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Influence of Abscisic Acid and Benzyladenine on Fruit Set and Fruit Quality of 'Bartlett' Pears

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***Abstract*. Experiments were conducted to evaluate abscisic acid (ABA) and the combination of ABA and benzyladenine (BA) as a thinner on 'Bartlett' pears. Application of 500 mg·L^{-1} ABA at bloom, petal fall, and at the 10-mm stage resulted in significant fruit thinning at all timings. Application at the 10-mm stage nearly defruited the trees. Rates of ABA between 50 and 500 mg·L^{-1} were evaluated at 10 mm and the thinning response was quadratic and highly significant. Rates as low as 50 mg·L^{-1} thinned. BA at 150 mg·L^{-1} at the 10-mm stage did not thin and when combined with 250 mg·L^{-1} ABA, no additional thinning was observed, but extensive thinning was done by the ABA alone. When thinning with ABA was achieved, return bloom was also enhanced. Thinning with ABA generally resulted in larger fruit, greater flesh firmness, and higher soluble solids. The russet seen on ABA-treated fruit was attributed primarily to the surfactant used. Extensive leaf yellowing and leaf abscission were noted after ABA application, especially with the 250 mg·L^{-1} and 500 mg·L^{-1} and this was considered commercially unacceptable. BA was unable to reverse or modify the leaf yellowing and abscission caused by ABA as it has been shown to do with other plant species.**

Chemical thinning is practiced in most tree fruit-growing areas around the world. It is the easiest, most practical and cost-effective way to reduce cropload on heavily cropping trees (Wertheim, 1997; Williams and Edgerton, 1981). Reduction in the number of fruit to a more favorable leaf-to-fruit ratio allows high-quality fruit to be produced in the current year and improves bloom the next year. There is an ongoing search for new thinning chemicals that have different modes of action. This search has been prompted by the withdrawal of some fruit thinners and fueled by consumer-driven concerns for food safety, thus stimulating a search for environmentally friendly and naturally occurring compounds (Dennis, 2000). Furthermore, there are fewer thinners that are available for use on or are effective on pears than on apples.

Recently there has been increased interest in understanding the way(s) chemical thinners cause fruit abscission (Greene, 2010). It is reasoned that greater understanding of the modes of action will lead to more consistent and effective results (Fallahi and Greene, 2010). This would be accomplished primarily by allowing use or application at times and under environmental conditions that would naturally supplement the natural tendencies of the compound to cause abscission. Several possible modes of action have been proposed for the presently used thinners (Dennis, 2002). Therefore, matching the thinner, timing, concentration, and the cultivar and with the environmental conditions at the time of and immediately after application is likely to improve the consistency of the chosen thinner (Robinson and Lakso, 2011). A fairly substantial body of evidence has accumulated in recent years linking the carbohydrate status within a tree with thinning effectiveness and severity (Byers et al., 1991; Kondo and Takahashi, 1987; Lakso, 2011; Stopar et al., 2001). Cited modes of action of naphthaleneacetic acid (Stopar et al., 1997), benzyladenine (Yuan and Greene, 2000), and carbaryl (Knight, 1983; Williams and Batjer, 1964) suggested that they all or in part work through their influence on the carbohydrate status within the tree or spur.

Abscisic acid is a naturally occurring plant hormone that is involved in several physiological responses (Milborrow, 1984). Perhaps one of the most visible and important plant processes that it regulates is stomatal opening and closing. The ability of ABA to regulate stomatal movement led to the development of a proprietary product that, among other things, is meant to improve plant survival by lowering water loss by closing stomata when plants are exposed to stressful conditions that may lead to excessive water loss (Blanchard et al., 2007; Waterland et al., 2010). ABA has the potential to influence the carbohydrate status within a plant by closing stomates, thus reducing photosynthesis during the time the stomates are closed. It is for this reason that ABA was evaluated as a thinner on apples, and it was found to be quite an effective abscission-promoting compound (Greene et al., 2011).

Benzyladenine is the most recently registered thinner for use on apples (Greene, 2002). It was subsequently registered for use on pears. In general higher rates are used on pears than are generally recommended for use on apple (Vilardell et al., 2005). BA has been reported to thin several pear cultivars including Clara Frijs (Bertelsen, 2002), Bartlett (Curetti et al., 2011; Dussi and Sugar, 2011), Packham's Triumph (Bound and Mitchell, 2002), and Conference (Maas et al., 2010; Vilardell et al., 2005). A mixture of thinning compounds is frequently recommended for use on apples because combinations are perceived to be a safer approach to thinning because lower rates of the individual thinners may be used and different thinner modes of action are involved (Greene, 2002; Schwallier, 1996; Williams and Edgerton, 1981). This strategy has been particularly effective when BA is combined with other thinners such as carbaryl on apples. Maas et al. (2010) reported that BA alone was a marginal thinner on 'Conference' pear but when combined with 1-naphthaleneacetic acid (NAA), significant thinning was achieved along with enhanced return bloom. The combination of ABA and BA as a thinning spray was used by Greene et al. (2011) on apples not only to improve thinner response, but also counteract the leaf yellowing and leaf abscission (Greene et al., 2011) effect caused by the ABA on some apple cultivars.

This investigation was undertaken for several reasons: 1) to determine if ABA might be a useful thinner on pears; 2) to determine the most effective time(s) of application; 3) to evaluate ABA and BA thinner combination; and 4) to determine if BA could counteract leaf yellowing and abscission that are frequently induced by ABA.

Materials and Methods

Plant material. All experiments were done on mature 'Bartlett'/seedling trees spaced 6 × 9 m growing at the University of Massachusetts Horticultural Research Center, Belchertown, MA. Trees were maintained using accepted commercial pest control and orchard management practices.

Expt. 1: Effect of abscisic acid time of application. Five uniform trees with similar bloom density were selected. When spur leaves started to separate to reveal developing flower buds, four uniform limbs per tree 10 to 15 cm in circumference were selected and tagged. When spurs opened to the point where flowers could be identified, all flowering spurs on the tagged portion of the tree were counted and the blossom cluster density calculated. On 8 May when trees were in full bloom, one limb per tree was sprayed to the drip point with a solution containing 500 mg·L^{-1} ABA (Valent BioSciences, Libertyville, IL) containing Tween 20 (Valent Biosciences) to make a 0.05% (v/v) solution using a hand pump sprayer (Hudson professional stainless steel, 7.6 L). Similar 500-mg·L^{-1} sprays were applied to the other designated limbs on the trees on 15 May

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(petal fall) and 24 May (10-mm stage). The forth limb was the untreated control. At the end of the June drop period in July, all persisting fruit on the tagged portion of the limbs were counted, recorded, and the fruit density calculated. On 4 Sept., a 20-fruit sample was harvested from each limb and taken to the laboratory for evaluation. All fruit were weighed and the circumference measured with a handheld caliper at the equator of each fruit. Flesh firmness was determined on two sides of a 10-fruit subsample using a Lake City Technical Products, Model EPT-1-R penetrometer (Kilowna, British Columbia, Canada) equipped with a 7-mm head. A composite juice sample was collected during the pressure test and the soluble solids concentration determined using a handheld refractometer (Fisher Scientific, Waltham, MA).

Expt. 2: Effect of abscisic acid plus benzyladenine combination. Seven trees were selected that had uniform bloom. Five limbs per tree 12 to 18 cm in circumference were tagged and at the pink stage of flower development, all flowering spurs on the tagged portion of the limbs were counted and blossom cluster density calculated. At petal fall on 14 May, one limb per trees was sprayed to the drip point with a 250 mg·L^{-1} ABA solution containing 0.05% Kinetic surfactant, v/v (Helena Chemical Company, Collierville, TN). On 24 May when fruit size averaged 9.6 mm, three limbs per tree received one of the following dilute sprays: ABA at 250 mg·L^{-1}, BA at 150 mg·L^{-1} (MaxCel®; Valent BioSciences), or ABA 250 mg·L^{-1} plus BA at 150 mg·L^{-1}. At the end of June drop in July, all persisting fruit were counted and fruit density calculated. On 2 Sept., a 25-fruit sample was harvested from each limb and taken to the laboratory for evaluation. Fruit weight and circumference were measured as previously described. Each harvested fruit was evaluated for russet using the following rating system: 1 = no russet, 2 = 1% to 2% of surface with russet, 3 = 3% to 5% russet, 4 = 5% to 20% russet, and 5 = more than 20% of the surface with russet. Flesh firmness and soluble solids were measured as previously described.

Expt. 3: Effect of abscisic acid concentration. Seven uniformly flowering trees were selected and on each, five uniform limbs, 12 to 18 cm in circumference, were tagged. All blossom clusters were counted at the pink stage of flower development. On 24 May when fruit size averaged 9.6 mm, one limb on each tree received a dilute spray of 50, 125, 250, or 500 mg·L^{-1} ABA in 0.05% Kinetic (v/v). Fruit set and harvest evaluations were the same as previously described.

Statistical analysis. Statistical analysis was done using analysis of variance. Where appropriate, means were separated by orthogonal polynomial comparison, analysis of regression, or Duncan's new multiple range test. All analyses were done using SAS 9.3 (SAS Institute, Cary, NC).

Results

Fruit thinning resulted when ABA was applied at 500 mg·L^{-1} to 'Bartlett' pears between full bloom and the 10 mm stage of fruit development (Table 1). The later that the ABA was applied in the developmental stage, the greater the thinning. There was modest thinning when applied at full bloom (FB) and excessive thinning at 10 mm that resulted in near defruiting the treated portion of the tree. Even application at petal fall (PF) caused substantial thinning that can be characterized as overthinning. Air temperature average on the day of FB application was 24.5 °C, at PF and the day after averaged between 28 °C and 29 °C and average, high temperature at the time of 10-mm application and soon after was near 31 °C. Leaf yellowing and leaf abscission were noted, especially after the 10-mm application.

Because ABA at 500 mg·L^{-1} significantly overthinned, a follow-up experiment was done to evaluate a range of ABA concentrations from 50 to 500 mg·L^{-1}. Thinning caused by ABA was highly significant (Table 2) and even at a rate as low as 125 mg·L^{-1}, it was judged to be excessive. Thinning treatments did significantly improve return bloom and this positive response increased linearly with increasing concentrations of ABA applied.

BA and ABA were evaluated as thinners alone and in combination in this investigation. Although 150 mg·L^{-1} reduced fruit set numerically by at least 35%, the reduction was not statistically significant (P = 0.21; Table 3). An indication that the crop reduction may be real is supported by the return bloom data for BA, which is significant at P = 0.08. ABA at 250 mg·L^{-1} thinned excessively, whether applied alone or in combination with BA. Return bloom doubled with the 10-mm application. A comparison of thinning at PF and 10 mm with 250 mg·L^{-1} ABA was made again in this investigation. ABA applied at PF reduced cropload by 40% but it was not significantly different from the untreated control. Although return bloom was more than doubled with the PF application, the increase was not significant. Return bloom after the 10-mm application was increased by ≈300% and this was statistically significant.

Fruit were harvested at a commercially acceptable harvest time and evaluated for treatment effects. When ABA at 500 mg·L^{-1} was applied at FB, it had no effect on the harvest parameters evaluated (Table 4). However, application at PF resulted in increased fruit weight and fruit diameter but it had no effect on flesh firmness or soluble solids at either timing. There were too few fruit from the 10-mm application timing to make meaningful fruit evaluation.

All rates of ABA from 50 to 500 mg·L^{-1} applied at the 10-mm fruit size stage resulted in increases in fruit weight, fruit diameter, flesh firmness, soluble solids, and the amount of fruit russeting (Table 5). With the exception of fruit russeting, the effects were linear with increasing ABA concentration.

BA had no influence on fruit quality parameters at harvest except for slightly

Table 1. Effect of the time of 500 mg·L^{-1} ABA application on bloom and fruit set of 'Bartlett' pears, Expt. 1.

		Bloom	Fruit set	
Treatment[z] timing	Date applied	Blossom clusters per cm LCSA	Fruit per cm LCSA	Percent set
Control	—	6.6 a[y]	7.4 a	115 a
Full bloom	8 May 2007	6.6 a	4.4 b	72 b
Petal fall	15 May 2007	6.6 a	1.5 c	27 c
10 mm	24 May 2007	6.7 a	0.1 d	1 d

[z]ABA was first dissolved in ethanol before adding to the tank. All treatments contained 0.05% Tween 20. Treatments applied as a dilute hand-gun application to the drip point.
[y]Mean separation within columns by Duncan's new multiple range test (P = 0.05).
ABA = abscisic acid; LCSA = limb cross-sectional area.

Table 2. Effect of increasing concentrations of ABA on fruit set and return bloom of 'Bartlett' pear, Expt. 3.

		Bloom	Fruit set		Return bloom
Treatment[z]	Concn (mg·L^{-1})	Blossom clusters per cm LCSA	Fruit per cm LCSA	Percent set	Blossom clusters per cm LCSA
Control ABA	0	7.4	5.1	78	5.8
ABA	50	7.3	3.2	43	5.6
ABA	125	7.3	1.1	22	8.5
ABA	250	7.3	0.3	5	11.7
ABA	500	7.4	0.7	4	9.6
Significance		NS[y]	***	***	*
Linear		NS	***	***	**
Quadratic		NS	**	**	NS
Cubic		NS	NS	NS	NS

[z]Treatments applied as a dilute hand-gun application on 24 May.
[y]NS, *, **, ***Nonsignificant or significant at P = 0.05, 0.01, or 0.001, respectively.
ABA = abscisic acid; LCSA = limb cross-sectional area.

Table 3. Effect of time of application and combination of ABA with or without BA on bloom, fruit set, and return bloom of 'Bartlett' pear, Expt. 2.

			Bloom	Fruit set		Return bloom
Treatment[z]	Concn (mg·L^{-1})	Date applied	Blossom clusters per cm LCSA	Fruit per cm LCSA	Percent set	Blossom clusters per cm LCSA
Control	—	—	8.1	6.6	82	3.6
BA 10 mm	150	24 May	7.9	4.0	55	8.2
ABA 10 mm	250	24 May	8.0	0.6	11	8.6
BA + ABA 10 mm	150 + 250	24 May	8.0	0.9	12	11.0
Significance			NS[y]	**	**	NS
ABA			NS	***	***	*
BA			NS	NS	NS	NS (0.08)
ABA*BA			NS	NS	NS	NS
Control	—	—	8.1[x] a	6.6 a	82 a	3.6 b
ABA PF	250	14 May	8.0 a	3.8 ab	65 a	8.6 ab
ABA 10 mm	250	24 May	8.4 a	0.6 b	11 b	10.7 a
Significance			NS	**	***	

[z]Treatments applied as a dilute hand-gun application.
[y]NS, *, **, ***Nonsignificant or significant at P = 0.05, 0.01, or 0.001, respectively.
[x]Mean separation Duncan's new multiple range test (P = 0.05).
ABA = abscisic acid; BA = benzyladenine; LCSA = limb cross-sectional area; PF = petal fall.

Table 4. Effect of the time of 500 mg·L^{-1} ABA application on fruit size and quality at harvest of 'Bartlett' pears, Expt. 1.

Treatment[z] timing	Date applied	Fruit wt (g)	Fruit size (cm)	Flesh firmness (N)	Soluble solids (%)
Control	—	159 b[y]	6.4 b	77.5 a	12.4 a
Full bloom	8 May 2007	191 ab	6.9 ab	78.4 a	12.5 a
Petal fall	15 May 2007	211 a	7.1 a	78.0 a	12.8 a
10 mm	24 May 2007[x]	—	—	—	—

[z]ABA was first dissolved in ethanol before adding to the tank. All treatments contained 0.05% Tween 20. Treatments applied as a dilute hand-gun application to drip.
[y]Mean separation Duncan's new multiple range test (P = 0.05).
[x]Insufficient fruit to analyze.
ABA = abscisic acid.

Table 5. Effect of increasing concentration of ABA on fruit quality and fruit characteristics of 'Bartlett' pear, Expt. 3.

Treatment[z]	Concn (mg·L^{-1})	Fruit wt (g)	Fruit diam (cm)	Flesh firmness (N)	Soluble solids (%)	Russet rating (1–5)
Control ABA	0	126	6.1	66.5	10.5	1.7
ABA	50	147	6.4	69.2	10.8	2.0
ABA	125	159	6.5	73.3	10.9	2.3
ABA	250	188	6.9	72.9	11.1	1.9
ABA	500	165	6.7	78.0	11.1	2.3
Significance		***[y]	***	*	*	*
Linear		***	***	**	**	NS
Quadratic		*	NS	NS	NS	NS
Cubic		NS	NS	NS	NS	NS

[z]Treatments applied as a dilute hand-gun application on 24 May.
[y]NS, *, **,***Nonsignificant or significant at P = 0.05, 0.01, or 0.001, respectively.
ABA = abscisic acid.

increasing the extent of fruit russeting (Table 6). ABA at 250 mg·L^{-1} in the same experiment increased fruit size, soluble solids, and fruit russeting and increased flesh firmness, although it was not statistically significant. There were ABA × BA interactions for size and firmness. When ABA and BA were applied together, the increases in fruit size (weight and diameter) and firmness caused by ABA were reversed. A comparison of ABA timing (PF and 10 mm) was included again in this experiment and the results generally confirmed those reported in Expt. 1. Increases were in general associated with the 10-mm time of application. Fruit russeting was not increased with the PF spray but it was with the 10-mm timing.

Discussion

Apple and pear fruit may be thinned over a relatively wide range of developmental stages, which roughly spans the time the king flower opens until ≈25 mm fruit diameter (Schwallier, 1996; Williams and Edgerton, 1981). Not all thinners work uniformly or equally well at all developmental stages (Greene, 2002). Most blossom thinners work by physically damaging the flower and impeding pollen germination or pollen tube growth; thus, their time of application is restricted to the bloom period. Hormone-type thinners such as NAA or ethephon have activity at bloom, but NAA especially is more effective when applied at other developmental stages such as PF to 15 mm fruit size. In this investigation, ABA thinned at all developmental stages tested: FB, PF, and 10 mm fruit size. Most presently used commercial thinners thin insufficiently if applied just once; thus, sequential application of thinners is appropriate to achieve the optimum final cropload (Wertheim, 2000). Therefore, ABA may be useful as a thinner when used at different times of application.

Damage or phytotoxicity to petals and leaves when applied at bloom was not noted. ABA does increase ethylene production in many plants including apple (Edgerton, 1971) and ethylene has been cited as a hormone that can cause leaf and fruit abscission (Osbourne, 1989).

The greatest amount of thinning occurred when ABA was applied at the 10-mm stage. This is the developmental range frequently cited as the most sensitive for thinner application (Greene, 2002; Schwallier, 1996; Wertheim, 2000; Williams and Edgerton, 1981). This stage of fruit development is also within the developmental period cited by Lakso et al. (2006) as one in which there may be reduced carbohydrate available because of strong competition among competing sinks, which include rapidly growing shoots and developing fruit. ABA is an instrumental hormone linked to stomatal function and closure (Beardsell and Cohen, 1975). Consequently, it is not surprising that an application that reduces carbohydrate supply by limiting photosynthesis through stomatal closure would be highly effective at causing fruit abscission. Similar treatments that limit photosynthesis at this critical time such as shading or use of photosynthetic inhibitors are also effective at causing fruit abscission (Byers et al., 1990a, 1990b; McArtney et al., 2004).

Fruit russet is a side effect of the application of some tree fruit spray applications

Table 6. Effect of time of application of ABA with or without BA on fruit quality and fruit characteristics of 'Bartlett' pear, Expt. 2.

Treatment[z]	Concn (mg·L^{-1})	Date applied	Fruit wt (g)	Fruit diam (cm)	Flesh firmness (N)	Soluble solids (%)	Russet rating (1–5)
Control	—	—	140	6.3	68.3	10.4	1.6
BA	150	24 May	162	6.6	72.9	10.8	2.4
ABA	250	24 May	184	6.8	76.6	11.0	2.5
BA + ABA	150 + 250	24 May	165	6.6	70.6	11.2	2.9
Significance			*[y]	**	NS	**	**
ABA			*	*	NS	**	**
BA			NS	NS	NS	NS	**
ABA*BA			*	*	*	NS	NS
Control	—	—	140 b[x]	6.3 b	68.3 a	10.4 a	1.6 a
ABA PF	250	14 May	163 ab	6.5 b	71.1 a	10.9 b	1.8 a
ABA 10 mm	250	14 May	184 a	6.8 a	76.6 a	11.0 b	2.5 b
Significance			**	**	NS	**	*

[z]Treatments applied as a dilute hand-gun application.
[y]NS, *, **, ***Nonsignificant or significant at $P = 0.05$, 0.01, or 0.001, respectively.
[x]Mean separation Duncan's new multiple range test ($P = 0.05$).
ABA = abscisic acid; BA = benzyladenine.

(Fallahi and Greene, 2010). In this investigation, spray containing both ABA and BA resulted in russet. However, this was noted only in the second year when applications were made only at the 10-mm stage of fruit development, a stage at which fruit russeting from foliar sprays is likely. It has been known for many years that BA can cause fruit russet (McLaughlin and Greene, 1984), but this has not been general enough or serious enough to be considered a problem. ABA is a relatively new compound that to date has not been reported to cause russet formation on fruit (Greene et al., 2011). One cannot dismiss the possibility that the surfactant used in Expts. 2 and 3, Kinetic, and included with ABA was the primary cause. The control treatment did not receive a surfactant-only application to test this. Furthermore, applications were made at the 10-mm stage when temperatures were near 30 °C, both factors that favor russet development on susceptible fruit.

Leaf yellowing and abscission are symptoms of senescence that are known to be promoted by ABA (Addicutt and Lyon, 1969). This type of senescent behavior has been reported when ABA is applied as a thinning spray on apples (Greene et al., 2011), but the presence or severity appears to be cultivar-dependent. It is known that cytokinins can delay senescence and reduce leaf yellowing (Gans and Amasino, 1995; Van Staden et al., 1988). BA was able to prevent leaf yellowing and abscission caused by ABA in susceptible apple cultivars (Greene et al., 2011). However, in this investigation, BA was unable to reverse, modify, or prevent any of these senescent effects caused by ABA. It appears that the abscission or yellowing caused by the 250-mg·L^{-1} and 500-mg·L^{-1} ABA rates would be too high to be commercially acceptable.

BA is the most recent approved thinner in the United States and in a number of locations for use on pears. It has been used successfully on many pear cultivars including 'Bartlett' ('Williams') (Curetti et al., 2011). In this investigation it was used alone and in combination with ABA at a rate of 150 mg·L^{-1}. It did not thin or contribute to the thinning when included with ABA and it marginally enhanced return bloom ($P = 0.08$). Although used within the recommended range, perhaps higher rates may be required to achieve a satisfactory level of thinning.

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