Postbloom Thinning Response of ‘Bartlett’ Pears to Abscisic Acid

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Abstract. Postbloom thinning of ‘Bartlett’ pears (Pyrus communis L.) is required to produce fruit of commercially acceptable size. In the Pacific Northwestern United States, low temperatures during early stages of pear fruitlet development often limit the efficacy of commercial thinning compounds. Hand thinning, therefore, remains the standard crop load management practice. Chemical thinning protocols are necessary to reduce the cost and dependence on hand labor. The plant hormone abscisic acid (ABA) was evaluated over multiple years in several ‘Bartlett’ pear orchards. ABA was applied to whole canopies at variable rates (50–500 ppm) when fruit diameter was generally between 10 and 12 mm. In three of four trials, ABA thinned in a dose-dependent manner. The relative degree of thinning for a given dose, however, was inconsistent among trials. Trees treated with ABA had a higher proportion of blank and single-fruited spurs than controls. ABA increased the rate of fruit drop, and return bloom generally increased with increasing ABA dose. Fruit weight and return bloom generally increased with increasing ABA rate. Fruit quality, when measured, was unaffected by ABA treatments. Inconsistent thinning response with ABA may be attributed to environmental factors, biological factors, or both.

The west coast states CA, OR, and WA account for ≈97% of the U.S. fresh market ‘Bartlett’ pear crop (U.S. Department of Agriculture National Agricultural Statistics Service, 2016). About half of those pears are produced in the Pacific Northwest (PNW) where the cultural practice of hand thinning is required to attain marketable fruit size. Over the past several decades, increasing costs and decreasing availability of labor have prioritized the development of alternative crop load management strategies (Wells et al., 1995). Both mechanical and chemical methods have shown potential to reduce or eliminate hand thinning of tree fruits. Recently, mechanical string thinner technology has been applied with varying success to peach, Prunus persica L. (Reighard and Henderson, 2012; Schupp et al., 2008), and apple, Malus x domestica Borkh. (Ellis et al., 2010; Schupp and Kon, 2014). Seehuber et al. (2015) reported positive effects of mechanical thinning on crop reduction and fruit size of 0.4 × 4.0 m hedgerows of pear trees on ‘Quince A’ rootstock; however, the voluminous, three-dimensional canopies that comprise the vast acreage of pear in the PNW would likely impede machine access to blossom clusters. Furthermore, string thinning is injurious to spurs and shoots (Ngugi and Schupp, 2009) potentially predisposing pear trees to increased risk of fire blight (Erwinia amylovora) infection, although this effect was not reported by Seehuber et al. (2015). Irrespective, chemical thinning approaches have been far more common for pear (Wertheim, 2000).

Thinning compounds differ with respect to their mode of action. Some chemicals applied around flowering [i.e., fish oil and lime sulfur (Yoder et al., 2009); ammonium thiosulfate (ATS) (Wertheim, 2000)] are caustic and primarily serve to damage tissues of reproductive organs. Bound and Mitchell (2002) reported significantly reduced fruit set of ‘Packham’s Triumph’ pear when ATS was applied at low concentrations (0.5% to 1.5%) at 20% and 50% of full bloom, with two applications improving the response. ATS concentrations of 3% were phytotoxic to other pear cultivars (Wertheim, 2000). Pears are generally thinned during postbloom developmental stages using chemicals that alter the source-to-sink ratio (Lakso et al., 2006) or hormonal balance (Bangerth, 2000). With the exception of ethephon, which is seldom used to thin pears, most of the hormone-like thinners are applied when fruit diameter is 10–12 mm. The cytokinin 6-benzyladenine (BA) is the most extensively used pear thinner throughout the world (Asin et al., 2009; Curetti et al., 2010; Dussi, 2011; Gimenez et al., 2009; Greene, 2012; Maas and van der Steeg, 2011; Theron et al., 2011; Wertheim, 2000). The auxin naphthalene-acetic acid (NAA) and its amide (NAD) also thin pears although results have been variable (Asin et al., 2009; Theron et al., 2011; Wertheim, 2000) and adverse effects such as induced premature ripening and reduced storage life of ‘Bartlett’ have been observed (Lombard and Grim, 1966). A critical drawback of BA and NAA/NAD is the relatively high temperature requirement for effective foliar penetration, uptake, and activity (Black et al., 1993; Edgerton and Haeseler, 1959; Luckwill and Lloyd-Jones, 1962; Wertheim, 2000). Thinning activity of BA was associated with temperatures >18 °C (Bubán, 2000). Foliar penetration of NAA was determined to increase 3-fold between 25 °C and 35 °C (Greene and Bukovac, 1971). Thus, predictable thinning outcomes can be difficult to achieve in cooler climates. Alternative thinning chemistries are needed.

Abscisic acid is a plant hormone associated with abscission and plant dormancy (Taiz and Zeiger, 2010). ABA also regulates stomatal aperture during periods of drought to prevent plant desiccation (Davies and Zhang, 1989). Exogenously applied ABA can mimic drought stress when soil moisture is nonlimiting (Correia et al., 1999). An obvious consequence of stomatal closure is reduced carbon fixation, which has been associated with improved thinner efficacy (Lakso, 2011; Lakso et al., 2006; Untiedt and Blanke, 2001). Thus, ABA may enhance fruit abscission by inducing a carbohydrate (CHO) deficit. ABA has also been associated with increased ethylene production and abscission of peach when treated at pit hardening (Giovana et al., 2015) and mature apples (Edgerton, 1971) but did not appear to...
explain ABA-induced pear fruitlet abscission when trees were treated 10 d after full bloom (dafb) (Einhorn and Arrington, 2017). Several researchers have sought to exploit these mechanisms to thin apple (Greene et al., 2011; McArtney et al., 2014) and pear (Greene, 2012). McArtney et al. (2014) reported reduced stomatal conductance (gs), and by extension, Lp (Lakso, 1994), of apple leaves treated with ABA, although this was not always associated with thinning. Greene (2012) observed consistent thinning when ABA was applied to ‘Bartlett’ pear, both alone and in combination with BA. ABA (500 ppm) reduced control fruit set by 37%, 77%, and 99% when applied at full bloom, petal fall, and 10 mm diameter phenology stages, respectively (Greene, 2012). Because these experiments were all conducted in the Eastern United States, and may not apply to the PNW, our primary objective was to evaluate ABA performance as a postbloom thinner in a major pear-producing region of the PNW.

Materials and Methods

Placing material, treatments, and experimental design. Four experiments were carried out in three ‘Bartlett’ pear orchards in Hood River and Parkdale, OR, between 2012 and 2014. In all trials, concentrations of ABA (ProTone; Valient BioSciences, Walnut Creek, CA) were combined with a surfactant (Sil 100; Clariant Corp., Mount Holly, NC) at 0.1% (v:v) and applied to drip between 0600 and 1000 hr using a hydraulic, pressurized spray gun. Dilute handgun applications generally require greater spray volume per tree than would be applied in a commercial application and may limit direct extrapolation of these results to commercial practices. Depending on the trial, ABA was applied between petal fall and 10–12 mm fruit diameter; actual dates varied according to forecasted precipitation and wind conditions. In each experiment, trees were pre-selected for uniformity of bloom and canopy size and then randomly assigned treatments. For all experiments, applications were made under calm conditions (i.e., wind speeds of <5 km h⁻¹). All other production practices were performed according to industry standards.

Expt. 1. In 2012, an eighth-leaf ‘Bartlett’ /‘OH × F 87’ orchard (3 × 5 m; 666 trees/ha) was selected in Hood River, OR, at the Oregon State University Mid-Columbia Agricultural Research and Extension Center (MCAREC) (long. 45.68, lat. 121.51). Soil is a Van Horn fine sandy loam. Treatments were arranged in a randomized complete block design (RCBD) with four single-tree replications. Blocks comprised single rows and were separated by five guard rows. Within blocks (i.e., rows), treatment trees were separated by a minimum of one guard tree to reduce the risk of spray contamination. The following treatments were applied: 1) control, 2) deionized (DI) water + 0.1% (v:v) surfactant, 3) 125 ppm ABA, 4) 250 ppm ABA, and 5) 500 ppm ABA. Treatments were applied 21 dafb. No significant differences were observed between the control and control + surfactant for any of the measured parameters. Results, therefore, are only provided for the control. In all ensuing experiments, the water + surfactant treatment was omitted from the treatment design. All ABA concentrations continued to be combined with 0.1% (v:v) surfactant. Expt. 2. In 2013, an 18-year-old ‘Bartlett’ /‘OH × F 97’ pear orchard (2.5 × 5.5 m; 727 trees/ha) was selected in Hood River, OR, at the MCAREC. Soil is a Van Horn fine sandy loam. Treatments were arranged in an RCBD with four single-tree replications. Blocks comprised single rows and were separated by five guard rows. Within blocks (i.e., rows), treatment trees were separated by a minimum of one guard tree to reduce the risk of spray contamination. Treatments consisted of a control; 50, 100, 150, and 200 ppm ABA. Applications were made 22 dafb.

Expt. 3. In 2013, a 10th-leaf commercial ‘Bartlett’ /‘OH × F 97’ pear orchard (3 × 6 m; 556 trees/ha) was selected in Parkdale, OR (long. 45.29, lat. 121.34). Soil is a Hutson fine sandy loam. Treatment trees were confined to three rows and were arranged in a completely randomized design (CRD) with four replications, each comprising two trees. A minimum of one guard tree was maintained in all directions. The following treatments were applied: 1) control, 2) 50 ppm ABA, 3) 100 ppm ABA, 4) 200 ppm ABA, and 5) 400 ppm ABA. Applications were made 20 dafb. Expt. 4. In 2014, a trial was established in the orchard described in Expt. 2 using trees not previously treated with thinning compounds. Treatments were arranged in an RCBD with four replications each comprising two trees. Blocks comprised single rows and were separated by five guard rows. Within blocks (i.e., rows), treatment trees were separated by a minimum of one guard tree to reduce the risk of spray contamination. The following treatments were applied: 1)
Table 3. Expt. 3. Effect of 2013 abscisic acid (ABA) applications (20 d after full bloom) on fruit set, number of fruit hand thinned, number of fruit harvested, yield, fruit weight, and return bloom of 10th leaf ‘Bartlett’/‘OH × F 97’ pear trees (3 × 6 m; 556 trees/ha) at a commercial orchard in Parkdale, OR. Data are means of four two-tree replications.

| ABA treatment (ppm) | Fruit set (no. fruit/cluster) | Hand-thinned fruit (no./tree) | Fruit no. (fruit/tree) | Yield (kg/tree) | Mean fruit wt (g) | Return bloom (% of control) |
|---------------------|-------------------------------|-----------------------------|-----------------------|-----------------|------------------|-------------------------------|
| 0                   | 1.36                          | 416.5                       | 510                   | 95.5            | 196.1            | 100                           |
| 50                  | 1.01                          | 309.3                       | 439                   | 82.9            | 193.8            | 92                            |
| 100                 | 0.77                          | 186.9                       | 349                   | 76.7            | 212.5            | 89                            |
| 200                 | 0.25                          | 111.3                       | 244                   | 51.5            | 238.3            | 106                           |
| 400                 | 0.03                          | 109.4                       | 172                   | 37.6            | 232.1            | 118                           |

Significance

Linear 0.0476 NS <0.001 NS <0.001 <0.001 0.0437 0.0468

Quadratic <0.001 NS NS NS NS NS NS NS NS NS

Table 4. Expt. 4. Effect of 2014 abscisic acid (ABA) applications (8 d after full bloom) on fruit set, number of fruit at harvest, yield, average fruit weight, and return bloom of 19-year-old ‘Bartlett’/‘OH × F 97’ pear trees (2.5 × 5.5 m; 727 trees/ha) at the Oregon State University Mid-Columbia Agricultural Research and Extension Center in Hood River, OR. Data are means of four two-tree replications.

| ABA treatment (ppm) | Fruit set (no. fruit/cluster) | Fruit no. (fruit/tree) | Yield (kg/tree) | Mean fruit wt (g) | Return bloom (% of control) |
|---------------------|-------------------------------|-----------------------|-----------------|------------------|-------------------------------|
| 0                   | 0.75                          | 494                   | 96.8            | 199.2            | 100                           |
| 50                  | 0.7                           | 458                   | 91              | 198.5            | 144                           |
| 100                 | 0.64                          | 450                   | 85              | 188.6            | 136                           |
| 200                 | 0.59                          | 480                   | 92.5            | 192.4            | 181                           |
| 400                 | 0.41                          | 379                   | 78.6            | 208.8            | 168                           |

Significance

Linear <0.001 NS NS NS NS NS NS NS NS NS

Quadratic <0.001 0.0308 0.0342 NS NS 0.0468

Table 5. The effect of 2014 abscisic acid applications on harvest and postharvest ‘Bartlett’ pear fruit quality. Postharvest analyses were performed after 60 d of regular air (RA) cold storage at −1 °C, >95% relative humidity and after a ripening period of 5 d at 20 °C. Data are means of four replications.

| ABA treatment (ppm) | Harvest | 60 d RA storage | 60 d RA storage plus 5 d ripening |
|---------------------|---------|-----------------|---------------------------------|
| FF (kg)             | SSC (%) | TA (%)          | FF (kg) | SSC (%) | TA (%)          |
| 0                   | 8.2     | 12.7            | 0.31    | 7.1     | 13.3            | 0.26    | 1.6     | 13.5         | 0.27 |
| 50                  | 8.1     | 12.5            | 0.33    | 7.7     | 13.4            | 0.3     | 1.6     | 13.8         | 0.24 |
| 100                 | 8.3     | 12.8            | 0.32    | 7.7     | 13.6            | 0.27    | 1.6     | 14.3         | 0.26 |
| 200                 | 8.3     | 13.1            | 0.31    | 7.6     | 14.2            | 0.28    | 1.5     | 13.5         | 0.26 |
| 400                 | 8.3     | 13.9            | 0.28    | 7.9     | 14.1            | 0.28    | NS      | NS          | NS   |

Significance

Linear NS NS NS NS NS NS NS NS NS NS

Quadratic NS NS NS NS NS NS NS NS NS NS

FF = fruit firmness; SSC = soluble solids concentration; TA = titratable acidity.

NS = nonsignificant.

Fig. 1. The effect of abscisic acid rate (0, 50, 100, 200, and 400 ppm) on the number of fruit retained per spur on ‘Bartlett’ pear limbs in Expt. 3. Measurements were taken 40 d after full bloom following natural fruit drop but before hand thinning. Data are means of four replications (n = 4 limbs, each with ≥40 spurs). Vertical bars are ±1 se.
Back transformation for presentation.

were performed using Microsoft Excel

Arccosine transformations for percent data

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regression model. The degree of magnitude

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Statistical analyses. All statistical analyses

were carried out in R-studio statistical

platform. A mixed model (lm4 package) was

used and blocking was assigned as a random

effect. Both linear [lm()] function and

quadratic [poly()] function models were tested

and significance was reported at \( P \leq 0.05 \).

Arcosine transformations for percent data

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(Microsoft Corporation, Bothell, WA) and

back transformed for presentation.

Results

Flowering and fruiting. Application of

ABA significantly reduced fruit set in three

of the four trials (Tables 1–4). When ABA

thinned, the effect was rate responsive. The

severe thinning observed in Expt. 1 was

explained better by a quadratic model, but

generally thinning cropping responses

were more strongly explained by the linear

regression model. The degree of magnitude

in thinning, however, was inconsistent

among trials for a given dose. For example,

fruit set of 200 ppm ABA-treated trees after

June drop differed markedly between trials

producing drastic thinning in Expt. 3 but

only slight thinning in Expt. 4 (Tables 3 and

4). The relatively light fruit set of control

trees in Expt. 2 and Expt. 4 (roughly half that

of Expt. 3) may have rendered chemical

thinning more difficult. ABA rates ≥200

ppm severely over-thinned, but in only two

of the four trials (Expts. 1 and 3; Tables 1

and 3), resulting in fewer harvested fruit and

lower yields despite hand thinning of control

trees (Tables 1 and 3). At the spur level,

ABA significantly increased the proportion

of spurs with 0 or 1 fruit and decreased the

proportion of spurs having ≥2 fruit com-

pared with the control (Fig. 1). ABA did not

thin fruit in Expt. 2, irrespective of rate.

Subsequently, all treatment trees were mini-

mally hand thinned and yield differences

were not detectable at harvest (Table 2).

When thinning was observed, fruit weight

increased with increasing ABA rate (Ta-

bles 1 and 3), except in Expt. 4 (Table 4).

In Expt. 2, fruit weight, like fruit set, was

unaffected by ABA treatments (Ta-

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bloom; however, significantly greater

return bloom tended to only occur when

high ABA concentrations caused exces-

sive thinning.

Fruit quality. Commercial harvest ma-

turity of fruit was unaffected by ABA (de-

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quality attributes at harvest and after 2

months of RA storage were not signifi-

cantly affected by ABA, irrespective of

rate (Table 5). ABA had no effect on fruit

quality attributes after ripening, and all

fruit were considered of fine eating quality

(juicy and buttery texture), although a for-

tmal sensory evaluation was not performed.

Leaf gas exchange. ABA significantly

lowered leaf \( P_n \) rate in Expt 3 (Fig. 2A).

Within hours from application, \( P_n \) was re-

duced 75% to 90% of control levels irrespec-

tive of concentration (Fig. 2A). Leaves

treated with 50 and 100 ppm ABA recovered

to ≥75% of control levels by 4 d from

application (dfa) and fully by 8 dfa. Con-

versely, trees treated with higher rates of ABA

(i.e., 200 and 400 ppm) required 15–20 dfa
to recover to control levels. In Expt. 2, \( P_n \)

measurements were not recorded between

1 and 6 dfa because of instrument malfunc-

tion; however, on 6 dfa, \( P_n \) of leaves treated

with 200 ppm ABA was significantly reduced

from control levels by ≥20% (Fig. 2B). By

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day 13, \( P_n \) rates of all ABA treatments were \( \geq 90\% \) of controls.

**Solar radiation and temperature.** Diurnal solar radiation patterns before and after ABA treatments differed drastically among trials (Fig. 3). Expt. 3 had the most days with reduced light compared with other experiments. Average daytime solar radiation was 40% to 50% of clear-sky conditions (\( \approx 900 \) W·m\(^{-2} \)) five of the 10 d following ABA applications, with the exception of a few sunbreaks. Expts. 1 and 4 had a similar number of cloudy days within the 10-d period following treatments but differed with respect to their occurrence relative to treatment timings. In contrast, 10 consecutive cloud-free days followed ABA treatments in Expt. 2 (Fig. 3B). Daytime temperatures tended to track well with solar radiation; cloudy days had much lower average and minimum temperatures than sunny days (Fig. 4). Minimum nighttime temperatures within the 10-d period after applications ranged from 5 to 10 °C for Expts. 1, 3, and 4 but exceeded 10 °C for most of the nights in Expt. 2.

**Discussion**

With the exception of one trial, ABA significantly thinned ‘Bartlett’ pears. For a given ABA dose, however, the rate of thinning varied among years. Greene (2012) reported consistent thinning when applying ABA to single limbs of mature ‘Bartlett’ pear trees at similar concentrations to those reported herein. Generally, efficacy of a given dose of ABA was markedly higher in that study, which may be attributed to differences between the two climates. Although ‘Bartlett’ is not regarded as a biennial bearer, return bloom was generally improved by ABA, commensurate with the level of thinning, as previously documented (Greene, 2012). In addition to fruit abscission, Greene (2012) reported irreversible leaf yellowing and abscission at high ABA rates (\( \approx 250 \) ppm) despite the addition of BA, which was previously demonstrated to counteract ABA-induced yellowing of apple leaves (Greene et al., 2011). We did not include BA in our trials. We did observe severe defoliation at 400 and 500 ppm ABA (Expts. 1 and 3, an estimated one-third of the leaf population though leaf abscission data were not recorded) and slight defoliation at 250 ppm (Expt. 1; \( \approx 10\% \) of leaves); however, appreciable leaf abscission was not observed in Expt. 4, despite treatment with 400 ppm ABA. These results indicate a potential interaction between ABA and environmental factors on leaf senescence processes. Middelberg et al. (2014) demonstrated increased ABA penetration following rewetting of ABA-treated leaves. Precipitation did accompany low solar radiation (i.e., cloudy conditions) the week after ABA applications in Expts. 1 and 3 and may have enhanced ABA uptake. Leaf abscission would have certainly contributed to the excessive thinning observed in Expt. 1 and Expt. 3.

ABA-induced stomatal regulation of pear (Einhorn and Arrington, 2017) and apple (McArtney et al., 2014) was similar in magnitude and duration, with the main exception of a much stronger inhibition of pear leaf gas exchange immediately after application (Fig. 2; Einhorn and Arrington, 2017). Despite a pronounced reduction of apple leaf \( g_s \), ABA did not cause thinning of ‘Morganspur Delicious’ fruit (McArtney et al., 2014). We also observed disparity between inhibition and thinning response of trees treated with 200 ppm ABA in Expt. 2. Although \( P_n \) data for that experiment are lacking between 1 and 6 daf, the significantly reduced \( P_n \) on 6 daf is evidence that ABA was effectively taken up by the leaf. We can extrapolate from the proportionately similar \( P_n \) reduction of 200 ppm ABA-treated trees in Expt. 3, from their controls, that much greater photosynthetic inhibition occurred immediately after ABA application in Expt. 2. Given the putative relationship between CHO deficit and fruitlet thinning (Lakso, 2011; Lakso et al., 2006; Untiedt and Blanke, 2001), insufficient CHO was clearly available to meet fruit demand in Expt. 2, withstanding the transient supply deficit imposed by ABA.

Studies on the transport, availability, and relative dependence of reserve CHO and current-season photosynthate by rapidly growing apples (Corelli Grappadelli et al., 1994; Hansen, 1971; Quinlan and Preston, 1971; Stopar et al., 2001; Yuan and Greene, 2000) generally agree that current-season photosynthate disproportionately supports fruit soon after flowering. Sink strength of newly expanding leaves for assimilates was greater than developing Japanese pears (Pyrus pyrifolia Nakai) within 30 daf (Zhang et al., 2005). Apple leaves similarly compete with developing fruit. Hansen (1971) determined that \( \approx 50\% \) of the total CHO of the first five to six extension shoot leaves was from reserve CHO pools. Moreover, export of CHO from extension shoots did not occur until 10–12 leaves had emerged (Johnson and Lakso, 1986). Developing fruitlets, therefore, rely heavily on spur leaf \( P_n \) (Wünsche et al., 1996). Leaf emergence of European pear does not occur until post-bloom, which is considerably later than that of apple. In the present study, ABA was applied between 10 and 20 daf, when extension shoots are typically 10–20 cm long and possess \( \approx 3–6 \) leaves (Einhorn, unpublished data), potentially providing longer lasting reserves to support early fruitlet development. Furthermore, the vast difference in tree size among our trials and, potentially CHO reserves, was noteworthy: \( \approx 10\)-year-old trees (i.e., Expts. 1 and 3) seemed easier to thin than \( \approx 20\)-year-old trees, which were either insensitive to ABA (Expt. 2) or required markedly higher ABA rates to induce moderate thinning (Expt. 4). However, the strong ABA thinning response of mature
'Bartlett' pear trees on seedling rootstock (Greene, 2012) with, presumably, high CHO reserves does not support this contention. In addition, less-severe thinning in Expt. 4 may have been due to the earlier application timing (8 dafb as opposed to ≈20 dafb in all other trials). Indeed, Greene (2012) demonstrated greater ABA efficacy at 10 mm 'Bartlett' fruit diameter compared with petal fall applications. A change in environmental factors from year to year after thinning applications may have additionally modulated the response to ABA as observed with other chemical compounds (Greene, 2002; Stover and Greene, 2005).

Ten consecutive days of high solar radiation following ABA sprays in Expt. 2 suggests that a surplus in CHO supply may have increased the difficulty to chemically thin pears. In contrast, reduced light in the week after ABA applications in Expts. 1, 3, and 4 may have resulted in CHO deficits, increasing the thinning activity of ABA. Cloudy conditions favor enhanced chemical thinning (Stover and Greene, 2005) owed, in part, to reduced CHO supply and altered CHO partitioning (Corelli Grappadelli et al., 1994). A strong correlation between $P_n$ inhibition and fruit abscission was observed for 'Bartlett' pear trees treated with either ABA or shade (Einhorn and Arrington, 2017). Fifteen days of moderate shade (44% reduced light) enhanced ABA thinning slightly, albeit nonsignificantly, but not 15 d of severe shade (77%) because light reactions inhibited $P_n$ far greater than the stomatal effect of ABA (Einhorn and Arrington, 2017). Additive thinning effects of shade and chemical thinnings were observed when the thinner’s mode of action was not $P_n$ inhibition, such as carbaryl (Byers et al., 1990, 1991; Lehman et al., 1987) and ethephon (Lehman et al., 1987). Elucidation of the complex interactions among environmental and genetic factors and their effect on chemical thinner efficacy will require controlled environment studies.

Temperature affects CHO metabolism and growth potential of fruits. Optimum net canopy assimilation and dry matter production of apple trees occur around 20 to 25 °C and 10 to 15 °C for day and night, respectively (Lakso, 2011). Higher temperatures, especially at night, were associated with increased thinning of apples (Byers, 2002) likely because of higher respiration. $P_n$ response to temperature was similar for leaves of apple and Asian pear (Pyrus serotina L.) (Higgins et al., 1992). Comparable data are not available for European pear. It is not unreasonable, however, to expect similar $P_n$ temperature thresholds between apple and pear because Pyrus communis L. and the major species hybridized to develop M. ×domestica Borkh. have similar centers of origin (Westwood, 1993), nearly equivalent photosynthetic light response behavior (Einhorn et al., 2012; Lakso, 1994), and early-season fruit growth and development patterns (Westwood, 1993). Based on data from apple and the previous assumptions, maximum daytime temperatures during Expt. 2 of 25 to 32 °C and nighttime temperatures between 5 and 9 °C (i.e., >15 °C) would have reduced available CHO because of increased respiratory costs. Conversely, low day and night temperatures following ABA sprays in Expts. 1 and 3 would not have been expected to increase fruit growth or respiratory demand. These conditions contrast those in the Eastern United States where cloudy days are often accompanied by high temperatures during early fruit development (D. Greene, personal communication). Notwithstanding extreme temperature fluctuations, pear fruit set may be more sensitive to light than temperature. Indeed, fruit set and light interception of mature Anjou pear trees were markedly improved when reflective fabrics were applied at full bloom (Einhorn et al., 2012).

ABA likely thinned ‘Bartlett’ pear by inducing a short-term carbon stress. However, the effect on carbon balance seems to be relatively short lived and it is unclear whether ABA thins solely by reducing $P_n$. Biotic and abiotic factors (light and carbon reserves) may additionally alter the thinning response. In high-light environments, ABA might not provide sufficient $P_n$ inhibition to effectively thin fruit. Because ≈250 ppm ABA induced significant phytotoxicity and excessive leaf abscission, increasing ABA rates when conditions are less conducive to thinning (i.e., high light) is not an effective option. In these regions, alternative thinning compounds should be used, or, potentially, successive applications of 200 ppm ABA.

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