Blossom Thinning in Apple and Peach with an Essential Oil

Stephen S. Miller¹ and Thomas Tworkoski
U.S. Department of Agriculture, Agricultural Research Service, Appalachian Fruit Research Station, 2217 Wiltshire Road, Kearneysville, WV 25430

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Abstract. A series of experiments was conducted with apple [Malus ×domestica] and peach [Prunus persica (L.) Batsch] from 2003 to 2008 to evaluate the flower thinning efficacy of eugenol and a eugenol-based essential oil. Flower thinning effects by hand defoliation and alternative chemical agents were compared with eugenol in different years. Eugenol or the eugenol-based contact herbicide Matran 2 EC (or Matratec AG) produced noticeable phytotoxicity to floral parts and exposed leaf tissue within 15 min to 1 h after application and injury was proportional to rate. At the highest rates (8% and 10%), eugenol resulted in complete burning of all exposed tissue except bark tissue, in which there were no visible signs of injury. Within 3 to 4 weeks of application, phytotoxicity was difficult to observe even at the higher rates of eugenol. In companion experiments, hand defoliation of young leaves at bloom resulted in abscission of young fruitlets in apple, but not in peach, indicating that eugenol may cause thinning by multiple mechanisms. Ammonium thiosulfate (ATS) [49.1 L. ha⁻¹ or 6.0% (v/v)] provided thinning in peach and showed little or no phytotoxicity, but the response was inconsistent. ATS was also inconsistent in thinning apple. The thinning response from monocarboxamidedihydrogen sulphate (MCDS; Wilthin) at 3.2% (v/v) was inconsistent in peach. At the rate used, MCDS caused some phytotoxicity on peach. Applications of 1% to 2% eugenol appear promising, but good blossom coverage is critical for thinning. Furthermore, eugenol formulations need improvement to ensure uniform coverage for more predictable thinning.

Apple and peach trees normally produce significantly more fruit than the tree can carry to a marketable size crop (Dennis, 2000; Wertheim, 2000). Hand thinning at 35 to 60 d after full bloom is the standard practice to reduce crop load and increase fruit size at harvest. Hand thinning is expensive and, with recent labor shortages, is more problematic for growers to complete in a timely manner. Chemical thinners have long been available and used in apple production (Byers, 2003). Thinning at bloom time results in larger fruit at harvest than achieved with the later hand thinning (Byers and Lyon, 1985). Removing 50% of peach flowers increased average size of the remaining fruit and increased overall crop value (Myers et al., 2002). Chemical thinning of peach flowers reduced the estimated cost of hand thinning up to $310 U.S. per ha (Southwick et al., 1995). A number of materials (Byers, 1999; Fallahi, 1997; Moran et al., 2000; Southwick et al., 1995; Wilkens et al., 2004) and mechanical techniques (Baugh et al., 1991; Glenn et al., 1994; Schupp et al., 2008) have been studied for bloom thinning, but none has proven completely successful and registration and/or acceptance by the peach-growing industry has been slow and difficult.

Numerous chemical flower thinners of apple and peach have been tested, including DNOC (Na 4,6-dinitro-ortho-cresylate; Elge-tol), ethephon (2-chloroethylphosphonic acid), pelargonic acid, monocarboxamidedihydrogen sulphate (Wilthin), ammonium thiosulfate (ATS), and urea (Byers, 1999; Costa and Vizzotto, 2000; Fallahi, 1997; Wertheim, 2000). Thinning apple and pear flowers with DNOC was widely used to consistently desiccate stigma tissues, but it was removed from the market in the United States in 1989 (Dennis, 2000). Most of the other chemicals have been less satisfactory as a result of inconsistent flower thinning or foliar phytotoxicity. However, fruit thinning of apples and peaches by chemical thinners may be associated with inhibition of photosynthesis (Pn) rather than directly inducing fruit abscission (Byers, 2003; Dennis, 2000). Byers et al. (1991) demonstrated and Byers (2003) described the effects of artificial shade and the subsequent fruit abscission in apple when photosynthesize reserves are depleted. Partial defoliation has also been shown to affect whole tree Pn (Ferree and Palmer, 1982) and fruit set (Llewelyn, 1968) in apple. Dormant spray oils have been shown to reduce Pn in apple leaves (Ferree and Hall, 1975) and enhance the thinning activity of mild chemical thinners (Byers and Carbaugh, 1991). McArney et al. (2006) reported that liquid lime sulfur (LS) and fish oil applied at bloom time suppressed Pn and likely contributed to the thinning response of these materials.

Currently, buds, blossoms, and fruit can be removed by hand or with chemicals, but the number of chemical thinners available is limited, especially in peach, and those available are not always effective (Costa et al., 2004). There is a need for new chemical thinners, especially “environmentally friendly thinners,” to replace the costly, labor-intensive hand thinning that is currently used by growers (Dennis, 2000).

Several chemicals, including sodium chloride, LS, acetic acid, and soybean oil, have been found to have potential flower-thinning application for organic apple orchards (Moran et al., 2000; Stopar, 2008). Tworkoski (2002) reported that an essential oil was effective as a contact herbicide and that such plant-derived oils may be acceptable for organic management systems. He found that low rates could cause burn-back of sensitive plant tissue without killing the plant. The eugenol and essential oils is eugenol [2-methoxy-4(2-propenyl)phenol] (Fig. 1). This report examines the efficacy of eugenol and a eugenol-based contact herbicide, Matran 2EC (50% clove oil; EcoSMART Technologies, Inc., Franklin, TN) or Matratec AG (50% clove oil; ClawEl Specialty Products, Pleasant Plains, IL), as blossom thinners in apple and peach.

Materials and Methods

Tests were conducted from 2003 to 2008 on bearing apple and peach trees planted at the Appalachian Fruit Research Station, Kearneysville, WV. Except where noted, all data in this study were analyzed with analysis of variance using SAS Proc GLM or SAS Proc MIXED (SAS Institute Inc., Cary, NC) and treatment means separated with the Duncan’s multiple range test (P ≤ 0.05).

Initial bloom thinning sprays in 2003 were applied with a hand wand sprayer and sprays to peach in 2005 were applied with a handgun high-pressure sprayer. Based on observed phytotoxicity to flowers and/or

¹To whom reprint requests should be addressed; e-mail stephen.miller@ars.usda.gov.
Eugenol

![Chemical structure of eugenol](image)

Fig. 1. Chemical structure of eugenol, the active ingredient of several essential oils.

young leaf tissue, it was obvious that hand-gun applications lacked uniform coverage within and between individual tree canopies despite every effort to apply a uniform spray. Therefore, all sprays beginning in 2006 and after as well as sprays to apple in 2005 were applied with a Durand-Wayland Model A-200-32 3-pt. hitch airblast sprayer (Durand-Wayland, LaGrange, GA) operating between 896 and 1034 kPa. The airblast sprayer’s axial fan was operated at the “high-speed” setting for large apple and peach trees (over 4.5 m tall) and at “low speed” for medium-stature trees (3 to 4 m tall). The fan was placed in “neutral” when spraying apple trees on Budgavsky 9 (B.9) dwarfing rootstock and the low stature (2.5 m tall or less) “John Boy”/’Halford’ peach trees. Operating the fan in neutral prevented spray drift to adjacent treatment rows in these plantings. In all studies, sprays were applied in a water carrier on a percent v/v basis unless indicated otherwise.

Apple

2003 tests. Initial work in 2003 was to determine general foliar and blossom injury response to increasing rates (0% to 10%) of eugenol on apple and peach. Naturally derived eugenol, extracted from cinnamon, Cinnamomum zeylanicum, and clove, Syzygium aromaticum, 99% a.i., was obtained from Citrus and Allied Essences, Ltd. (Floral Park, NY). Eugenol was prepared as a suspension in water and applied with agitation using a handheld wand sprayer (Sure Shot; Milwaukee Sprayer Mfg. Co., Inc., Milwaukee, WI) to flowers to the point of first drain. Eugenol was applied to 7-year-old apple trees [‘Ace Spur Red Delicious’ on Malus × domestica Borkh. (M.7) rootstock] on 23 Apr. 2003 when “king” blossoms were just opening. Temperatures were 18 °C under partly sunny conditions. One hundred five cluster groups of flowers were evaluated for damage 24 h after application. Surviving fruit from the original clusters were counted 1 and 2 months after application. Apples were harvested on 17 Sept. 2003 from each treated tree. Total fruit number, weight, and size of individual fruit were measured.

2005 tests. Three spray treatments were applied with the airblast sprayer to ‘Royal Gala’/M.26 apple trees beginning with their eighth leaf in the orchard with at least 50% of the available spurs flowering: ATS (Amthio; Allied Chemical Company, Houston, TX), Matran EC (50% clove oil containing 81% eugenol; EcoSMART Technologies, Inc.), and naturally derived eugenol (99%) (Citrus and Allied Essences, Ltd., Floral Park, NY). Sprays were applied on 26 Apr. at the 80% to full bloom (FB) stage of development at ≈1421 L ha⁻¹. The calculated tree-row volume (TRV) for the test trees was 477 L ha⁻¹. Application rates were ATS at 4%, Matran at 2%, 4%, and 6%; and eugenol at 4% and 6%. Sprays were applied to four three-tree plots in a randomized complete block (RCB) design. A non-thinned control treatment was included for comparison. Available yield (kg/tree) and mean fruit weight (g) were determined on two trees per plot at harvest using an Omni Weight Sizer (Durand-Wayland, LaGrange, GA). Crop load density (number of fruit per cm² trunk cross-sectional area) was calculated from the number of fruit harvested per tree and trunk circumference measurements.

2006 tests. The block of ‘Royal Gala’/M.26 apple trees used in the 2005 test was again selected for treatment in 2006. In addition to a non-thinned control, treatments included: ATS at 6%, LS at 3% + dormant spray oil at 2.5 mL L⁻¹, and Matran at 4% and eugenol at 2% and 4% all applied on 19 Apr. at 95% to 100% FB. Sprays were applied at 1216 L ha⁻¹ to four three-tree plots in a RCB design. The calculated TRV for the block was 1543 L ha⁻¹. A second test of bloom thinners was applied in 2006 to a group of 22-year-old ‘Ace Spur Delicious’/seedling apple trees. Trees selected had 70% or more of the available spurs flowering: treatments were applied to two five-tree plots at 935 L ha⁻¹ on 16 Apr. when trees were at the 90% to 100% FB stage. The calculated mean TRV for the block was 1412 L ha⁻¹. Treatments included a non-thinned control, ATS 6%, liquid LS 2%, Matran at 4% and 6%, and eugenol at 2% and 4%. At harvest, total yield, fruit weight, and crop load density were determined as described.

2007 tests. Two tests were conducted with bloom thinners on apple. In the first test, Matran was applied at 0%, 4%, 6%, and 8% concentrations to 10-year-old ‘Ramey York’/M.26 apple trees on 25 Apr. 2007 at the 60% to 70% FB stage. Trees were arranged on three randomly assigned blocks, each containing 12-tree plots that received a treatment. The calculated TRV for the test orchard was 1468 L ha⁻¹ and sprays were applied at ≈1310 L ha⁻¹. At harvest, four trees were randomly selected from each plot and the total yield and mean fruit weight determined using a Durand-Wayland Omni Weight Sizer. Crop load density was determined from total fruit count and trunk size measurements. In a second test on apple, a group of 5-year-old ‘Golden Delicious’ apple trees on Budgavsky 9 (B.9) received 0%, 2%, 3%, 4% eugenol alone or they received 0% and 4% eugenol and were manually defoliated on 29 Apr. when trees had reached the FB stage of development. A hand-thinned control was also included for comparison. Trees were arranged in four randomly assigned blocks, each containing three-tree plots that received a spray treatment. The calculated TRV was 1159 L ha⁻¹ and sprays were applied at ≈1590 L ha⁻¹. Hand defoliation was performed on whole trees by physically removing all shoot and spur leaves using scissors to cut the petiole halfway through the point of attachment and the leaf blade. The number of blossoms showing necrotic petals and withered stamens and pistils was determined on two tagged limbs per tree on 2 May 72 h after treatment. Initial crop load density [fruit per cm² limb cross-sectional area (LCSA)] was determined on the two tagged limbs per tree at the time of hand thinning on 12 June. At maturity, fruit were harvested from tagged limbs, counted, weighed, and sized. Fruit remaining on the tree was counted, weighed, and the diameter of individual fruit recorded.

2008 tests. The ‘Royal Gala’/M.26 apple block used in the 2006 tests was again selected for treatments in 2008. In addition to a non-thinned control and a hand-thinned control, spray treatments included a standard post-bloom thinning spray of 100 mg L⁻¹ 6-BA (MaxCel; Valant BioSciences Corp., Libertyville, IL) plus 2.5 mL L⁻¹ carbaryl (Sevin XLR Plus; Bayer CropScience, Research Triangle Park, NC) plus 2.5 mL L⁻¹ spray oil, 6.0% (v/v) Matmatec AG, or 3.0% eugenol plus 0.62 mL L⁻¹ Latron B-1956 (a surfactant with 77% a.i. as modified phthalic glycerol alkyd resin; Loveland Industries Ltd., Greeley, CO) applied 23 Apr. when trees had reached 95% to 100% FB. The post-bloom thinner treatment was applied on 13 May when fruit averaged 12.5 mm in diameter. Hand thinning was performed on 10 June ≈49 d after full bloom (DAFB). The calculated TRV for the block was 2197 L ha⁻¹ and sprays were applied at ≈1590 L ha⁻¹. Treatments were assigned at random to six three-tree plots in a RCB design. At harvest, fruit were counted, weighed, and sized using the Omni Sort Weight Sizer.

A similar group of treatments was applied in a second trial to 6-year-old ‘Cameo’/B.9 and ‘Sun Fuji’/B.9 apple trees. In this trial, Matttec AG was applied at 4.0% and eugenol was applied at 2.0%; otherwise, treatments were identical to those applied in the ‘Royal Gala’ described. Treatments were applied to four three-tree plots in a RCB. The ‘Cameo’ trees were estimated to be ≈80% FB and the ‘Sun Fuji’ trees at ≈95% to 100% FB when bloom sprays were applied on 24 Apr. The calculated TRV was 1069 L ha⁻¹ and sprays were applied at ≈1300 L ha⁻¹. The hand-thinned treatment was performed on 8 June ≈45 DAFB. In late July, some additional fruit were removed from all trees where the potential for limb breakage existed. At maturity, whole trees were harvested and data recorded as described.

Peach

2003 tests. Spray was applied to 7-year-old ‘Redhaven’/’Lovell’ peach trees at 414 kPa when air temperature was ≈21 °C in sunny conditions. Peach tree flowers were ≈60% in bloom when eugenol was applied on 14 Apr. 2003. One tree received one application of each concentration of eugenol
Bloom thinners at the following rates: ATS, same date). Four materials were applied at
reached 90% to 100% FB (high winds pre-
selected for blossom-thinning treatments in 2005. Sprays were applied with a handgun
high-pressure sprayer operated at 869 kPa
to wet the bloom. Treatments were applied between 14 and 16 Apr. when trees had reached
90% to 100% FB (high winds pre-
hand thinning to space fruit
excess fruit and prevent limb breakage. An
July (Table 1). Little or no leaf or fruit
injury was observed, even at the highest concentration on 12 June, 7 weeks after application. The effective range for flower
thinning and fruit retention appeared to occur between 2% and 6% eugenol (Table 1). The
number of apples per tree began to decrease at concentrations of 2% eugenol and the proportion of apples in the larger size
classes increased in trees thinned with euge-
(Table 2). Eugenol at 4% increased fruit weight by 30%, whereas ATS at 6% or eugenol at 2% only increased
fruit weight by 15% or 11%, respectively, over control fruit. Both 6% Matran and 4% eugenol
resulted in excessive yield reduction (73% and 86%, respectively) on ‘Ace Spur Delicious’. The 4% eugenol treatment increased average
fruit weight from 157 g (control treatment) to
230 g, but the size increase was offset by the severe reduction in yield.

In 2007, a thinning response was observed on ‘Ramey York’ apple with increasing rates
of Matran decreased crop load in 2006 to ‘Ace Spur Delicious’, all spray treatments except 2% liquid LS re-
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Table 2. Response of ‘Royal Gala’/M.26 apple trees and ‘Harrow Beauty’/Lovell peach trees to bloom thinning agents in 2005.

| Treatment          | Chemical concn (%) | Eugenol concn (%) | Crop density (fruit/cm² TCSA) | Yield (kg/tree) | Fruit wt (g) |
|--------------------|--------------------|-------------------|-------------------------------|----------------|--------------|
| Control            | 0                  | 0                 | 8.6 a                         | NA             | NA           |
| Hand thinned       | 0                  | 0                 | NA                           | NA             | NA           |
| ATS                | 6.0                | 0                 | 7.4 a                         | 80 a           | 120 cd       |
| Withlin           | 3.2                | 0                 | NA                           | NA             | NA           |
| Matran EC 2.0      | 2.0                | 0.8               | 7.7 a                         | 72 ab          | 119 cd       |
| Matran EC 4.0      | 4.0                | 1.6               | 4.9 bc                        | 53 bc          | 118 cd       |
| Matran EC 6.0      | 6.0                | 2.4               | 4.5 c                         | 49 c           | 139 ab       |
| Matran EC 8.0      | 8.0                | 3.2               | NA                           | NA             | NA           |
| Eugenol 2.0        | 2.0                | 0                 | NA                           | NA             | NA           |
| Eugenol 4.0        | 4.0                | 0.9               | 1.5 d                         | 21.0           | 148 a        |
| Eugenol 6.0        | 6.0                | 6.0               | 1.0 d                         | 10 d           | 129 bc       |
| Eugenol 8.0        | 8.0                | 8.0               | NA                           | NA             | NA           |

Table 3. Response of ‘Royal Gala’/M.26 and ‘Ace Spur Delicious’/seedling apple trees to bloom thinners in 2006.

| Thinner treatment | Concen (%) | Crop load density (fruit/cm² TCSA) | Mean fruit (g) | Yield (kg/tree) |
|-------------------|------------|-----------------------------------|----------------|-----------------|
| Royal Gala        | 9.8 a      | 117 c                             | 6.53 c         | 100.7 ab        |
| ATS               | 6.0        | 123 bc                            | 6.70 abc       | 79.8 bc         |
| Matran EC 3.0 + 0.025 | 9.0 a   | 120 c                             | 6.60 bc        | 113.1 a         |
| Eugenol           | 4.0        | 134 ab                            | 6.88 a         | 58.0 c          |
| Eugenol           | 2.0        | 133 ab                            | 6.91 a         | 72.9 bc         |
| Eugenol           | 1.4 d      | 138 a                             | 6.81 ab        | 21.1 d          |

Table 4. Effect of Matran EC (50% clove oil) applied as a bloom thinner on ‘Ramey York’/M.26 apple trees in 2007.

| Thinner treatment | Concen (%/v/v) | Crop load density (fruit/cm² TCSA) | Mean fruit wt (g) | Yield (kg/tree) |
|-------------------|---------------|-----------------------------------|-------------------|-----------------|
| Control           | 0             | 8.8 a                             | 123 c             | 117.3 a         |
| Matran EC 4.0     | 4.0           | 6.3 b                             | 172 b             | 97.9 ab         |
| Matran EC 6.0     | 6.0           | 3.9 c                             | 179 b             | 76.4 b          |
| Matran EC 8.0     | 8.0           | 3.3 c                             | 199 a             | 79.1 b          |
| P                 | 0.0001        | 0.0001                            | 0.0001            | 0.0001          |
| r²                | 0.6984        | 0.5968                            | 0.2789            |                 |
| Significance      | L***          | L***                              | L***              |                 |

Table 5. Response of ‘Royal Gala’ apple trees to bloom thinning treatments.

| Treatment          | Crop load estimate (1–6) | Yield (kg/tree) | Fruit diam (cm) |
|--------------------|--------------------------|-----------------|-----------------|
| Control            | 5.6 a                    | 81 a            | 6.3 c           |
| Hand thinned       | 2.6 c                    | 84 ab           | 6.6 bc          |
| ATS                | 3.8 c                    | 50 c            | 6.6 bc          |
| Withlin           | 3.1 d                    | 33 c            | 7.0 a           |
| Matran EC 2.0      | 5.4 a                    | 84 ab           | 6.6 bc          |
| Matran EC 4.0      | 4.8 ab                   | 96 a            | 6.6 bc          |
| Matran EC 6.0      | NA                       | NA              | NA              |
| Matran EC 8.0      | NA                       | NA              | NA              |
| Eugenol 2.0        | 4.4 bc                   | 84 ab           | 6.6 ab          |
| Eugenol 4.0        | 3.2 de                   | 45 c            | 7.0 a           |
| Eugenol 6.0        | 2.1 f                    | 37 c            | 7.0 a           |

In 2008, a single rate of 50% clove oil (Matratec AG) (6%) or eugenol (3%) + Eugenol 2.0 applied as a bloom thinner on ‘Royal Gala’ apple trees (Fig. 2). Results did not differ from the post-bloom spray of 6-BA (MaxCel) + carbaryl (Sevin XLR Plus) + oil. The bloom-thinning sprays reduced crop load to a greater extent than hand thinning, but fruit weight was greater for the bloom-thinning sprays compared with the hand-thinned treatment or the non-thinned control. All thinning treatments reduced crop load, but the thinning achieved with clove oil at 6% and eugenol + Latron B-1956 at 3% was excessive. The single rate of eugenol + Latron B-1956 (2%) or clove oil (Matratec AG, 4%) each thinned ‘Cameo’ and ‘Sun Fuji’ apple trees to a similar level as the traditional post-bloom thinner 6-BA (MaxCel) + carbaaryl + oil (Table 6). Crop load on ‘Cameo’ was equal to that achieved with hand thinning. However, hand-thinned ‘Sun Fuji’ had a greater crop load but smaller fruit weight and diameter than the chemical thinner treatments. Hand-thinned ‘Sun Fuji’ had a reduced crop load compared with the non-thinned control, but fruit size was equal to that of the non-thinned control.

Peach. In 2003, within 1 h of application of the essential oil, peach flowers began to appear bleached and leaf tips developed necrotic lesions. Injury was apparent at 2% and increased proportionately as concentrations increased to 10%, which had notable injury (Table 1). Little injury to peach flowers was observed at concentrations below 1.5% (data not shown). By 4 to 5 weeks after application, little injury could be observed on peach trees treated at the highest concentration, 10%, but few fruit remained on the tree at this concentration. The effective rate for flower thinning and fruit retention was between 2% and 6% eugenol (Table 1). No fruit or leaf injury was seen on 12 June 2003 at the 6% concentration. The total number and weight of peaches per tree began to decrease at concentrations of 2% essential oil and average fruit weight generally was higher in thinned peach trees (data not shown).

Four bloom spray treatments in 2005 reduced the yield of ‘Harrow Beauty’ peach trees compared with the control trees (hand-thinned treatment).
Table 5. Response of 5-year-old 'Golden Delicious'/Budagovsky 9 (B.9) apple trees to eugenol blossom thinner and hand defoliation treatments in 2007.

| Thinning treatment | Concen. (°/v/v) | Hand defoliated (%) | Blossoms injured (%) | Crop load* | Fruit
group | Initial (fruit/cm² LCSA)* | Harvest (fruit/cm² LCSA)* | Yield (kg/tree) | Diam (cm) | Wt (g)
|-------------------|----------------|---------------------|----------------------|------------|---------|--------------------------|-------------------|---------------|----------|----------|
| Control           | 0              | No                  | 0 c                  | 11.2 a     | —       | 24.2 a                   | 5.92 b            | 90 b          |          |          |
| Control           | 0              | Yes                 | 0 c                  | 2.3 bc     | 0 b     | —                        | —                | —             |          |          |
| Hand thinned      | 0              | No                  | 0 c                  | 7.6 ab     | 0 b     | 22.7 a                   | 6.54 ab           | 103 b         |          |          |
| Eugenol 4.0      | No             | 68 b                | 5.1 bc               | 1.3 c      | 0.4 b   | 0.2 b                    | 7.50 a            | 168 a         |          |          |
| Eugenol 2.0      | No             | 68 b                | 6.1 b                | 15.4 a     |          |                          |                   |               |          |          |
| Eugenol 2.0      | No             | 88 ab               | 0 c                  | 0 b        | 0.2    | 7.50 a                   | 168 a             |               |          |          |
| Eugenol 4.0      | Yes            | 95 a                | 0 c                  | 0 b        | 0 b    | 0 b                      | 7.69 ab           | 7.25 b        |          |          |

*Eugenol sprays applied with airblast sprayer at 1590 L ha⁻¹ at full bloom (29 Apr. 2007).

Table 6. Effect of blossom thinners or a post-bloom thinner on crop load and fruit size in 6-year-old 'Cameo'/Budagovsky 9 (B.9) and 'Sun Fuji'/B.9 apple trees in 2008.

| Treatment*         | Crop load (fruit/cm² LCSA) | Mean fruit wt. (g) | Mean fruit diam (cm) |
|--------------------|-----------------------------|--------------------|----------------------|
|                    | Cameo | Fuji | Cameo | Fuji | Cameo | Fuji | Cameo | Fuji |
| Non-thinned control| 17.7  | 22.7 | 135 b | 101 c | 6.76  | 6.00 |
| Hand-thinned       | 9.7 b | 13.7 | 162 a | 117 c | 7.30  | 6.46 |
| 6-BA, 100 ppm + carbyl, 1 qt/100 + oil, 1 qt/100 | 7.5 b | 6.2 d | 185 a | 204 a | 7.74  | 7.71 |
| Clove oil, 4% (v/v) | 7.1 b | 9.7 c | 148 a | 18 b  | 7.61  | 7.1 b |
| Eugenol, 2% (v/v) + Latron B-1956, 0.5 pt/100 | 7.5 b | 7.8 ed| 186 a | 160 b | 7.69  | 7.25 |

*6-BA [6-benzyladenine as MaxCel (Valent BioSciences, Libertyville, IL) + carbyl] + [Sevin XLR Plus ( Bayer CropScience, Research Triangle Park, NC)] + oil (dormant spray oil) applied 14 May at 10–24-mm stage; clove oil (50%) [as Matratec AG (ClawEl Specialty Products, Pleasant Plain, IL)] and eugenol (99%, Citrus and Allied Essences, Ltd., Floral Park, NY) applied 24 Apr.; Latron B-1956 (Loveland Industries Ltd., Greeley, CO) is a surfactant. Hand thinning applied approximately 45 d after full bloom.

Discussion

Weather patterns in the mid-Atlantic region during the normal apple and peach bloom period (late March through April) are extremely variable and day-to-day conditions (temperature, precipitation, sun, cloud cover, wind, etc.) can be quite volatile, unpredictable, and present a significant challenge for the orchardist in their attempt to apply sprays at defined phenological stages of development. Unexpected high temperatures one day can lead to dramatic changes in bloom development within an 8- to 24-h period. This is particularly true in the case of peach. For these reasons as well as resource limitations, no attempt was made to apply an identical group of treatments each year over the life of the study. However, sufficient similarities in treatment concentrations and timing have been included in this study to draw conclusions regarding the efficacy of eugenol or eugenol-based materials as bloom thinners. Thinning is needed to obtain good marketable size fruit. These experiments evaluated a novel thinning agent, eugenol, and an essential oil-based plant growth regulat-
Table 7. Response of ‘Harrow Beauty’/‘Lovell’ peach trees to chemical bloom thinners and hand thinning in 2006.

| Thinner treatment | Conc (% eugenol) | No. fruit removed by hand thinning | Yield (kg/limb) | Fruit diam (cm) | Fruit/cm² | LCSA* |
|-------------------|-----------------|-----------------------------------|-----------------|-----------------|-----------|-------|
| Control           | 0               | 232 ab                            | 14.2 a          | 6.72 cd         | 2.8 a     |
| ATS*              | 6.0             | 12 c                              | 3.1 c           | 7.79 a          | 0.3 c     |
| Matran EC         | 4.0             | 220 ab                            | 11.4 ab         | 6.45 cd         | 2.5 ab    |
| Eugenol           | 2.0             | 104 bc                            | 4.9 bc          | 6.35 d          | 2.1 abc   |
| Eugenol           | 4.0             | 127 abc                           | 9.5 abc         | 7.00 bcd        | 2.0 abc   |
| Eugenol           | 6.0             | 76 c                              | 5.5 bc          | 7.19 abc        | 1.4 abc   |
| Eugenol           | 8.0             | 33 c                              | 5.0 bc          | 7.65 ab         | 1.0 bc    |
| Control           | 0               | 232 ab                            | 14.2 a          | 6.72 cd         | 2.8 a     |

*All sprays applied with airblast sprayer at 1216 L/ha; at 65% to 85% full bloom. Control trees hand-thinned ≈50 d after full bloom.

*In water as volume/volume.

*Mean separation within columns by Duncan’s new multiple range test (P ≤ 0.05).

Table 8. Response of ‘John Boy’/‘Halford’ peach trees to chemical bloom thinners and hand thinning.

| Treatment (boxes/ha)* | Crop load (fruit/cm²) | Hand thinning (min/tree) | Fruit diam (cm) | Yield (boxes/ha)* |
|-----------------------|-----------------------|--------------------------|-----------------|-------------------|
| Control               | 10.5 a                | 19.7 a                   | 6.72 d          | 650 a             |
| 2.0%–80% FB          | 5.2 b                 | 6.2 c                    | 7.13 c          | 398 b             |
| 3.0%–80% FB          | 0.5 e                 | 0.8 d                    | 7.52 ab         | 163 c             |
| 4.0%–80% FB          | 1.0 d                 | 1.2 cde                  | 7.53 ab         | 237 bc            |
| 5.0%–50% FB          | 1.0 de                | 1.4 d                    | 7.63 a          | 269 bc            |
| 2.0%–20% FB and 80% FB| 1.9 cde               | 1.6 d                    | 7.50 ab         | 301 bc            |
| 2.0%–20% FB and 80% FB| 2.2 cd                | 3.6 cd                   | 7.33 bc         | 339 bc            |
| 1.0%–20% FB and 2.0%–80% FB | 5.5 b                  | 11.1 b                   | 7.20 c          | 578 a             |
| 1.0%–20% FB and 3.0%–80% FB | 2.6 c                  | 4.4 cd                   | 7.32 bc         | 398 b             |
| 2.0%–20% FB and 3.0%–80% FB | 1.5 cde               | 2.4 cd                   | 7.47 ab         | 232 bc            |

*Eugenol treatments applied with a Durand-Wayland AF100-32 Model 3-pt. hitch airblast sprayer. Treatment identification is % eugenol rate (%v/v) followed by bloom stage expressed as percent of bloom open. FB = full bloom.

*TCSA = trunk cross-sectional area.

*Boxes = 21.8 kg.

*Mean separation within columns by Duncan’s new multiple range test (P ≤ 0.05).
suggested as a causal factor in fruit thinning (Byers, 2003). Injury to spur leaves of shading followed by reductions in Pn could reduce fruit size. However, support for this theoretical thinning trials is inconsistent (Byers et al., 1990a, 1990b; Fallahi, 1997; Fallahi et al., 1997; Noordijk and Schupp, 2003). In the present study, apple treated with Matran (Table 4) or eugenol (Tables 5 and 6) at sufficient rates to cause phytotoxicity showed no negative effects on fruit size. It should be pointed out, however, when eugonol was applied at a concentration of 1% or above (equivalent to Matran 6% or greater), there was generally a significant reduction in crop density (Tables 2–5). In some cases, the magnitude of the size increase was less than might be expected given the low crop load density. Although these findings provide no definitive proof of a negative effect of eugenol or Matran on fruit size, they suggest the potential exists. In our study, peach showed minimal foliar phytotoxicity and no negative effects on fruit size, which agrees with work by Byers (1999) with bloom thinners on peach.

Higher concentrations of eugenol quickly caused phytotoxicity and more extensive injury than lower concentrations. In addition, apple floral tissue, especially the reproductive tissue, appeared more susceptible than the same tissue in peach. In the flower, the stamen tissue appeared more susceptible to the thinning effect of the eugenol than the pistil. Flowers in an early stage of bloom sustain little damage to their reproductive tissues because the petals cover the anthers and pistil. In peach, the petals often surround and protect the anthers and pistil even in late bloom. Under these conditions, spray contact can be prevented, resulting in reduced efficacy. When the floral reproductive tissue was fully exposed, severe phytotoxicity was observed with the essential oil applied to all tissue in both apple and peach, especially at rates of 4% or above.

We have investigated the use of eugenol and eugenol-containing essential oils as caustic defoliant agents since 2003. Essential oils are considered safe and non-toxic to humans and would be suitable to organic producers. In other research, Isman et al. (2007) also reported the potential apple deblossoming use for eugenol-based clove oil but noted that the oil caused leaf and fruit russetting and was cultivar-dependent. Fruit russetting was found only in one cultivar, ‘Golden Delicious’, when crensic acid and tar oil distillates were used as caustic deblossoming agents (Magnes et al., 1939). The eugenol-based herbicide Matran EC was used along with eugenol to evaluate the effects of a commercial formulation on uniformity of spray and thinning. Matran EC and Matecrate AG contain 50% clove oil and eugenol is the a.i. of clove oil. Eugenol alone induced a blossom-thinning dose response that translated to a reduction in fruit number as the concentration of eugenol increased. Optimal concentrations likely are between 2% and 4%. The eugenol-based products may have particular value as blossom thinners in organic management systems.

Non-eugenol thinners that have similar caustic effects on blossoms were also included in these tests. Within and ATS provided acceptable and comparable thinning to eugenol in peach in 2005, but ATS overthinned peach in 2006. ATS was not effective at thinning apple in 2005 but was in 2006. Like in previous experiments, thinning results with ATS and Within were inconsistent. Benzylaminopurine (benzyladenine) has been used to thin apple trees by stimulating ethylene biosynthesis (Angeli et al., 2004). Eugenol may stimulate ethylene synthesis as an injury response to defoliation. Clearly, defoliation can induce flower or fruit drop in apple and eugenol-induced injury to leaves likely contributed to thinning. In contrast, thinning of peach flowers by eugenol was not likely associated with foliar injury because defoliation did not affect flower or fruit drop. McAfee and Rom (2005) applied 2% essential oils (cinnamon and cedarwood oils) to vegetative apple trees under controlled environmental conditions and reported no significant effect. They noted that clove oil was very phytotoxic and defoliated all the trees in their study. They further reported that cinnamon and cedarwood oils decreased evaportranspiration and stomatal conduction. Because clove oil defoliated trees, they were unable to measure these parameters for treated trees. More work is needed to determine the direct and indirect causes of thinning by eugenol and other essential oils in deciduous fruit crops.

Low concentrations of eugenol sprays may provide partial thinning that could be followed up with hand thinning. Partial removal of flowers at full bloom with follow-up hand thinning of small peaches at 42 DAFB increased fruit size at harvest compared with thinning at 24 DAFB alone (Myers et al., 2002). This strategy has been used to reduce costs and reliance on manual labor. Additional studies are needed to improve efficacy of the essential oils as blossom thinners, especially in peach. Multiple applications, the first at an early bloom stage and at the lower concentration, should be evaluated for increased efficacy.

Conclusions

The a.i. of several essential oils, eugenol, was determined to be effective in thinning flowers of both peach and apple when applied at concentrations between 1% and 10%. Thinning increased average fruit weight and the proportion of harvested fruit in the larger size classes. Caustic injury to leaves and shoots with the eugenol was transitory with full recovery in 3 to 4 weeks in most cases and in 4 to 5 weeks at the highest rates and most severe level of observed phytotoxicity. Eugenol and the commercially available eugenol-based herbicide, Matran, were found to provide excellent peach and apple flower burn-back at concentrations between 4% and 8%, but lack of uniform spray coverage increased response variation. Variability in thinning response was significantly reduced by using an airblast sprayer that enabled uniform coverage of blossoms with eugenol. The thinning effect of the essential oil on apple may be partially the result of leaf phytotoxicity and reduced photosynthetic rates as well as a direct effect on the flower reproductive tissues. Our results indicate that essential oils have potential as blossom thinners in apple and peach.

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