Evaluation of GA₄₊₇ plus 6-Benzyladenine as a Frost-rescue Treatment for Apple

Steven McArtney^{1,5}, Duane Greene², Terence Robinson³, and James Wargo⁴

ADDITIONAL INDEX WORDS. cytokinins, fruit set, gibberellins, *Malus × domestica*, parthenocarpy

SUMMARY. Freeze events during bloom can be a relatively frequent occurrence in many apple (*Malus × domestica*) production areas in the United States that significantly reduce orchard productivity and profitability. This study investigated the potential for a proprietary mixture of gibberellin A₄ + A₇ and 6-benzyladenine (GA₄₊₇ plus 6-BA) to increase fruit set and cropping of apple following freeze events at three locations across the United States during bloom in 2012. GA₄₊₇ plus 6-BA increased fruit set in two of five experiments, and increased fruit number and yield per tree in three of five experiments. GA₄₊₇ plus 6-BA increased fruit set and yield of ‘Taylor Spur Rome’ following freezes on two consecutive days during bloom when the minimum temperature reached 23.9 and 28.4 °F. Fruit set was increased due to a stimulation of parthenocarpic fruit growth. Using locally obtained market prices, GA₄₊₇ plus 6-BA treatments increased the crop value of ‘Taylor Spur Rome’, ‘Ginger Gold’, and ‘Jonagold’ by \$3842, \$977, and \$6218 per acre, respectively. Although GA₄₊₇ plus 6-BA application(s) after a freeze increased fruit set and cropping in some instances, tree yields were well below the average yields previously obtained in the test orchards.

Temperatures near or below freezing during bloom in apple orchards occasionally results in significant reductions in fruit set and cropping due to death of the ovule/embryo before fertilization. Apple flowers are most sensitive to freezing temperatures at the full bloom stage, when air temperatures of 28 and 25 °F are predicted to kill 10% and 90% of the blooms, respectively (Ballard et al., 1998).

Foliar gibberellin (GA) sprays during bloom increase fruit set in pear (*Pyrus communis*) by stimulating parthenocarpic fruit development (Deckers

and Schoofs, 2002; Dreyer, 2013; Luckwill, 1960; Zhang et al., 2008). This strategy is used in commercial practice to increase fruit set and cropping in pear cultivars that naturally have poor fruit set (Lafer, 2008; Vilardell et al., 2008), and to increase fruit set of pear after frost damage during bloom (Ouma, 2008; Yarushnykov and Blanke, 2005). Deckers and Schoofs (2002) suggested that GAs need to be applied to pear within 4 d after a frost event to alleviate damage, and that gibberellic acid (GA₃) increased fruit set more effectively than GA₄₊₇.

Gibberellins, and in particular GA₄, induce and sustain parthenocarpic growth of apple fruit (Bukovac, 1963; Davison, 1960; Luckwill, 1960). Bukovac (1963) reported that gibberellins “induced parthenocarpic fruit growth and promoted fruit

development to maturity at growth rates and with final size, color, and general quality comparable to seeded fruits” in the cultivars Sops-of-Wine, Wealthy, and Delicious. However, Wertheim (1973) showed that GA₄₊₇ only temporarily increased fruit set of ‘Cox’s Orange Pippin’ apple flowers after effemination. Thus, the efficacy of GA₄₊₇ to promote parthenocarpy may vary between apple cultivars. Application of gibberellins together with the synthetic cytokinin N-(2-chloro-4-pyridyl)-N-phenylurea (CPPU) had a positive synergistic effect on set of parthenocarpic fruit and fruit size in apple (Bangerth and Schröder, 1994; Watanabe et al., 2008).

While GA sprays are commonly used to increase fruit set and cropping of pear following a freeze, there is no information describing the efficacy of this treatment in apple. The objectives of the current studies were to investigate the potential for a proprietary formulation of GA₄₊₇ plus 6-BA (Promalin®; Valent BioSciences Corp., Libertyville, IL) to increase fruit set and cropping of apple following freeze events during bloom. A series of spring freezes throughout major apple production regions in the eastern United States in 2012 provided the opportunity to evaluate GA₄₊₇ plus 6-BA applications as a frost-rescue treatment.

Materials and methods

HENDERSON COUNTY, NC. A commercial formulation of 1.8% w/w each of GA₄₊₇ and 6-BA (Promalin®) was applied at a rate of 25 or 50 mg·L⁻¹ to mature ‘Taylor Spur Rome’/‘Malling 7’ (‘M.7’) apple trees in a commercial orchard in Henderson County, NC. There was minimal elevation change across the orchard. There were a total of three treatments in the study: an unsprayed control, and GA₄₊₇ plus 6-BA applied at 25 or 50 mg·L⁻¹. Each treatment was assigned to fully guarded

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¹Department of Horticultural Science, North Carolina State University, Mountain Horticultural Crops Research and Extension Center, 455 Research Drive, Mills River, NC 28759

²Stockbridge School of Agriculture, Bowditch Hall, University of Massachusetts, Amherst, MA 01003

³Department of Horticulture, New York State Agricultural Experiment Station, Cornell University, Geneva, NY 14456

⁴Valent USA Corporation, 2600 Century Parkway, Suite 100, Atlanta, GA 30345

⁵Corresponding author. E-mail: steve_mcartney@ncsu.edu.

Units

To convert U.S. to SI, multiply by	U.S. unit	SI unit	To convert SI to U.S., multiply by
0.4047	acre(s)	ha	2.4711
0.3048	ft	m	3.2808
9.3540	gal/acre	L·ha ⁻¹	0.1069
25.4	inch(es)	mm	0.0394
6.4516	inch ²	cm ²	0.1550
0.4536	lb	kg	2.2046
28.3495	oz	g	0.0353
1	ppm	mg·L ⁻¹	1
(°F – 32) ÷ 1.8	°F	°C	(°C × 1.8) + 32

four-tree plots arranged in a randomized complete block design experiment with six replications. The GA₄₊₇ plus 6-BA treatments were applied on 12 Apr. and again on 13 Apr. with an airblast sprayer calibrated to deliver 100 gal/acre. Fruit set was recorded on two uniform limbs on each of the two middle trees in each plot. Fruit set was calculated as the number of fruit persisting on each limb after June drop per 100-flower clusters. No additional fruit drop was observed from June drop until harvest. The plots and sample limbs were identified on 10 Apr. when the trees were in full bloom. Two calibrated temperature loggers (button model DS1921G; Maxim Integrated, San Jose, CA) were programmed to record temperatures at 10-min intervals and placed in a solar radiation shield (model RS3; Onset Computer Corp., Pocasset, MA) attached to the trunk of one tree at either end of the test orchard at a height of 1.0 m. The treatments were applied at ≈ 1100 HR on 12 Apr. and at the same time on 13 Apr. All of the fruit on the two middle trees in each plot were harvested when the fruit reached commercial maturity as determined by a starch pattern index between 5.0 and 6.0 on the Cornell Starch Chart (Blanpied and Silsby, 1992). Mean fruit weight, yield per tree, and total yield in bushels/acre (1 bushel = 42 lb) were calculated from this data. A random sample of 10 fruit was removed from each of the middle two trees in each plot for measuring treatment effects on fruit length:diameter (L:D) ratio, and the number of fully developed seeds. The number of fruit on each tree that exhibited ring russet at the calyx end due to cold injury, shape defects such as flattened or lopsidedness, or small fruit size (<50 mm in diameter) was counted. Crop value was calculated on a per acre basis assuming cull fruit (fruit with ring russet, shape defects or small) were sold in the processing market with a value of \$0.20/lb, while the marketable fruit was sold for an average fresh price of \$0.57/lb. These values reflect average fruit prices received by commercial growers in North Carolina for processing and fresh fruit in 2012, a short crop year.

GENEVA, NY. GA₄₊₇ plus 6-BA was applied as the Promalin® formulation at a concentration of 50 mg·L⁻¹ with an airblast sprayer calibrated to

deliver 100 gal/acre to 12-year-old trees of the apple cultivars Gala, Jonagold, and Ginger Gold on ‘Malling 9’ (‘M.9’) rootstock. GA₄₊₇ plus 6-BA was applied to 10-tree plots with the treatments arranged in a randomized complete block design with five blocks and two treatments (untreated control, GA₄₊₇ plus 6-BA). GA₄₊₇ plus 6-BA was initially applied on 22 Apr. following a low temperature of 30 °F on 18 Apr. (tight cluster stage), and then reapplied on 1 May following low temperatures on 28 Apr. (27 °F), 29 Apr. (31 °F), and 30 Apr. (29 °F) (late bloom stage with some petals falling from the king flowers).

To assess the effect of the treatments on fruit set the number of flower clusters was counted on three representative branches per tree (top, middle, and bottom of canopy) on two random trees per plot at full bloom (28 Apr.) and then at harvest the number of fruit on each of the three branches was counted. Fruit set was calculated as the number of fruit harvested per 100-flower cluster. The fruit of each cultivar was harvested at normal commercial maturity. At harvest all 10 trees in each plot were harvested and the total number and weight of fruit per tree recorded. Mean fruit weight was calculated from these data. Fruit size distribution (packout) was estimated using the mean fruit weight and assuming a normal distribution of fruit sizes and a standard deviation of 20 g. Long-term average fruit prices were assigned to the yield in each packout size to calculate a gross crop value excluding packing, storage, and sales charges. Only yield and fruit size were considered for the calculation of gross crop value, and this calculation did not account for fruit color or other fruit defects. Seed number was determined from a 10-fruit sample collected from each of two ‘Ginger Gold’ trees per plot. Data were analyzed by analysis of variance as a randomized complete block experiment with five blocks and with 10 sample trees per block used for yield, fruit size, and crop value data and two sample trees per block for fruit set and seed number data.

AMHERST, MA. In a block of mature ‘Empire’/‘M.9’ apple trees, 24 trees were selected that appeared to have an adequate number of flowering spurs to carry a commercial crop. Two uniform limbs were selected on each tree at the tight cluster stage. The

number of blossom clusters on each limb was counted and expressed as blossom cluster density (clusters per square centimeter limb cross-sectional area). Trees were separated into eight groups (blocks) of three trees each based upon the calculated blossom cluster density. Within each group, trees were randomly assigned to receive one of the following three treatments: Control (no treatment), GA₄₊₇ plus 6-BA at 25 or 50 mg·L⁻¹. Thus, the study was a randomized complete block design with eight replications. The phenological development in this orchard was tight cluster (9 Apr.), pink bud stage (16 Apr.), early petal fall (23 Apr.), and petal fall (30 Apr.). GA₄₊₇ plus 6-BA was applied in a water volume of 100 gal/acre using an airblast sprayer on 18 Apr., 5 d after a frost of 31.8 °F recorded at early pink (13 Apr.). This location also recorded frosts on three consecutive days during petal fall (31.6, 30.1, and 30.4 °F on 28, 29, and 30 Apr., respectively). The number of fruit on each sample limb was counted at the end of June drop and final fruit set expressed as fruit/100 blossom clusters. No additional fruit drop was observed between June drop and harvest. The fruit from each tree were counted and weighed when normal commercial maturity was reached, and yields (kilograms per tree, bushels per acre) were calculated from this data. The number of misshapen fruit and those with frost rings were determined and the seed count was taken on a 25-apple subsample from each tree. Crop value was calculated on a per acre basis assuming misshapen and frost ring-damaged fruit would be sold as culls at a value of \$0.15/lb and the remaining marketable fruit were sold for \$0.55/lb.

Results

HENDERSON COUNTY, NC. The test orchard experienced freezing temperatures on two consecutive nights during full bloom in 2012, the first on 12 Apr. when the minimum air temperature reached 23.9 °F and the second on 13 Apr. when the minimum air temperature was 28.4 °F. Air temperatures were below 32 °F for ≈ 5 h each night (Fig. 1). GA₄₊₇ plus 6-BA significantly increased fruit set, yield, and fruit number per tree at harvest compared with the untreated control (Table 1). In addition, the marketable yield per tree and the percent of

Fig. 1. Air temperatures recorded at 10-min intervals in the North Carolina study. Temperature loggers were placed in solar radiation shields and attached to the trunk of apple trees at a height of 1.0 m (3.3 ft) at each end of the row used in study. Vertical arrows indicate the time of each gibberellin $A_4 + A_7$ and 6-benzyladenine application following the freeze events; $(^{\circ}\text{F} - 32) \div 1.8 = ^{\circ}\text{C}$.

fruit with frost russet at harvest were higher on the GA_{4+7} plus 6-BA treated trees compared with the control (Table 2). Fewer than 5% of fruit on control trees exhibited parthenocarp, compared with $\approx 70\%$ of the fruit on trees sprayed with GA_{4+7} plus 6-BA. Thus, GA_{4+7} plus 6-BA increased fruit set and yield after the two freeze events by stimulating production of parthenocarpic fruit (Table 3). Parthenocarpic ‘Taylor Spur Rome’ fruit had similar weight (Table 1) and shape as measured by L:D ratio (Table 3) compared with control fruit. The crop value in the GA_{4+7} plus 6-BA treatments was $\approx \$4000/\text{acre}$ higher than the crop value of the untreated control.

GENEVA, NY. GA_{4+7} plus 6-BA significantly increased fruit set of ‘Jonagold’, but did not significantly improve fruit set of ‘Ginger Gold’ or ‘Gala’ although there was a numeric

increase in set for all three cultivars (Table 4). Fruit number per tree, yield, and crop value of ‘Ginger Gold’ and ‘Jonagold’ were increased by GA_{4+7} plus 6-BA, but not significantly in ‘Gala’ (Table 4). GA_{4+7} plus 6-BA increased the crop value of ‘Ginger Gold’ and ‘Jonagold’ by \$977 and \$6218/acre, respectively, but the increase in crop value of ‘Gala’ (\$941/acre) was not significant. There was no effect of treatment on mean fruit weight of any of the cultivars. GA_{4+7} plus 6-BA resulted in a significant reduction in average seed number per fruit in ‘Ginger Gold’ due to a (nonsignificant) increase in the number of parthenocarpic fruit. About 20% of the control fruit were parthenocarpic compared with 70% of fruit from the GA_{4+7} plus 6-BA treatment. Seed number was not measured in ‘Gala’ or ‘Jonagold’. The yield of

untreated ‘Ginger Gold’ was estimated to be $\approx 4\%$ of a full crop while the yield of untreated ‘Jonagold’ and ‘Gala’ was estimated to be $\approx 11\%$ and 55% of a full crop, respectively. Applications of GA_{4+7} plus 6-BA increased the percentage of a full crop to $\approx 12\%$, 39%, and 66% of a full crop for ‘Ginger Gold’, ‘Jonagold’, and ‘Gala’, respectively.

‘EMPIRE’ IN AMHERST, MA. There was no effect of GA_{4+7} plus 6-BA application on fruit set or yield of ‘Empire’ (Table 5). There was no effect of GA_{4+7} plus 6-BA on the percent of misshapen fruit, the percent of fruit with frost rings (data not shown), or seed number per fruit at harvest. Total yield in the control plots (580 bushels/acre) was $\approx 70\%$ of the normal expected crop for trees in this orchard.

Discussion

These results demonstrate the potential for GA_{4+7} plus 6-BA to increase fruit set, yield, and crop value of apple following freeze events during bloom. Although production following GA_{4+7} plus 6-BA treatments was only a fraction of the expected normal yields, they did increase yields to make the treatments economically worthwhile under some conditions. For ‘Taylor Spur Rome’ and ‘Ginger Gold’, the positive effect of GA_{4+7} plus 6-BA on fruit set was due to stimulation of parthenocarpic fruit development. This result was in agreement with previous findings that GA_4 stimulated parthenocarpic fruit development of several apple cultivars (Bukovac, 1963). GA_{4+7} plus 6-BA spray(s) were without effect on fruit set of ‘Gala’/‘M.9’ in Geneva, NY or ‘Empire’/‘M.9’ in Amherst, MA. The relatively

Table 1. Effects of gibberellin $A_4 + A_7$ and 6-benzyladenine (GA_{4+7} plus 6-BA) treatments after freezes during full bloom on 12 and 13 Apr. 2012 on fruit set, total yield, fruit number per tree, and mean fruit weight of ‘Taylor Spur Rome’/‘M.7’ apple in Henderson County, NC.

Treatment ^a	Fruit set (fruit/100 clusters)	Yield		Fruit (no./tree)	Mean fruit wt (g) ^z	Crop value (\$/acre) ^y
		(kg/tree) ^z	(bu/acre) ^z			
Untreated control	2.6 a ^x	11.7 a	94 a	58 a	198	1965
GA_{4+7} plus 6-BA (25 mg·L ⁻¹)	17.7 b	36.8 b	296 b	195 b	185	5807
GA_{4+7} plus 6-BA (50 mg·L ⁻¹)	14.9 b	33.9 b	273 b	185 b	182	5328
Significance ^w	**	***	***	***	NS	***

^z1 mg·L⁻¹ = 1 ppm, 1 kg = 2.2046 lb, 1 42-lb (19.1 kg) bushel (bu) per acre = 47.0757 kg·ha⁻¹, 1 g = 0.0353 oz.

^yCalculated assuming cull fruit had a value of \$0.20/lb (\$0.441/kg) and fresh fruit had a value of \$0.57/lb (\$1.257/kg); \$1/acre = \$2.4711/ha.

^xValues in a column with different letters are statistically different by Duncan’s multiple range test at $P \leq 0.05$.

^wNS, **, ***Nonsignificant or significant at $P \leq 0.01$ or 0.001, respectively, based on analysis of variance.

high yield of untreated ‘Gala’ (55% of a full crop) was largely due to the excessive production and set of lateral flower clusters on 1-year-old wood. The delayed bloom of flower clusters on 1-year-old wood resulted in improved survival compared with earlier blooming flower clusters on spurs or

terminal buds. These late blossoms on 1-year-old wood (lateral flower clusters) went on to set fruit. However, fruit size of ‘Gala’ was quite small because of the high percentage of the fruits originating from these late blossoms. ‘Jonagold’ also had some lateral flower clusters, but less than

‘Gala’, while ‘Ginger Gold’ had few lateral flower clusters.

Apple cultivars differ in their response to a parthenocarpic stimulus provided by GA₄ (Bukovac, 1963). Fruit growth rates, final size, color, and general quality were comparable in parthenocarpic and seeded fruits of ‘Sops-of-Wine’ and ‘Wealthy’; whereas parthenocarpic ‘Delicious’ were smaller than seeded fruits at maturity, and parthenocarpic ‘Jonathan’ and ‘Rhode Island Greening’ fruit abscised before reaching maturity. It was suggested that gibberellins present in the receptacle and/or ovary before flowering may be important for inducing parthenocarpy, whereas cytokinins may be responsible for continued growth of parthenocarpic fruit (Watanabe et al., 2008). If this suggestion is valid, the combination of GA₄₊₇ plus 6-BA might be a more effective frost-rescue treatment compared with GA₄₊₇ alone since presumably the 6-BA could provide a stimulus for normal growth and expansion of the parthenocarpic fruit. Additional research is needed to establish the separate roles of gibberellin and cytokinin on parthenocarpic fruit development in apple.

In this study, seeded and parthenocarpic fruit of ‘Taylor Spur Rome’ were not different in either size, L:D ratio, or the incidence of misshapen fruit at harvest. The effects of GAs on apple fruit shape are not consistent between cultivars. Bukovac (1963) reported that parthenocarpic fruit of the cultivars Sops-of-Wine and Wealthy induced by GA₄ had significantly lower transverse diameter, smaller core

Table 2. Effects of gibberellin A₄ + A₇ and 6-benzyladenine (GA₄₊₇ plus 6-BA) treatments after freezes during full bloom on 12 and 13 Apr. 2012 on marketable yield and cull fruit of ‘Taylor Spur Rome’/‘M.7’ apple in Henderson County, NC.

Treatment ^z	Marketable yield (kg/tree) ^z	Cull fruit (kg/tree)	Cull fruit (% total fruit no.)		
			Frost russet	Misshapen	Small ^y
Untreated control	10.3 a ^x	1.4 a	3.1 a	6.6	7.3 a
GA ₄₊₇ plus 6-BA (25 mg·L ⁻¹)	29.3 b	7.5 b	9.4 b	8.4	9.7 ab
GA ₄₊₇ plus 6-BA (50 mg·L ⁻¹)	26.8 b	7.0 b	7.2 b	7.5	12.9 b
Significance ^w	***	***	*	NS	*

^z1 mg·L⁻¹ = 1 ppm, 1 kg = 2.2046 lb.

^yFruit < 50 mm (1.97 inch) in diameter.

^xValues in a column with different letters are statistically different by Duncan’s multiple range test at $P \leq 0.05$.

^wNS, *, ***Nonsignificant or significant at $P \leq 0.05$ or 0.001, respectively, based on analysis of variance.

Table 3. Effects of gibberellin A₄ + A₇ and 6-benzyladenine (GA₄₊₇ plus 6-BA) treatments after freezes during full bloom on 12 and 13 Apr. 2012 on the number of fully developed seeds per fruit, the percent of parthenocarpic fruit, and fruit length:diameter (L:D) ratio of ‘Taylor Spur Rome’/‘M.7’ apple in Henderson County, NC.

Treatment ^z	Seeds (no./fruit)	Parthenocarpic fruit (%)	Fruit shape (L:D ratio)
Untreated control	4.1 a ^y	4.3 a	0.87
GA ₄₊₇ plus 6-BA (25 mg·L ⁻¹)	1.1 b	69.4 b	0.87
GA ₄₊₇ plus 6-BA (50 mg·L ⁻¹)	0.8 b	71.5 b	0.85
Significance ^x	***	***	NS

^z1 mg·L⁻¹ = 1 ppm.

^yValues in a column with different letters are statistically different by Duncan’s multiple range test at $P \leq 0.05$.

^xNS, ***Nonsignificant or significant at $P \leq 0.001$, respectively, based on analysis of variance.

Table 4. Effect of 50 mg·L⁻¹ (ppm) gibberellin A₄ + A₇ and 6-benzyladenine (GA₄₊₇ plus 6-BA) sprays after a series of frost/freeze events during pink bud and full bloom on fruit set, yield, crop load, mean fruit weight, seed number per fruit, and crop value of ‘Ginger Gold’, ‘Gala’, and ‘Jonagold’ apple trees on ‘M.9’ rootstock in Geneva, NY.

Cultivar	Treatment	Fruit set (fruit/100 clusters)	Fruit (no./tree)	Yield		Crop load (%) full crop)	Mean fruit wt (g) ^z	Seeds (no./fruit)	Crop value (\$/acre) ^y
				(kg/tree) ^z	(bu/acre) ^z				
Ginger Gold	Control	8.5	9	1.6	50	4	207	5.5	967
	GA ₄₊₇ plus 6-BA	25.4	24	4.6	141	12	198	1.6	1944
	Significance ^x	NS	**	**	**		NS	**	**
Gala	Control	39.9	168	21.6	664	55	133	—	5057
	GA ₄₊₇ plus 6-BA	49.4	200	25.9	797	66	132	—	5988
	Significance	NS	NS	NS	NS		NS	—	NS
Jonagold	Control	18.3	20	4.8	148	11	268	—	2238
	GA ₄₊₇ plus 6-BA	45.6	71	17.9	550	39	257	—	8456
	Significance	**	**	**	**		NS	—	**

^z1 kg = 2.2046 lb, 1 42-lb (19.1 kg) bushel (bu) per acre = 47.0757 kg·ha⁻¹, 1 g = 0.0353 oz.

^yLong-term average fruit prices were assigned to the yield in each packout size to calculate a gross crop value excluding packing, storage, and sales charges; \$1/acre = \$2.4711/ha.

^xNS, **Nonsignificant or significant at $P \leq 0.01$, respectively, based on analysis of variance.

Table 5. Effect of a gibberellin A₄ + A₇ and 6-benzyladenine (GA₄₊₇ plus 6-BA) application on 18 Apr. 2012 following frost on 13 Apr. on fruit set, yield, and mean fruit weight of ‘Empire’/‘M.9’ apple at harvest in Amherst, MA.

Treatment ^a	Fruit set (fruit/100 clusters)	Crop density (fruit/cm ² LCSA) ^y	Fruit (no./tree)	Yield		Mean fruit wt (g) ^z	Crop value (\$/acre) ^x
				(kg/tree) ^z	(bu/acre) ^z		
Control	25	2.8	143	28.4	580	200	12,181
GA ₄₊₇ plus 6-BA (25 mg·L ⁻¹)	18	2.0	146	27.8	569	197	12,042
GA ₄₊₇ plus 6-BA (50 mg·L ⁻¹)	21	2.2	171	30.9	632	182	13,535
Significance ^w	NS	NS	NS	NS	NS	NS	NS

^a1 mg·L⁻¹ = 1 ppm, 1 kg = 2.2046 lb, 1 42-lb (19.1 kg) bushel (bu) per acre = 47.0757 kg·ha⁻¹, 1 g = 0.0353 oz.

^yLCSA = limb cross sectional area; 1 fruit/cm² = 6.4516 fruit/inch².

^xCalculated assuming cull fruit had a value of \$0.15/lb (\$0.331/kg) and fresh fruit had a value of \$0.55/lb (\$1.213/kg); \$1/acre = \$2.4711/ha.

^wNS = Nonsignificant based on analysis of variance.

diameter, increased thickness of the apical cortex, and smaller locular cavities at harvest. Greene (1984) reported that GA₄₊₇ plus 6-BA increased the L:D ratio of ‘Richared Delicious’ apple; however, this increase was not always a result of increased fruit length. Increasing concentrations of GA₄₊₇ plus 6-BA caused a linear reduction in fruit diameter, fruit weight, and seed number of ‘Richared Delicious’ (Greene, 1984). Watanabe et al. (2008) reported that GA₃ or GA₄₊₇ increased fruit diameter and L:D ratio, but had no effect on cortex width of the normally parthenocarpic cultivar Ohri. Variability in the morphological response to treatments that induce parthenocarpy may be due to changes in the capacity to metabolize GAs or cytokinins in different regions of the apple fruit over time, to differences in GA or cytokinin metabolism between cultivars, or to differential expression of enzymes involved in promotion of cell division.

‘Rome’ strains of apple do not have a pronounced calyx, and did not respond to GA₄₊₇ plus 6-BA applications for enhancing fruit “typiness” at petal fall in this study. While the majority of ‘Taylor Spur Rome’ fruit on trees treated with GA₄₊₇ plus BA were parthenocarpic, ≈30% of fruit had one or more fully developed seeds at harvest. Assymetric seed distribution throughout the locules normally results in assymetric fruit shape, or lopsidedness (Drazeta et al., 2004). Interestingly, in spite of assymetric seed distribution in ‘Taylor Spur Rome’, fruit development (size, shape, and symmetry) was typical of the cultivar. While internal fruit quality was not measured in the current studies, parthenocarpic ‘Golden Delicious’ fruit

induced by GA + CPPU had significantly higher flesh firmness at harvest but also exhibited a greater incidence of (unspecified) calcium deficiency symptoms (Bangerth and Schröder, 1994). Since a relationship between seed number, fruit calcium content, and storage disorders is occasionally reported in apple (Bramlage et al., 1990), growers need to carefully assess the increased risks of postharvest disorders and storage potential of parthenocarpic fruit resulting from application of GA₄₊₇ plus BA as a frost-rescue treatment.

Although GA₄₊₇ plus 6-BA increased fruit set, yield, and crop value of several apple cultivars after freeze events during bloom in 2012, tree productivity was not completely restored to average levels. Further restoration of cropping to expected levels might result from combining application of GA₄₊₇ plus 6-BA with additional growth regulators. Vilardell et al. (2008) reported that following an application of GA₄₊₇ plus 6-BA during bloom with prohexadione-calcium (P-Ca) 15 d after bloom improved the yield of ‘Abate Fetel’ pear compared with GA₄₊₇ plus 6-BA alone in an orchard that did not experience cold injury. Similarly, application of the ethylene biosynthesis inhibitor aminoethoxyvinylglycine (AVG) 15 d after a full bloom application of GA₄₊₇ plus 6-BA increased fruit set of ‘Packhams Triumph’ pear (Rufato et al., 2011). If the opportunity presents itself in the future, studies should be undertaken to evaluate the individual and combined effects of GA₄₊₇ plus 6-BA at petal fall, followed by either AVG or P-Ca applications as a frost-rescue treatment in apple in an attempt to further enhance fruit set and cropping.

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