Reducing Flowering with Gibberellins to Increase Fruit Size in Stone Fruit Trees: Applications And Implications in Fruit Production

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SUMMARY. Many commercially grown stone fruit including apricots (*Prunus armeniaca* L.), peaches and nectarines [*P. persica* (L.) Batsch], plums (*P. salicina* Lindl., *P. domestica* L.), prunes (*P. domestica* L.), and pluots (*P. salicina* x *P. armeniaca*) have a tendency to produce high numbers of flowers. These flowers often set and produce more fruit than trees can adequately size to meet market standards. When excessive fruit set occurs, removal of fruit by hand thinning is necessary in most *Prunus* L. species to ensure that remaining fruit attain marketable size and reduce biennial bearing. Over the years there have been numerous attempts to find chemical or physical techniques that would help to reduce the costs associated with and improve efficiencies of hand thinning, however, alternate strategies to hand thinning have not been widely adopted for stone fruit production. In the past 10 years, several chemical treatments have shown promise for reducing hand thinning needs in stone fruit. Management of flowering by chemically reducing the number of flowers has been particularly promising on stone fruit in the Sacramento and San Joaquin Valleys of California. Gibberellins (GAs) applied during May through July, have reduced flowering in the following season in many stone fruit cultivars without affecting percentage of flowers producing fruit. As a result, fruit numbers are reduced, the need for hand thinning is reduced and in some cases eliminated, and better quality fruit are produced. There are risks associated with reducing flower number before climatic conditions during bloom or final fruit set are known. However, given the changes in labor costs and market demands, the benefits may outweigh the risks. This paper reviews relevant literature on thinning of stone fruit by gibberellins, and summarizes research reports of fruit thinning with GAs conducted between 1987 and the present in California. The term thin or chemically thin with regard to the action of GA on floral buds is used in this paper, consistent with the literature, although the authors recognize that the action of GA is primarily to inhibit the initiation of floral apices, rather than reduce the number of preformed flowers. At relatively high concentrations, GA may also kill floral buds. Chemical names used: gibberellic acid, potassium gibberellate.

Apricot, nectarine, peach, and plum trees often produce too many fruit to achieve acceptable market size. Fruit size is increased by reducing fruit per tree during early fruit growth, so that tree resources are distributed among fewer fruit. Commercially, fruit removal is currently achieved by hand thinning or by mechanical shaking (prunes and apricots).

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If fruit removal is delayed for 30 d after full bloom (DAFB) or longer, growers can selectively remove smaller, damaged, or misshapen fruit by hand, but this delay may compromise size of remaining fruit through early competition. The labor cost for hand thinning is one of the greatest expenses in stone fruit production but frequently is justified by poor returns from small fruit size on trees that are not thinned. Hand thinning is necessary for most commercial peach, apricot, plum, prune, pluot, and nectarine cultivars worldwide. Effective chemical fruit thinning, as used in apples, would reduce production costs but attempts to develop such methods have had limited success. Alternatively, flower thinning offers the possibility for reducing hand-thinning costs, with potential for greater fruit size or total yield through reducing early competition, and flower thinning may be accomplished by hand, mechanical or chemical means (Moran and Southwick, 2000). This paper will focus on use of GA to reduce flower numbers in stone fruit, thereby enhancing fruit size with less need for hand thinning.

General background of GA thinning experiments in California

Experiments were conducted from 1988 through 1999 on apricot, nectarine, peach, plum and prune cultivars. Trees were fully mature and growing on commercial peach or plum rootstocks. Trees were mostly sprayed with aqueous solutions of gibberellin (GA). The sprays were applied at 935 $L \cdot ha^{-1}$ (100 gal / acre) volume with a pressurized handgun (high volume), backpack mist blower (Stihl SR 400, Andreas Stihl, Waiblingen, Germany) or with commercial orchard sprayers. Sprays were timed by calendar date and were applied from late April through early August (Southwick and Fritts, 1995; Southwick et al., 1995a, 1995b, 1997a; Southwick and Yeager, 1990; Southwick and Yeager 1991; Southwick and Yeager, 1995). Concentrations of GA ranged from 10 to 1000 $mg \cdot L^{-1}$ (ppm); however, as the registration of a commercial product neared, it became clear that a concentration of about 127 $mg \cdot L^{-1}$ would be as high as the label would allow. Flower number, fruit set, size and yield were measured similarly throughout experiments; fruit set was calculated as number of fruit produced divided by number of flowers, assessed per centimeter of shoot length, or per node (Southwick and Fritts, 1995; Southwick et al., 1995a, 1995b, 1997b, 1999).

EFFECT OF GAS ON FLORAL INITIATION. Gibberellins have been widely studied for use in reducing flower numbers in both stone and pome fruit (Luckwill and Silva, 1979; Moran and Southwick, 2000; Tromp, 1982). Gibberellin application is thought to inhibit flower bud development during the inductive period (late May through July in stone fruit); the first experimental evidence of this action was described in *Prunus* sp. by Hull and Lewis (1959) and Bradley and Crane (1960). Clanet and Salles (1976) showed that GA prevented floral initiation in peach if applied during the inductive period, reducing total flower production. Timing of GA application is critical in that the processes of bud development can only be affected during a limited period each year. Thus, the period of floral induction and differentiation must be known for each species, or each cultivar when there is a range of maturity date. Development of flower buds for several stone fruit was reviewed by Tufts and Morrow (1925). Flowering in deciduous perennial fruit has also been extensively reviewed by Sedgley (1990).

EFFECTS OF GA APPLICATION TIMING. Painter and Stembridge (1972), working in South Carolina, applied 75 $mg \cdot L^{-1}$ GA_3 to 'Redskin' peach every 2 weeks from late May through early November and assessed effects on the following year's bloom. GA significantly reduced flowering when applied at two time periods, during peach flower initiation (late May to mid June) and just before leaf fall (during September), suggesting that GA also affected processes other than flower initiation. Earlier work indicated that potassium gibberellate (KGA) applications to peach during September caused mortality in flower buds that had already initiated, and this mortality occurred by December, before freezing temperatures (Stembridge and LaRue, 1969). Interestingly, October applications resulted in delayed bloom in the subsequent season and the authors suggested that the effect was due to a delay in development of surviving flower buds. Clanet and Salles (1976) also found that treatment after induction, during the differentiation period, delayed floral differentiation and bloom without affecting flower number. In 'Elegant Lady' peach, anatomical sections of bud clusters collected in September 1994 showed that the reduction of flowering from GA sprays of 75 and 100 $mg \cdot L^{-1}$ in late May 1994 was due to a reduction in the ratio of floral:vegetative buds (Glozer, Southwick and Martin, unpublished data). In peach, there are usually three buds per node with outer floral buds and an inner vegetative bud, and this experiment revealed that many of the GA-treated outer buds developed as vegetative buds. Treatments made in mid-June at the same concentrations had no effect on the floral to vegetative bud ratio and floral differentiation was not reduced.

We sprayed GA on 'Patterson' apricot in late May through early August using a hand-held sprayer (Southwick et al., 1995a; Southwick and Yeager, 1991, 1995), and observed flower reduction when sprays were applied in late May through early July (about 2 weeks after harvest). Sprays applied in August were ineffective, however, full bloom date was delayed by the early August sprays (Southwick et al., 1995a; Southwick and Yeager, 1991). With orchard sprayers and volumes of 935 $L \cdot ha^{-1}$ the spray timings of late May through early June were most effective on 'Patterson' apricot and late June sprays were not effective (Southwick et al., 1997a). At that same spray timing and GA concentration the higher spray volume from a hand-held sprayer, compared to the orchard sprayer, apparently increased the total GA penetration into plant tissues so that early July sprays did effectively reduce flower numbers. There was a linear reduction in flower number as GA concentration increased from 50 to 120 $m \cdot L^{-1}$ in 'Loadel' cling peach from GA sprays applied on 9 July (Southwick et al., 1995b). The reduction in flower number was greater from GA sprays of the same concentration made on 15 June versus 9 July, indicating variable sensitivity to GA spray at different times of application (Southwick et al., 1995b).

EFFECTS OF GA CONCENTRATION. In 'Patterson' apricot, GA sprays of 75 and 100 $mg \cdot L^{-1}$ applied in late May 1994 (Stage III of fruit growth), consistently reduced the ratio of

Table 1. Effect of 1993 gibberellin (GA) sprays on flower density, thinning, harvest fruit weight and total yield in 1994 in 'Loadel' cling peach. All trees were consistently hand-thinned to the same fruit spacing on 5 May 1994 (Southwick et al., 1995b).

GA application date (1993)	Concn ($mg{\cdot}L^{-1}$)	Flowers/cm shoot length[z]	Thinning time/tree (min)	Reduction in hand-thinning time (%)	Harvest wt/fruit (g)[y]	Total yield (kg/tree)[x]
15 June	50	0.15 ef[w]	0	100	137.0 ef	149.8 ab
	75	0.08 f	0	100	166.7 bcd	90.4 ef
	100	0.13 ef	0	100	180.5 b	66.5 f
	120	0.06 f	0	100	208.3 a	67.2 f
July 9	50	0.27 cd	15.0 a	30	140.4 ef	155.1 a
	75	0.33 bc	17.0 a	20	136.6 f	161.6 a
	100	0.21 de	13.2 a	38	156.2 cde	145.1 abc
	120	0.16 def	15.1 a	29	168.0 bc	133.3 bcd
27 July	50	0.39 ab	19.8 a	7	152.1 c–f	113.0 de
	75	0.48 a	22.6 a	–6	148.6 def	120.6 cd
	100	0.48 a	17.8 a	17	148.4 def	145.2 abc
	120	0.47 a	20.6 a	4	147.3 ef	138.0 a–d
Hand-thinned control		0.43 ab	21.4 a	0	155.1 ef	121.5 cd

[z]1.00 flower / cm = 0.39 flower / inch.
[y]28.35 g = 1.0 oz.
[x]1.0 kg / tree = 2.2 lb / tree.
[w]Mean separation within columns by Duncan's multiple range test, 5% level.

floral:vegetative buds on spurs, when collected in late September and examined microscopically (Glozer, Southwick and Martin, unpublished data). When treated in mid-June (near harvest), only the higher concentration of GA was effective in reducing the floral to vegetative bud ratio. The later GA application at the higher concentration reduced the ratio of floral to vegetative buds by killing part of the existing apricot flowers, rather than inhibiting initiation, as evidenced by necrotic floral apices (vegetative buds appeared normal). Thus, while the result of reduction in flower numbers was the same, the mechanism whereby that reduction was accomplished may vary depending on application timing and rate.

Brown et al. (1968) found that 50 $mg{\cdot}L^{-1}$ was effective for light-blooming peach cultivars while 100 $mg{\cdot}L^{-1}$ was required for heavy-blooming cultivars. We have sprayed GA at concentrations from 10 to 1000 $mg{\cdot}L^{-1}$ on 'Patterson' apricot (Southwick and Yeager, 1991) and 50 to 120 $mg{\cdot}L^{-1}$ on 'Loadel' cling peach (Table 1) (Southwick et al., 1995b) to find effective concentrations for reducing flower numbers. Most effective concentrations for consistent flower reduction without overthinning were 50 to 100 $mg{\cdot}L^{-1}$ and risk of overthinning was reduced by concentrations of 50 to 75 $mg{\cdot}L^{-1}$. Our objective has been to reduce flowering by about 50%, however, and when using the aforementioned GA concentrations, a range in flower reduction from very little to about 50% was be found. On tested cultivars, we have never observed overthinning when using GA concentrations of 50 to 75 $mg{\cdot}L^{-1}$, and fruit set (proportion of flowers setting fruit) was never increased, therefore the need for hand thinning was reduced in more than 70% of applications within the sensitive time period. Only when very high GA concentrations have been sprayed and where flower numbers were reduced drastically has fruit set been increased (Southwick, unpublished data) or sometimes reduced (Southwick and Yeager, 1991). Often fruit size at or near hand-thinning time has been increased. Because of these changes, and the possibility of sizing more fruit when early competition is reduced, modifications in hand-thinning strategy are often required to capture the maximum benefits of this GA-thinning program. Lower GA concentrations appear to be more effective when applied during a period of greater sensitivity to GA application (Table 1) (Southwick et al., 1995b, 1997a).

FLOWER DIFFERENTIATION AND FRUIT DISTRIBUTION ALONG SHOOTS; SPECIES AND CULTIVAR EFFECTS. Dorsey (1935) found that floral differentiation in peach varied with timing and nodal position. He pointed out that peach shoots vary in final length and that the initial steps of floral differentiation may take place over an extended period of time along a shoot. Variation in the timing of bud formation and floral initiation along a shoot may permit selective reduction of flower numbers in specific sections of shoots within an orchard. Edgerton (1966) found that 80 $mg{\cdot}L^{-1}$ KGA applied to peach on a single date (23 July), had different effects on buds depending on their position along the floral shoot axis. Terminal floral buds showed a delayed initiation (not fully inhibited) while basal buds which initiated before treatment were delayed in their development. Li et al. (1989) found that the response to GA (and therefore the duration of the inductive period) varied among three peach cultivars (a mid-early ripening cultivar, mid-late ripening and late ripening). Differing varietal responses were apparently due to the proportion of long, medium and short shoots on trees of each cultivar, as well as bud physiological condition along a given shoot. These authors noted that floral induction began earlier on short shoots than long shoots, and progressed acropetally for both types of shoots. Furthermore, they suggested that while bud development duration should vary between short and long shoots, induction should end at the same time for all buds along a given shoot. In each cultivar examined, GA treatment was effective during the period of 6 to 8 weeks before the cessation of shoot growth. The end of the inductive period in France was between the end of June and the first 10 d of July, corresponding to the time of flower initiation reported by

Clanet and Salles (1976). Byers et al. (1990) working in Virginia applied 100 mg·L^{-1} GA at 36 and 47 DAFB and affected mostly buds on short shoots [7 to 20 cm (2.8 to 7.9 inches) long], whereas on long shoots [20 to 50 cm (7.9 to 19.7 inches)] only the buds on the basal half of the shoot were affected. Both Byers et al. (1990) and Taylor and Geisler-Taylor (1998), suggested that flowers could be preferentially reduced on short shoots [<10 cm (3.9 inches)] versus long (>10 cm) through use of selective GA spray timing. Byers et al. (1990) also reasoned that short shoots differentiate their flower buds earlier, or stop growing earlier, than long shoots, since the increase in buds per terminal was greater on short shoots compared to long shoots the year following hand thinning during the bud differentiation period, and it is known that flower bud differentiation begins four buds back from the shoot apex on expanding shoots of peach (Dorsey, 1935). Any change in the competitive allocation of resources during flower bud differentiation, such as would occur during fruit thinning (typically 49 DAFB), may affect the differentiation of flower buds (Byers et al., 1990). Ward (1993) found that 25 to 100 mg·L^{-1} GA reduced flower bud density in select locations along the shoot, depending on time of application, in studies conducted in Illinois. These results suggested that GA spray timing could be adjusted to selectively reduce flower numbers along specific sections of a shoot (i.e. apical, medial or basal). In 'Loadel' cling peach treated with GA during mid-June through mid-July in California, even fruit distribution along shoots has resulted (Southwick et al., 1995b). Even fruit distribution along bearing shoots has promoted uniform fruit sizing in our experience with GA-reduced flowering and has minimized the need for hand thinning.

Several factors can alter shoot growth at the time of floral initiation and bud formation (Dorsey, 1935) in perennial fruit species, including light (Grant and Ryugo, 1984), climate (Palma and Jackson, 1981; Tufts and Morrow, 1925), irrigation regime (Bustamante-Garcia, 1979; Carbonneau and Casteran, 1979), nutrient status (Weinbaum et al., 1980), rootstock, pruning (Lord et al., 1979; Rom and Ferree, 1984; Warriner et al., 1985; Webster and Shepherd, 1984; Westwood, 1993), and geographic location (Tufts and Morrow, 1925). This list suggests that finding an appropriate GA concentration and spray timing for adequate flower reduction may be difficult from season to season and among cultivars. However, in reality, the period of GA effectiveness has been consistent in our experience, within a 3-week period from season to season with only slight modifications for different cultivars, and some adjustments based upon spring temperatures and length of fruit development period. For example, we have found that a delay in fruit growth and maturity due to cool spring conditions of about 2 weeks indicates that a 2-week delay in GA treatments should be appropriate (Southwick et al., 1999). Adjustments for cultivars of differing harvest dates may be suggested from data presented in the following section.

SPECIES AND CULTIVAR DIFFERENCES IN GA EFFECTS ON FLOWERING. A number of different cultivars of cling and free-

Table 2. Effect of 1993 gibberellin (GA) sprays on flowering in selected cling and freestone peach cultivars in 1994, in California (Southwick and Fritts, 1995).

Cultivar	Harvest date (1993)	Application date (1993)	Concn (g·ha^{-1})	Flowers/cm shoot length	Reduction in flowering (%)
Queen Crest	12 May	26 April	39.5	0.45 a[x]	0
			118.6	0.34 b	24
		25 May	59.3	0.28 c	38
			118.6	0.24 c	47
			Nontreated	0.45 a	---
June Lady	9 June	26 May	59.3	0.33 c	35
			118.6	0.29 c	43
		3 June	59.3	0.45 b	12
			118.6	0.38 b	25
			Nontreated	0.51 a	---
Elegant Lady	4 July	26 May	59.3	0.36 b	25
			118.6	0.24 d	50
		8 June	59.3	0.27 cd	44
			118.6	0.24 d	50
			Nontreated	0.48 a	---
Carson	18 July	30 June	59.3	0.03 c	90
			118.6	0.01 c	97
			Nontreated	0.29 b	---
Andross	27 July	17 June	59.3	0.50 a	11
			118.6	0.38 b	32
		30 June	59.3	0.34 b	39
			118.6	0.23 c	59
			Nontreated	0.56 a	---

[z]70 g·ha^{-1} = 1.0 oz / acre (oz by weight).
[y]1.00 flower / cm = 0.39 flower / inch.
[x]Mean separation by cultivar within columns by Duncan's multiple range test, 5% level.

Table 3. Effect of 1993 gibberellin (GA) sprays on flowering in various nectarine cultivars in 1994, in California. (Southwick and Fritts, 1995); May Glo(R) = Reedley location; May Glo(T) = Traver location.

Cultivar	Harvest date (1993)	Application date (1993)	Concn ($g\cdot ha^{-1}$)	Flowers/cm shoot length	Reduction in flowering (%)
May Fire		26 April	39.5	0.81 a[x]	0
			118.6	0.79 a	2
			59.3	0.80 a	1
			118.6	0.61 b	25
	7 May		Nontreated	0.81 a	---
May Glo(R)		26 May	59.3	0.52 a	5
			118.6	0.44 b	20
	20 May		Nontreated	0.55 a	---
May Glo(T)		11 May	39.5	0.16 ab	16
			118.6	0.14 bc	26
		15 June	59.3	0.15 bc	21
			118.6	0.12 c	37
	24 May		Nontreated	0.19 a	---
Royal Giant		22 June	59.3	0.31 b	16
			118.6	0.29 b	22
		6 July	59.3	0.30 b	19
			118.6	0.36 a	3
	6 Aug.		Nontreated	0.37 a	---

[z]70 $g\cdot ha^{-1}$ = 1.0 oz / acre (oz by weight).
[y]1.00 flower / cm = 0.39 flower / inch.
[x]Mean separation by cultivar within columns by Duncan's multiple range test, 5% level.

stone peaches and nectarines have demonstrated a thinning response to the application of GA (Tables 2 and 3) (Southwick and Fritts, 1995; Taylor and Geisler-Taylor, 1998), as have apricot and plum cultivars (Tables 4 and 5) (Southwick and Fritts, 1995). We compared GA concentration (dose) and spray timing effects on cling peach cultivars of different maturity dates: 'Loadel', an early-maturing canning peach, 'Andross', a midseason cultivar, and 'Ross', a late-maturing cultivar. We applied GA_3 at rates (a.i.) of about 70 and about 94 $g\cdot ha^{-1}$ (1.0 and 1.34 oz / acre; oz by weight) in 935 $L\cdot ha^{-1}$ (75 and 100 $mg\cdot L^{-1}$) on 15 July (120 DAFB) and 29 July 1998. The second treatment date was immediately after harvest of 'Loadel', with 'Andross' and 'Ross' harvested about 2 and 3 weeks later, respectively. GA reduced flowering on all tested cultivars, but flower reduction in 'Ross' was much greater following the later application and showed stronger rate responsiveness (Southwick et al., 1999). These results are consistent with later floral induction and initiation in the late-maturing 'Ross', which might be expected to have a later date for floral induction than earlier cultivars such as 'Loadel' and 'Andross'. This is consistent with the theory that GA sensitivity is somewhat time- and cultivar-specific, depending on timing of meristematic activity or sensitivity in floral buds.

Proebsting and Mills (1974) found that GA, applied 43 DAFB at 100 $mg\cdot L^{-1}$ in Washington State, reduced flowering on 1-year-old wood and spurs of sweet cherry in the following season. Facteau et al. (1989) found that 20 $mg\cdot L^{-1}$ GA, applied to sweet cherry 19 d before harvest (DBH) in Oregon, reduced numbers of terminal flowers more than spur flowers in the following year. Shahrok (1993) found that 'Bing' sweet cherry has sequential flower differentiation within the inflorescence (cluster), supporting the possibility that flowers, and thus fruit, might be selectively reduced in number by GA within the inflorescence.

Peach cultivars differ in seasonal vegetative vigor, and thus, flower bud formation. It may be expected for this and other reasons that stone fruit cultivars would vary in the seasonal sensitivity of response to GA application due to variation in timing of flower induction and initiation. The effective period for GA action can also be quite long, depending on species. Westwood (1993) reported that plum flower initiation occurs in late summer primarily, but has been found as early as 5 July and as late as September.

Effect of season. Optimal timing of GA sprays to reduce flowering appears to be affected by growing conditions, but further work is needed. In the 1998 growing season, conditions in California were unseasonably cool. All tree fruit crops had delays in fruit maturity when compared to the normal harvest timing and the harvest season was about 2 weeks later than normal. It was clear that normal development was delayed during the early part of fruit growth and development. We surmised that peach flower bud initiation might be delayed as well and postponed our sprays from normal timing (late June to mid-July; Southwick et. al, 1995b) to mid- and late-July, obtaining results similar to earlier treatments in previous years with more typical spring conditions (Southwick et al., 1999). These preliminary results suggest that conditions affecting fruit development (e.g., temperature) may influence flower bud initiation / development. Consequently, GA spray timing for a cultivar may be varied based upon seasonal temperatures and fruit development.

Different GAs. GA_3 has been used in most published work on GA-induced flower reduction in stone fruit. We compared GA_3, GA_4, and GA_7 at 30 and 60 $mg\cdot L^{-1}$ on three dates from 8 May to 8 June, to determine their relative efficacy in reducing flowering

Table 4. Effect of 1993 gibberellin (GA) sprays on flowering in various apricot cultivars in 1994, in California (Southwick and Fritts, 1995).

Cultivar	Harvest date (1993)	Application date (1993)	Concn ($g\cdot ha^{-1}$)	Flowers/cm shoot length	Reduction in flowering (%)
Improved Flaming Gold	17 May	1 June	49.4	1.66 b[x]	46
			98.8	1.52 b	50
			Nontreated	3.07 a	---
Katy	24 May	1 June	49.4	1.49 b	19
			98.8	1.30 b	29
			Nontreated	1.84 a	---
Modesto	2 June	21 May	49.4	1.65 b	20
			98.8	1.11 c	46
		28 June	49.4	1.00 c	51
			98.8	1.14 c	44
			Nontreated	2.05 a	---
Patterson	9 June	21 May	49.4	0.81 b	44
			98.8	0.58 c	60
		1 June	49.4	0.51 c	65
			98.8	0.17 d	88
			Nontreated	1.44 a	---
Royal / Blenheim	14 June	21 May	49.4	0.91 a	17
			98.8	0.37 b	66
		1 June	49.4	0.48 b	56
			98.8	0.12 c	89
			Nontreated	1.10 a	---

[z]70 $g\cdot ha^{-1}$ = 1.0 oz / acre (oz by weight).
[y]1.00 flower / cm = 0.39 flower / inch.
[x]Mean separation within columns by Duncan's multiple range test, 5% level.

of 'Royal / Blenheim' apricot; only GA_4 at 60 $mg\cdot L^{-1}$ applied on 20 May significantly reduced flowering the following year. However, on one date, both concentrations of GA_7 increased flowering and on two dates the low rate of GA_3 increased flowering. Increased flowering in 'Patterson' apricot from low concentrations of GA_3 (10 $mg\cdot L^{-1}$) has been reported previously (Southwick et al., 1995a).

Fruit thinning, size, and yield effects. Flower reduction generally leads to larger fruit at thinning time, a reduction in the need to hand thin, and in some cases, no hand thinning required. Often fruit size on GA-treated trees is as great as on hand-thinned trees with equivalent yields per tree. In some cases, early reduction in competition results in greater yield than hand-thinned trees with similar size (Table 1, 15 June at 50 $mg\cdot L^{-1}$ and 9 July treatments at 50 and 75 $mg\cdot L^{-1}$), and the yield of fruit per tree may sometimes be as great as that from nonthinned trees (Southwick et al., 1995b, 1997b).

Tree age and vigor effects. It has been suggested that young trees are more sensitive to the effects of GA sprays than less vigorous mature trees (Taylor and Geisler-Taylor, 1998). Due to the enhanced sensitivity of young trees (less than 5 years old) to GA sprays, GA-thinning may be best suited for mature trees (Southwick and Fritts, 1995; Valent BioSciences Corp., 1999).

GA use over several seasons. In experiments with 'Patterson' apricot conducted over three consecutive seasons, flowering was consistently reduced by about 50% in the first two seasons by GA sprays applied in early June at 50 $mg\cdot L^{-1}$ (Southwick et al., 1997a). In the third season, insufficient winter chilling occurred and low numbers of viable flowers resulted. Even with low flower numbers in the untreated control, the 50 $mg\cdot L^{-1}$ GA spray applied in early June did not reduce flowering more than the untreated control. It was clear from these data that GA sprays at 50 $mg\cdot L^{-1}$ did not further reduce an already low flower number in apricot. Similar results were found in peach treated with GA over a 3-year period (Taylor and Geisler-Taylor, 1998). These results indicate that GA sprays are helpful in years where thinning is required, which is most years in many stone fruit growing regions, and may be of little or no value in years when thinning is not necessary, but was not deleterious in these studies. This is in contrast to the fear of many growers that GA sprays will reduce flower number below that on untreated trees.

GA_3 sprays appear to be environmentally safe and we have never observed any phytotoxic effects of GA_3 when sprayed at rates (a.i.) from about 47 to about 94 $g\cdot ha^{-1}$ in 935 $L\cdot ha^{-1}$ (50 to 100 $mg\cdot L^{-1}$) during the May through July period on stone fruit growing under California conditions. Brown et al. (1968) reported twig dieback in five cling peach cultivars treated in California with 200 $mg\cdot L^{-1}$, however this is well above the current label recommendation. In California, weather conditions are relatively predictable in the late spring and early summer months when GA is most effective for reducing flowering in peaches and other stone fruit, which may contribute to more consistent response in California compared to other areas. The period of effectiveness for GA sprays can be several weeks (Southwick et al., 1997b, 1998a; data presented in section on timing) which provides greater flexibility and possibly greater consistency than is likely

Table 5. Effect of 1993 gibberellin (GA) sprays on flowering in selected plum cultivars in 1994, in California (Southwick and Fritts, 1995).

Cultivar	Harvest date (1993)	Application date (1993)	Concn ($g\cdot ha^{-1}$)	Flowers / cm shoot length	Reduction in flowering (%)
Black Amber	18 June	1 June	59.3	1.14 b[x]	51
			118.6	0.63 c	73
		8 June	59.3	1.25 b	7
			118.6	0.56 c	76
			Nontreated	2.34 a	---
Friar	9 July	15 June	59.3	0.34 b	56
			118.6	0.28 b	64
		28 June	59.3	0.50 b	37
			118.6	0.25 b	68
			Nontreated	0.79 a	---

[z]70 $g\cdot ha^{-1}$ = 1.0 oz / acre (oz by weight).
[y]1.00 flower / cm = 0.39 flower / inch.
[x]Mean separation by cultivar within columns by Duncan's multiple range test, 5% level.

with other more time-sensitive chemical thinning agents. However, there is some variation in GA dose response, at different spray timings within the sensitive period. For example in 'Loadel' peach 50 $mg\cdot L^{-1}$ is as effective when applied mid-June as 100 $mg\cdot L^{-1}$ applied in mid-July under California conditions. On cultivars tested thus far, our experience has shown that consistent results have been obtained with sprays of 47 to 94 $g\cdot ha^{-1}$ (0.67 to 1.34 oz / acre) in 935 $L\cdot ha^{-1}$ (50 to 100 $mg\cdot L^{-1}$) for peach and 47 to 70 $g\cdot ha^{-1}$ (0.67 to 1.0 oz / acre) in 935 $L\cdot ha^{-1}$ (50 to 75 $mg\cdot L^{-1}$) for apricot. We have found an even distribution of fruit along shoots after GA_3 application on peaches in California, in contrast to reports in peach from the eastern U.S. This may be due to greater synchrony of flower differentiation in our climate.

By reducing early competition through reducing flower numbers it appears that greater croploads can be left following GA-induced flower reduction compared to hand thinning, and still obtain the desired final fruit size. To optimize economic returns when using GA flowering reduction, some hand thinning may often be advisable, but growers should increase the remaining fruit numbers per tree or per acre when using GA thinning, and fruit in clusters of two and three can often achieve adequate size without being hand thinned to a single fruit per cluster (Southwick, et al., unpublished data). Hand-thinning strategies will need to be adjusted based on growers' experience with an individual variety or orchard's response to GA, since laborers may over-thin by hand if they do not adjusted their fruit spacing practices after GA reduction of flowering.

A number of concerns hamper widespread commercial use of GA-induced flowering reduction in stone fruit. A primary problem is that application must be made without knowing whether light bloom or poor conditions at bloom may excessively compromise cropping. Other concerns are that percentage fruit set may decline following GA sprays, and that companies marketing GA for thinning may be exposed to high liability. Thinning programs where a low concentration of GA is applied in the growing season, followed by a thinning spray at bloom with a surfactant (Southwick et al., 1998b) would be an appropriate introduction to chemical thinning of stone fruit for many growers. Even though reducing flowering is troubling for many growers, it may become more attractive as labor costs continue to rise, perhaps making it more cost-effective to over-thin rather than strive for a perfect hand-thinning operation. Development of GA spray timing models, integrating factors such as spring temperatures, minimum node number and cultivar should help improve consistency of results, enhance grower confidence, and reduce fears of chemical company liability.

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