarf skin to 5 = severe milk color blocking red.
[v]Means within columns with different letters are significantly different at $P \leq 0.05$ using Duncan multiple range test.

10-d intervals beginning at PF reduced the severity of scarf skin in the 'Red Rome' study compared with the control. Combining P-Ca with the first application of $GA_{4+7}$ as a tank mixture resulted in a further reduction in scarf skin on 'Red Rome' ($P \leq 0.05$) compared with $GA_{4+7}$ alone. P-Ca alone was without effect on scarf skin in the 'Buckeye Gala' experiment, whereas $GA_{4+7}$ sprays increased the proportion of fruit with low scarf skin severity. Combining P-Ca with the first application of $GA_{4+7}$ as a tank mixture increased the proportion of 'Buckeye Gala' fruit with a low scarf skin severity compared with $GA_{4+7}$ sprays alone at $P \leq 0.10$ but not at $P \leq 0.05$.

A single application of 138 ppm P-Ca at PF reduced mean fruit weight of both 'Red Rome' and 'Buckeye Gala' at harvest by 22 g and 10 g, respectively, compared with the control (Table 4). $GA_{4+7}$ sprays increased mean fruit weight of 'Red Rome' and 'Buckeye Gala' by 12 g and 7 g, respectively, compared with the control. The positive effect of $GA_{4+7}$ on mean fruit weight did not overcome the negative effect of P-Ca on mean fruit weight when both materials were applied to 'Red Rome' in combination. However, for 'Buckeye Gala', the contrasting effects of $GA_{4+7}$ and P-Ca on mean fruit weight nullified each other. Fruit weight for the combined treatment was not different from the control. The effects of treatment on crop load were not measured in these experiments. There were minor treatment effects on fruit maturity parameters at harvest. $GA_{4+7}$, either alone or in combination with P-Ca, reduced flesh firmness of 'Red Rome' by ≈4.4 N. P-Ca reduced the soluble solids concentration of both cultivars compared with the control. Only the combined treatment reduced flesh firmness of 'Buckeye Gala'.

Table 2. Effects of $GA_{4+7}$ and prohexadione-Ca (P-Ca) on frequency distribution of fruit within different categories of scarf skin severity at harvest for two canopy positions within 'Red Rome'/M.7 apple trees in Henderson County, NC, in 2004 (Expt. 2).

| | | Scarf skin severity (% fruit surface area covered) | | | | | |
|---|---|---|---|---|---|---|---|
| Treatment | Canopy position | 0–10 | 11–20 | 21–30 | 31–40 | 41–50 | >50 |
| Control | Lower | 11 | 38 | 29 | 14 | 3 | 5 |
| | Upper | 20 | 38 | 25 | 10 | 3 | 4 |
| Tank mix[z] | Lower | 54 | 31 | 12 | 3 | 0 | 0 |
| | Upper | 25 | 41 | 21 | 10 | 1 | 3 |
| Separate sprays[x] | Lower | 55 | 34 | 11 | 0 | 0 | 0 |
| | Upper | 37 | 40 | 17 | 5 | 1 | 0 |
| *P* | | | | | | | |
| Treatment | | 0.0004 | NS | 0.0001 | 0.01 | 0.05 | NS |
| Canopy position | | 0.02 | NS | 0.11 | NS | NS | NS |
| Treatment × canopy position | | 0.016 | NS | 0.05 | NS | NS | NS |
| Tank mix vs. separate sprays | | NS | NS | NS | NS | NS | NS |

[z]20 ppm $GA_{4+7}$ + 250 ppm P-Ca applied as a tank mix at PF followed by two additional sprays of 20 ppm $GA_{4+7}$ at 10-d intervals.

[x]20 ppm $GA_{4+7}$ applied at 0, 10, and 20 d after PF, 250 ppm P-Ca applied 2 d after PF.

[NS]Nonsignificant.

## Discussion

Byers (1977) reported that the severity of scarf skin varied by location on the tree; substantially more scarf skin occurred on fruit from inside the canopy and from lower positions within the canopy. These findings agree with those observed in experiment two in the present study. Scarf skin was more severe in the lower canopy than the upper canopy. Multiple sprays of $GA_{4+7}$ beginning at PF were effective in reducing the severity of scarf skin at harvest in agreement with earlier findings (Ferree et al., 1984b). However, it was surprising to find that a single application of P-Ca at PF also reduced the severity of scarf skin in two of three experiments. The effects of P-Ca on $GA_4$ metabolism might explain this response. P-Ca inhibits the 2β-hydroxylase enzyme responsible for conversion of biologically inactive $GA_{20}$ into highly active $GA_1$, resulting in a reduction in longitudinal shoot growth (Rademacher, 2000). Paradoxically, inhibition of other 2β-hydroxylase enzymes by P-Ca may protect endogenous active GAs such as $GA_4$ from conversion to inactive forms. Rademacher and Kober (2003) suggested that inactivation of exogenously applied $GA_4$ by 2β-hydroxylation could be inhibited by simultaneous treatment with P-Ca, resulting in increased activity. If this mechanism were to increase the endogenous pool of $GA_4$, it might explain how a gibberellin biosynthesis inhibitor such as P-Ca can have similar responses to exogenous applications of $GA_{4+7}$. The combined application of both P-Ca and $GA_{4+7}$ sprays had an additive effect on the reduction of scarf skin in the present studies; tank mixes of P-Ca and the first $GA_{4+7}$ spray were generally as effective as when either material was applied 2 d apart. Again, this result might be explained by P-Ca resulting in elevated pools of endogenous $GA_4$ as a result of reduced inactivation of endogenous $GA_4$ as well as exogenously applied $GA_{4+7}$ resulting from the inhibition of 2-oxoglutaric acid-dependent dioxygenases by P-Ca.

Mean fruit weight at harvest was consistently increased in the present studies by multiple $GA_{4+7}$ sprays beginning at PF. This increase was in the absence of an effect on fruit set in the one experiment where it was measured in agreement with earlier reports (McLaughlin and Greene, 1984; Wertheim, 1982). Although statistically significant, the increases in mean fruit weight only ranged from 7 to 13 g over the control treatment in each of these instances. It is unlikely that this strategy could be recommended as an effective means for increasing fruit weight given the magnitude of the fruit size response and the high cost of multiple applications of $GA_{4+7}$. Mean fruit weight was consistently reduced by a single P-Ca spray at PF, independently of fruit set in the one experiment in which this was measured. Because neither fruit set nor crop load were measured in any of the other experiments, we cannot assume that treatment effects on fruit weight were not mediated by crop load effects. Others have documented a reduction in mean fruit weight after multiple sprays of P-Ca in association with an increased fruit set or crop load (Greene, 1999; Glenn and Miller, 2005). The economic benefits arising from combining P-Ca and $GA_{4+7}$ sprays to reduce scarf skin compared with application of either material alone will need to be considered in light of the minor reduction in mean fruit weight that was observed from the combined treatment in two of three experiments. If these reductions in mean fruit weight are related to increases in fruit set, then they may be overcome by adopting a more aggressive approach to chemical thinning.

The additive effects of P-Ca and $GA_{4+7}$ sprays on scarf skin in the present studies

Table 3. Effects of $GA_{4+7}$ and prohexadione-Ca (P-Ca) alone or as a tank mixture on frequency distribution of fruit within different categories of scarf skin severity at harvest on 'Red Rome'/M.7 and 'Buckeye Gala'/M.7 apples in Henderson County, N.C., in 2005 (Expts. 3 and 4).

| | Scarf skin severity (% fruit surface area covered) | | | | | |
|---|---|---|---|---|---|---|
| Treatment | 0–10 | 11–20 | 21–30 | 31–40 | 41–50 | >50 |
| | | | 'Red Rome'/M.7 | | | |
| Untreated control | 71 a[z] | 17 a | 6 | 3 | 3 a | 1 |
| P-Ca | 81 bc | 12 bc | 5 | 1 | 0 b | 1 |
| $GA_{4+7}$ | 80 b | 14 ab | 5 | 1 | 0 b | 0 |
| P-Ca + $GA_{4+7}$ | 87 c | 8 c | 3 | 1 | 0 b | 1 |
| Significance | 0.0497 | 0.0480 | NS | NS | 0.0196 | NS |
| | | | 'Buckeye Gala'/M.7 | | | |
| Untreated control | 22 a | 19 a | 20 | 17 a | 13 a | 9 a |
| P-Ca | 22 a | 24 ab | 22 | 14 a | 9 b | 10 a |
| $GA_{4+7}$ | 33 b | 28 b | 24 | 9 b | 3 c | 2 b |
| P-Ca + $GA_{4+7}$ | 39 b | 29 b | 21 | 6 b | 3 c | 2 b |
| Significance | 0.0483 | 0.0955 | NS | 0.0407 | 0.0031 | 0.007 |

[z]Means within columns with different letters are significantly different at $P \leq 0.05$ using Duncan multiple range test.

[NS]Nonsignificant.

Table 4. Effects of $GA_{4+7}$ and prohexadione-Ca (P-Ca) alone or as a tank mixture on mean fruit weight and harvest fruit maturity of 'Red Rome'/M.7 and 'Buckeye Gala'/M.7 apples in Henderson County, N.C., in 2005 (Expts. 3 and 4).

| Treatment | Mean fruit wt (g) | Fruit firmness (N) | Soluble solids (° Brix) | Starch index (1–8) |
|---|---|---|---|---|
| | 'Red Rome'/M.7 | | | |
| Untreated control | 182 b[z] | 92.1 a | 10.1 a | 3.1 a |
| P-Ca | 160 c | 90.1 a | 9.8 b | 3.2 ab |
| $GA_{4+7}$ | 194 a | 87.6 b | 10.1 a | 3.3 b |
| P-Ca + $GA_{4+7}$ | 160 c | 88.1 b | 10.0 a | 3.2 ab |
| Significance | 0.0001 | 0.0001 | 0.0001 | 0.03 |
| lsd ($P$ = 0.05) | 7.7 | 1.8 | 0.1 | 0.1 |
| | 'Buckeye Gala'/M.7 | | | |
| Untreated control | 128 b | 90.3 a | 10.3 a | 2.1 a |
| P-Ca | 118 c | 89.4 a | 10.0 b | 2.0 a |
| $GA_{4+7}$ | 135 a | 89.0 a | 10.3 a | 2.6 b |
| P-Ca + $GA_{4+7}$ | 129 b | 85.8 b | 10.4 a | 2.7 b |
| Significance | 0.0001 | 0.0001 | 0.001 | 0.0001 |
| lsd ($P$ = 0.05) | 3.4 | 1.8 | 0.2 | 0.3 |

[z]Means within columns with different letters are significantly different at $P \leq 0.05$ using Duncan multiple range test.

were not expected. One hypothesis for this response is that the inhibitory effect of P-Ca on 2-oxoglutaric acid-dependent dioxygenase enzymes resulted in increased levels of endogenous $GA_4$ and reduced inactivation of exogenously applied $GA_{4+7}$. This phenomenon may open up interesting possibilities for enhancing the efficacy of $GA_{4+7}$ sprays in other horticultural processes such as russet control.

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