Reducing Floral Initiation and Return Bloom in Pome Fruit Trees—Applications and Implications

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SUMMARY. Regulation of biennial bearing in pome fruit is usually accomplished by chemically removing fruit during the “on” cycle. The advantages and disadvantages of regulating biennial bearing by inhibiting flowering in the “off” cycle were discussed. Gibberellins and the two phenyl urea cytokinin-like compounds, thidiazuron and CPPU have been shown to inhibit flowering in pome fruit. It was concluded that inhibition of flowering with commercially available gibberellins was not a commercially acceptable approach to regulate biennial bearing. The inhibition of flowering was erratic, fruit thinning and increased fruit set could not be predicted, and seed abortion following gibberellin application could predispose fruit to reduced postharvest life because of reduced calcium uptake. Regulation of flowering by inhibiting flower bud formation appeared to be a viable way to regulate cropping on nonbearing tress or trees that were not carrying a crop.

Control of biennial bearing in pome fruit is one of the most difficult tasks that an orchardist is required to do. Usually the focus of attempts to regulate flowering is to increase flower bud formation. The primary way this is done is through chemical thinning, but other strategies such as rootstock and cultivar selection, or appropriate management techniques are often utilized. Another approach to establish more regular flowering is by inhibiting flower bud formation.

Inhibiting flower bud formation

A representation of the biennial bearing cycle of pome fruit is illustrated in Fig. 1. Under good pollinating conditions a tree with a snowball bloom will generally have very heavy fruit set. This will result in no or few resting spurs, so there will be limited flower bud formation for the following year. With reduced or no bloom there will be many resting spurs, thus most spurs will initiate flowers for a snowball bloom the following year.

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Fig. 1. Cycle of biennial bearing of pome fruit (Williams and Edgerton, 1981).

Chemical thinning is used to break or modify the biennial bearing cycle, in the year of heavy bloom, by either preventing pollination or ovule fertilization with blossom thinners, or by reducing fruit set with the appropriate application of postbloom thinners (Williams, 1979). An alternative method to break this biennial bearing cycle is to inhibit flowering during the “off” year when there are many resting spurs (Luckwill, 1969). The goal with this approach is to apply a hormone spray to inhibit flower bud formation in some of the resting spurs, so that the trees will not have a snowball bloom the following year.

Advantages of reducing biennial bearing by inhibition of flowering

Chemical thinning is not a precise science, since many factors must interact to produce good thinning results. Many factors have been identified that influence thinner efficacy, but their precise effect, and the way that they interact with other factors has not been established. Weather, and especially temperature following application, is a dominant factor that determines the extent of thinning (Schwallier, 1996). Poor or inadequate thinning may result if the period of fruit susceptibility to chemical thinners and favorable weather following thinner application do not coincide. Some cultivars are extremely biennial, and regulation of flowering by chemical thinners, even if started at bloom, may be insufficient to break the biennial bearing cycle (Forshey, 1986). With these cultivars, and perhaps with others, inhibition of flowering in the “off” year may be a better way to establish regular flowering.

Increased fruit size may be more easily achieved by inhibiting flowering

rather than depending upon chemical thinners. The bloom and postbloom period is a time of intense competition for photosynthate and stored reserves among competing sinks in apples (*Malus domestica* Borkh.), pears (*Pyrus communis* L.) and other pome fruit (Lakso, 1994). Even if chemical thinners reduced crop load to an ideal level after June drop, fruit size at harvest would be affected because of this early fruit-to-fruit competition. Cell number is reduced by early fruit competition, and final fruit size at harvest is determined by both the number of cells and mean size within a fruit (Denne, 1960). If flower bud formation is inhibited the previous year, there would be fewer flowers and fruit competing during this bloom-postbloom period, thus more cell division could occur, and larger fruit may be realized at harvest.

Generally lower bloom density means a larger percent of the flowers present will set fruit (Williams, 1979). This may be an advantage under low light and warm temperature conditions where fewer fruit are in competition for available photosynthate.

Tree growth, especially on young trees, may be improved on trees where flower bud formation has been reduced (Unrath and Whitworth, 1991). The majority of apple trees being planted in the United States and elsewhere are propagated on very precocious rootstocks. Early flowering and fruit set can slow tree growth to the extent that trees are prevented from filling their allotted space, and never reach their full yield potential. Further, heavy set on young trees may cause leader or limb breakage which would result in substantial structural damage to the tree.

Disadvantages of reducing biennial bearing by inhibiting flowering

There are situations where it is detrimental to reduce numbers of flowers at bloom. The decision to regulate flowering by inhibiting flower bud formation must be made as early as 1 year before flowers actually open. During that 11 or 12 month period many things can happen that may affect the viability of flowers including winter injury, drought stress, and defoliation due to insects or diseases. Poor pollinating weather, poor pollinator activity, or frost at or following bloom may affect fruit set so severely that large numbers of

flowers at bloom would be required for adequate fruit set.

Use of chemicals for bloom reduction has not been perfected so that growers can select chemicals, timing, and concentrations to give reasonably precise and predictable reduction in flowering (Greene, 1993). More research is required to make flower bud inhibition consistent from year to year.

There may be unwanted and undesirable vegetative side effects. High rates of some gibberellins may result in production of blind wood (Greene, 1989). Treatments to inhibit flowering may be somewhat incomplete, resulting in the production of small flowers with the potential to produce only small fruit.

Chemicals to inhibit flower bud formation

The ability of gibberellins to inhibit flowering in pome fruit has been recognized for over a third of a century (Marcelle and Sironval, 1963) and it has been confirmed many times since. The natural cause of biennial bearing in pome fruit appears to reside within the seeds (Chan and Cain, 1967). It is believed that the gibberellins produced within the seeds diffuse out and inhibit flowering in the bourse bud (Hoad, 1978; Luckwill, 1969). Gibberellins differ in their ability to inhibit flowering in pome fruit (Marino and Greene, 1981; Tromp, 1982). While there is not complete agreement in the literature, it appears in general that, GA₄ is least inhibitory, GA₇ the most inhibitory, and GA₃ and GA₄₊₇ are intermediate in their ability to inhibit flowering (Tromp, 1982). Looney et al. (1985) provided substantial evidence that some gibberellins under some circumstances may in fact increase flowering. They reported that GA₄ and C-3 epi-GA₄ increased flowering in the “off” year on ‘Golden Delicious’ apple trees.

CPPU [N-(2-chloro-4-pyridyl)-N'-phenylurea] and thidiazuron (N-phenyl-N'-1,2,3-thiadiazol-5-ylurea) are phenylurea compounds with greater cytokinin activity in some systems than that of naturally occurring adenine-based cytokinins with a sidechain in the N⁶ position (Fellman et al., 1987). In addition to reducing return bloom, these compounds have other positive effects that may make them commercially useful on apples. These effects include: fruit thinning, increased fruit size, increased flesh firmness at harvest and following storage, and increased length to diameter (L/D) ratio (Curry and Greene,

Table 1. Effect of time of application of 150 ppm (mg·L⁻¹) GA₄₊₇ on fruit set and return bloom of mature 'McIntosh/Malling 7' apple trees. (Greene, 1989).

Time after full bloom of GA ₄₊₇ application (d)	Fruit set in year of treatment (fruit/LCSA ²)	Return bloom in year after GA treatment (blossom clusters/LCSA)
None	11.6	5.6
-6	16.8	1.0
0	14.9	0.4
7	18.4	0.6
13	17.0	0.3
21	13.7	0.2
28	16.1	0.1
35	13.9	0.9
45	11.3	4.5
60	12.2	8.7
Significance	1***	1***

²Number per cm limb cross sectional area; 1.0 fruit or blossom clusters per centimeter of limb cross sectional area = 0.39/inch.

***Significant at $P = 0.001$.

1993; Elfving and Cline, 1993; Greene, 1995, 1996). Compared to gibberellins, very little is known about the flower inhibiting characteristics of these compounds. More work is needed to better understand their potential use (so the remainder of this discussion will focus on gibberellins).

Applications and implications for using gibberellins to inhibit flowering

TYPES OF GIBBERELLINS. Greene (1993) reported on a study where GA₄ and GA₄₊₇ were applied in each of 4 years to 'Golden Delicious' apple trees in the same block at rates and timings used commercially to reduce fruit russetting. Return bloom was measured the following year. GA₄₊₇ decreased flowering in 3 of the 4 years. GA₄ increased flowering 2 years, had no effect one year, and decreased flowering one year. The conclusion from this series of experiments was that the effects of gibberellins on flowering may be too inconsistent and unpredictable for commercial use.

TIMES OF APPLICATION. Gibberellins can inhibit flower bud formation over a wide range of times starting when applications are made before bloom and extending for several weeks after bloom. This period of time is essentially the same as that where removal of flowers or fruitlets can have a positive effect on flower bud formation. GA₄₊₇ at 150 ppm (mg·L⁻¹) was applied to mature 'McIntosh' trees over a 9-week period.

Flowering was inhibited comparably (less than 20% of the bloom on nontreated trees) when the gibberellins were applied at pink through 5 weeks after bloom (Table 1). Flowering was inhibited marginally when treatments were applied 45 d after bloom, whereas there was no effect when treatments were applied 60 d after bloom. Gibberellins applied at this time can also have the undesirable side effect of increasing fruit set with a corresponding reduction in fruit size. This does not happen all of the time, but it happens frequently enough, perhaps 25% of the time, to be considered a potential problem. Tromp (1982), reported that 500 mg·L⁻¹ of GA₄ and GA₄₊₇ inhibited flowering of 1-year-old 'Cox's Orange Pippin' trees when applied 9 weeks after bloom whereas the same concentration and time of application of GA₄ and GA₃ had no influence. Unrath and Whitworth (1991) reported that four monthly sprays of GA₄₊₇ beginning 1 month after petal fall eliminated a large portion of the return bloom on young 'Delicious' trees. It appears that the effective period is quite long for using gibberellins to inhibit flowering on rapidly growing nonbearing trees, and the length of time is influenced by gibberellin type and concentration.

NUMBER OF APPLICATIONS. If flower bud inhibition is caused by gibberellins emanating from seed during early development then one can speculate that the most effective strategy to inhibit flower bud formation may be to mimic this with several applications of a gibberellin over time. However, one application

made during the first 2 weeks after bloom was generally as effective as multiple applications made during the 8 weeks after bloom (Greene, 1989; Marino and Greene, 1981; Tromp, 1982).

GIBBERELLIN CONCENTRATION. Generally, inhibition of flower bud formation is linear with increasing gibberellin rate (Greene, 1989, 1993).

CROP LOAD. One can speculate that less exogenous gibberellin would be required to inhibit flower bud formation as crop load increases, since endogenous gibberellins produced by seeds should contribute to inhibiting flower bud formation. This is consistent with the observation that flowering is difficult to inhibit with GA applied to vegetative trees in the "off" year. However, other studies indicate that the relationship between intermediate crop loads and GA inhibition of flowering is less clear.

A group of 'Empire'/'Malling 26 (M.26) trees were selected and blossom cluster density was adjusted by hand removal of flowers at bloom. All flowers were removed from one group of trees, while some flowers were removed on others trees to achieve four blossom clusters per centimeter (1.56/inch) of limb cross sectional area, and on some trees no flower adjustment was made, to give a final bloom density of 13 blossom clusters per centimeter (5.1/inch) limb cross sectional area. Trees of each bloom density were divided into two groups, those that received two applications of GA₄₊₇ at 50 ppm (mg·L⁻¹) at 7 and 17 d after full bloom, and those that received no GA. Gibberellins reduced fruit set in the year of application and return bloom the following year, and blossom removal reduced fruit set but increased return bloom (Table 2). However, there was a thinning × gibberellin interaction. Gibberellin sprays thinned 'Empire' severely in the year of application, which negated any effects of initial flower density adjustment on bloom the following year. Gibberellins only thin sporadically (perhaps 33% of my experiments), but this occurs with sufficient frequency that the use of gibberellins to inhibit flowering appears to be inappropriate on cropping apple trees.

Effect of gibberellin sprays on fruit quality

Gibberellins sprays applied during the postbloom period can reduce seed number and increase the incidence of senescent breakdown (Greene et al., 1982). Bramlage et al., 1990,

Table 2. Effect of two 50 ppm (mg·L⁻¹) applications of GA₄₊₇ on fruit set and return bloom of mature 'Empire'/Malling 26' apple trees with different bloom densities. Trees were manually adjusted to 0 or 4 blossom clusters per centimeter limb cross-sectional area (BC/LCSA) or left unadjusted (13 BC/LCSA) at bloom before GA application (Greene, 1989).

Bloom density (BC/LCSA) when GA was applied	GA ₄₊₇ applications (no.)	Fruit set in year treated (fruit/LCSA) ^z	Return bloom in year after GA treatments (BC/LCSA)
0	0	0	16.5
4	0	1.7	14.1
13	0	6.6	9.6
0	2	0	8.6
4	2	0.7	9.6
13	2	1.9	8.3
Significance			
GA		*	**
Density (D)		**	*
GA × D		**	*

^zNumber per centimeter LCSA; 1.0 fruit or BC per centimeter of LCSA = 0.39 fruit or BC per inch of LCSA.

*,**Significant at *P* = 0.05 or 0.01, respectively.

demonstrated that there is a positive and highly significant linear relationship between seed number in apples and fruit flesh calcium content. Low fruit flesh calcium has been directly associated with reduced postharvest life because of increased incidence of senescent breakdown, fruit decay, bitter pit and cork spot. Therefore, if fruit are present on trees that receive a gibberellin spray to reduce flowering, postharvest life of these fruit may be diminished because of low seed number.

Conclusions

Gibberellins can effectively inhibit flower bud formation on pome fruit trees. However, inhibition of flowering on bearing trees to combat biennial bearing is not commercially viable with the current commercial gibberellin formulations because the extent of flower reduction is not predictable, and there are several potentially serious negative side effects which occur inconsistently but at unacceptably high frequency. These negative side effects include increased fruit set, fruit thinning, and reduced postharvest life. However, regulation of cropping and inhibition of flowering with gibberellins may be commercially viable on young precocious trees and bearing trees that are in the "off" year.

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