Controlling Plum Curculio Adults and Larvae Using Odor-baited Trap Trees and Entomopathogenic Nematodes: Results from a Six-year Study

Jaime C. Piñero[1], David Shapiro-Ilan[2], Daniel R. Cooley[1], Arthur F. Tuttle[1], Alan Eaton[3], Patrick Drohan[4], Kathleen Leahy[5], Aijun Zhang[6], Torri Hancock[7,8], Anna K. Wallingford[3] and Tracy C. Leskey[8]

[1]Stockbridge School of Agriculture, University of Massachusetts, Amherst, MA
[2]USDA ARS Southeastern Fruit and Tree Nut Research Laboratory, Byron, GA
[3]University of New Hampshire Cooperative Extension, Durham, NH
[4]Department of Ecosystem Science and Management, Penn State University, University Park, PA
[5]Polaris Orchard Integrated Pest Management for New England, Colrain, MA
[6]USDA-ARS Invasive Insect Biocontrol and Behavior Laboratory, Beltsville, MD
[7]USAMIRIID, Fort Detrick, Frederick, MD
[8]USDA-ARS, Appalachian Fruit Research Station, Kearneysville, WV

Efforts to reduce insecticide inputs against plum curculio (PC) include perimeter-row insecticide sprays applied after the whole-orchard petal fall spray to manage dispersing adults and, more recently, post-petal fall insecticide sprays confined to odor-baited trap trees. Entomopathogenic nematodes (EPNs) can be applied to the ground underneath trap tree canopies to kill PC larvae. These two approaches may provide growers with the opportunity to reduce PC populations by killing both adults and larvae. To quantify the potential to manage this pest more sustainably in a reduced-spray environment, we conducted a 6-year study that aimed at addressing the following questions: (1) does the presence of a synergistic lure in trap trees consistently result in significant aggregation of fruit injury within these tree canopies compared to unbaited tree canopies? (2) can the orchard-wide injury by PC be maintained at economically acceptable levels under a reduced spray scenario involving the trap tree management strategy? (3) does the level of injury received by odor-baited trap trees extend to neighboring trees? and (4) are EPNs applied to the soil underneath trap trees effective at suppressing PC in multiple orchards over multiple years?

Materials & Methods

This investigation was conducted over a 6-year period (2013-2016, 2018-2019) in seven commercial orchards located in Massachusetts (Clark Brothers Orchards in Ashfield; Clarkdale Fruit Farms in Deerfield; University of Massachusetts Cold Spring Orchard in Belchertown), New Hampshire (Apple Hill Farm in Concord; Gould Hill Farm in Contoocook; Poverty Lane Orchards in Lebanon), and Vermont (Scott Farm in Dummerston). Not every orchard participated in this study on each year.

Study 1: Attract-and-kill using trap trees. For each participant orchard, we evaluated two treatments: (1) odor-baited trap tree management strategy; and (2) grower standard plots that received insecticide treatment as prescribed by the grower. Within each orchard, two experimental plots were established. One plot was randomly assigned to the trap tree treatment, and the second plot was selected for grower standard sprays. The average area of experimental plots was 3.6 and 2.8 acres for the trap tree and the grower standard plots, respectively. The same two plots within an orchard were used on each year, but the assignation of trap tree and grower standard treatments was switched on most years. All orchard plots received a full-block spray of insecticide (most commonly an organophosphate, an oxadiazine, or a neonicotinoid) by the time of petal fall. Subsequent sprays were applied to either, trap trees only in trap tree plots, or as prescribed by the growers in the grower standard plots.

During full bloom on each year, selected perimeter-row trap trees were baited with four benzaldehyde (BEN) dispensers and one PC pheromone (grandisoic acid = GA) dispenser. Each BEN dispenser was suspended inside of an inverted colored plastic drinking cup to minimize the potential negative impact of ultraviolet light on the stability of BEN. All BEN lures were left in place for the entire period of PC activity, while the GA lures were replaced once, typically 4 weeks after initial deployment. The distance between trap trees was 35 yards. On average, there were 3-4 trap trees per acre.

Treatment performance was assessed for each orchard by means of fruit injury evaluations conducted between 23 Jun and 5 July of each year. The total number of fruit with PC oviposition scars was recorded, based on a sample of 25 fruit/tree from trap trees in the trap tree plot and from unbaited (control) trap trees in the grower standard plot. To quantify the level of spillover to trees immediately adjacent to the odor-baited trap tree, 25 fruit per tree were sampled from six peripheral trees (three to the right and three to the left) next to the trap tree and the control trap tree (in the grower standard plot). To provide a measure of the efficacy of each treatment regime to protect interior-plot fruit from PC damage 20 interior trees (25 fruit/tree) were sampled within each plot. In all, 92,676 fruit were sampled across all years and orchards.

Study 2: Application of entomopathogenic nematodes (EPNs) against PC larvae in the soil. Here, we evaluated the efficacy of EPN application formulated in water targeting PC larvae in the soil. The performance of EPNs was compared against a water-only control. We used two approaches to measure the number of adult PCs emerging from the soil after EPN application. The first approach involved mini-plot cylindrical enclosures (Figure 1) made of PVC. The enclosures were buried to 7-8 inches deep. After EPN application (see below), a boll weevil trap, consisting of a green plastic cylindrical base, a molded screen cone and a collection chamber, was buried using each enclosure as a 'sleeve'. As they emerged, adult PCs were collected in the collection chamber. This type of

Figure 1. Depiction of the PVC enclosure (**left**) and pyramidal emergence cage (1 × 1 yards at the base) (**center**) used for the evaluation of entomopathogenic nematodes (EPNs) in the second study.

experimental arena was used in 2013, 2014, and 2015. The second approach consisted of pyramidal emergence cages (1 × 1 yards at the base) made of PVC and steel screen (Figure 1). One pyramidal emergence cage was placed underneath the canopy of each trap tree (the same tree used for the PVC enclosure). Emergence cages were used in 2013–2015, and 2018.

EPN treatments. We compared the performance of the EPN *Steinernema riobrave* at a rate of 100 IJs/cm^2 using one gallon of water against the same amount of water alone (control). For the 2013-2015 studies, EPNs were provided by Dr. Shapiro-Ilan (USDA-ARS) while for the 2018 study, EPNs were donated by BASF.

For the PVC enclosures, 30 fully-developed PC larvae were placed inside the enclosures 24 h prior to EPN application. For emergence pyramidal cages, approximately 75 PC-infested fruit were placed on the center of each caged area, 24 h before EPNs were applied, to allow the larvae to crawl in soil. After treatment application, the emergence cages were placed on the ground, covering the fruit, and the edges of the cages were buried in the soil to ensure the emerged adults would not escape. Each of the treatments (three nematode species) and the control were replicated five times. For both experiments, no additional water (except for natural precipitation) was added to the cages. Two weeks after EPN application, the number of adult PCs collected in the experimental arenas (PVC enclosures and emergence cages) was recorded on a weekly basis for four weeks. All insects were counted and removed from the capturing devices.

Results

Study 1: Attract-and-kill using trap trees. For the first question ("does the presence of the BEN+GA lure in trap trees consistently result in significant aggregation of fruit injury in these specific tree canopies compared with unbaited tree canopies?"), we found that the level of fruit injured by PC within the canopies of odor-baited trap trees ranged from 4.4% (in 2015) to 17.3% (in 2018) in trap tree plots. In contrast, in grower standard plots the level of injury on control (unbaited) trap trees ranged from 0.2% (in 2015) to 2.1% (in 2013). Across all six years, mean percent fruit injury was about eight times greater in trap trees (11.3%) than in control trees (1.4%) (Figure 2A).

The results generated to address question (2) ("can the orchard-wide injury by PC be maintained at economically acceptable levels under a reduced spray scenario involving the trap tree management strategy?" provided a measure of the efficacy of each treatment regime to protect interior-plot fruit. For each year, and

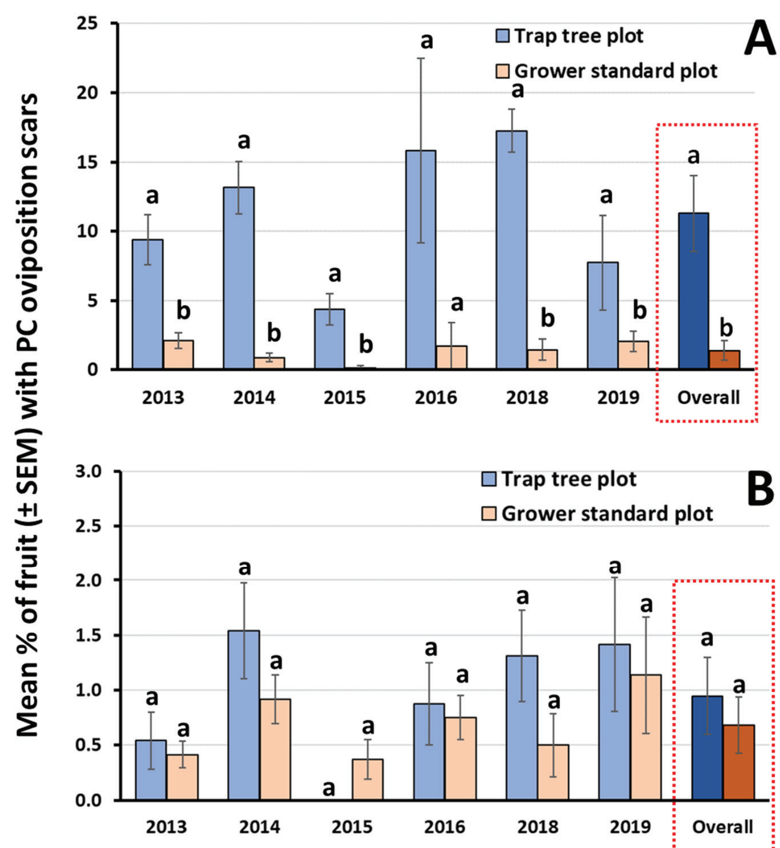

Figure 2. For each year and across all six years, level of fruit injury (mean ± standard error of the mean [= SEM], *a measure of how precise the estimate is*) caused by PC to (**A**) trap trees in trap tree plots and control (unbaited) trees in grower standard plots, and (**B**) interior trees according to treatment. Interior-tree injury is the strongest measure of treatment performance. Means within a panel and for each pair of bars capped with different letters are significantly different at odds of 19:1.

across all years, the mean percent injury in interior trees located in trap tree plots did not differ statistically from that recorded in plots subject to grower standard sprays (Figure 2B).

For the third question ("does the level of injury spill over to neighboring trees?"), across all years and orchards, the average level of injury caused by PC in odor-baited trap trees (11.3%) in trap tree plots was significantly greater than that recorded in any laterally located peripheral trees (3.7, 2.3 and 1.8%, for adjacent trees, and for trees located two away, and three away, respectively) (Figure 3). In contrast, in grower standard plots the level of injury recorded in the control tree (1.4% on average) did not differ statistically from that recorded in the most adjacent perimeter-row trees (1.2%) or in trees located further away (1.5 and 1.2% for trees located two away and three away, respectively) (Figure 3).

Study 2: EPN Application against PC larvae in the soil. The application of the EPN *S. riobrave* to the soil underneath trap trees consistently resulted in significant reductions in the number of summer-generation PC that emerged from the soil, when compared to the water control. In 2013, 2014, and 2015, significantly fewer adults were recovered from PVC enclosures that received *S. riobrave* compared to the water control (Figure 4A). For emergence cages, significantly fewer adult PCs were recovered when *S. riobrave* was applied when compared to the water control on each year, except for 2014 due to high variability among samples (Figure 4B).

Conclusions

The present study indicated that, over multiple years and locations (1) odor-baited trap trees consistently aggregated fruit injury by PC; (2) insecticide sprays confined to trap trees only after the petal fall spray resulted in similar level of fruit injury in interior trees, compared to plots that received grower-prescribed sprays; (3) small spillover effects were noted in trap tree plots involving the trees most adjacent proximal to odor-baited trap trees; and (4) the EPNs *S. riobrave* was consistently effective at killing PC larvae. The economic feasibility of using EPNs applied underneath the canopies of trap trees is very promising because, even if high rates of nematodes are applied, such applications would only need to be made to a small proportion of the acreage.

Overall, this study supports a reduced-spray IPM program that integrates the use of synergistic lures and insecticide applications to the canopies of baited trees to kill adult PCs, and one timely EPN application in the areas underneath trap trees, to kill PC larvae.

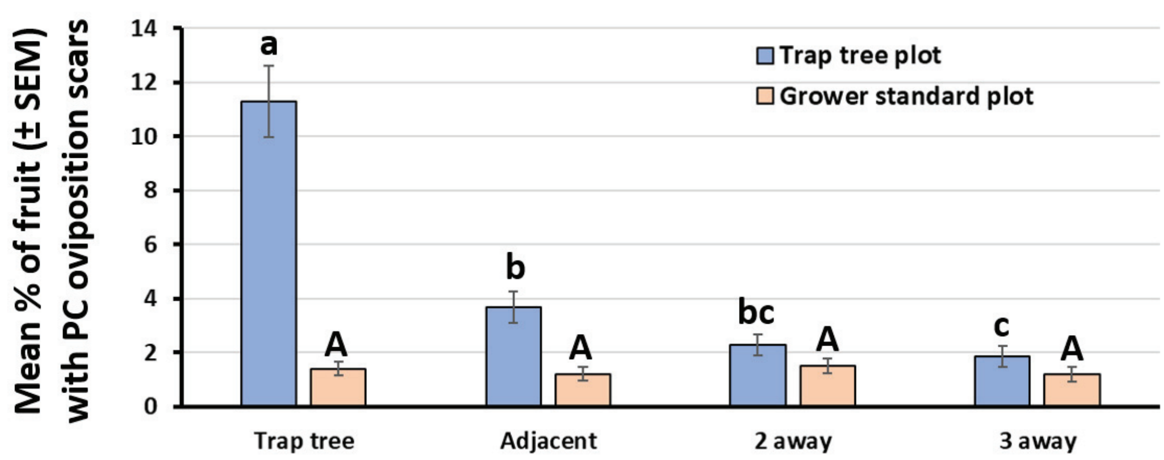

Figure 3. For the quantification of potential spillover effect, level of PC injury (mean ± standard error of the mean [= SEM], *a measure of how precise the estimate is*) to fruit sampled from odor-baited trap trees in trap tree plots, from control (unbaited) trees in grower standard plots, and from peripherally located neighboring trees. For each treatment, bars capped with different letters are significantly different at odds 19:1.

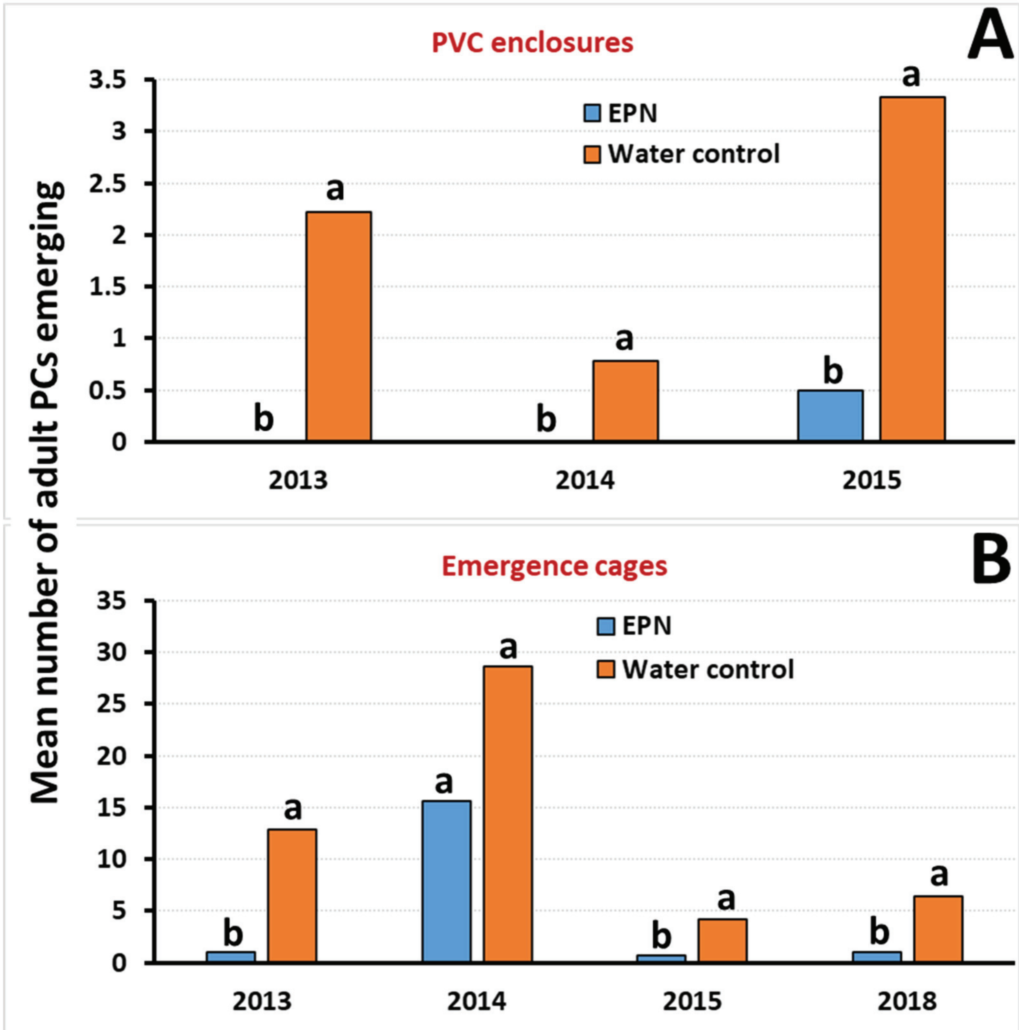

Figure 4. For each year, cumulative number of adult PCs that emerged from the soil in the trapping devices (PVC enclosures and emergence cages) according to treatment (EPN *Steinernema riobrave* versus water control). The lower the number of PCs emerging, the most effective EPNs were when compared to water control. For each year, bars capped with different letters are significantly different at odds 19:1.

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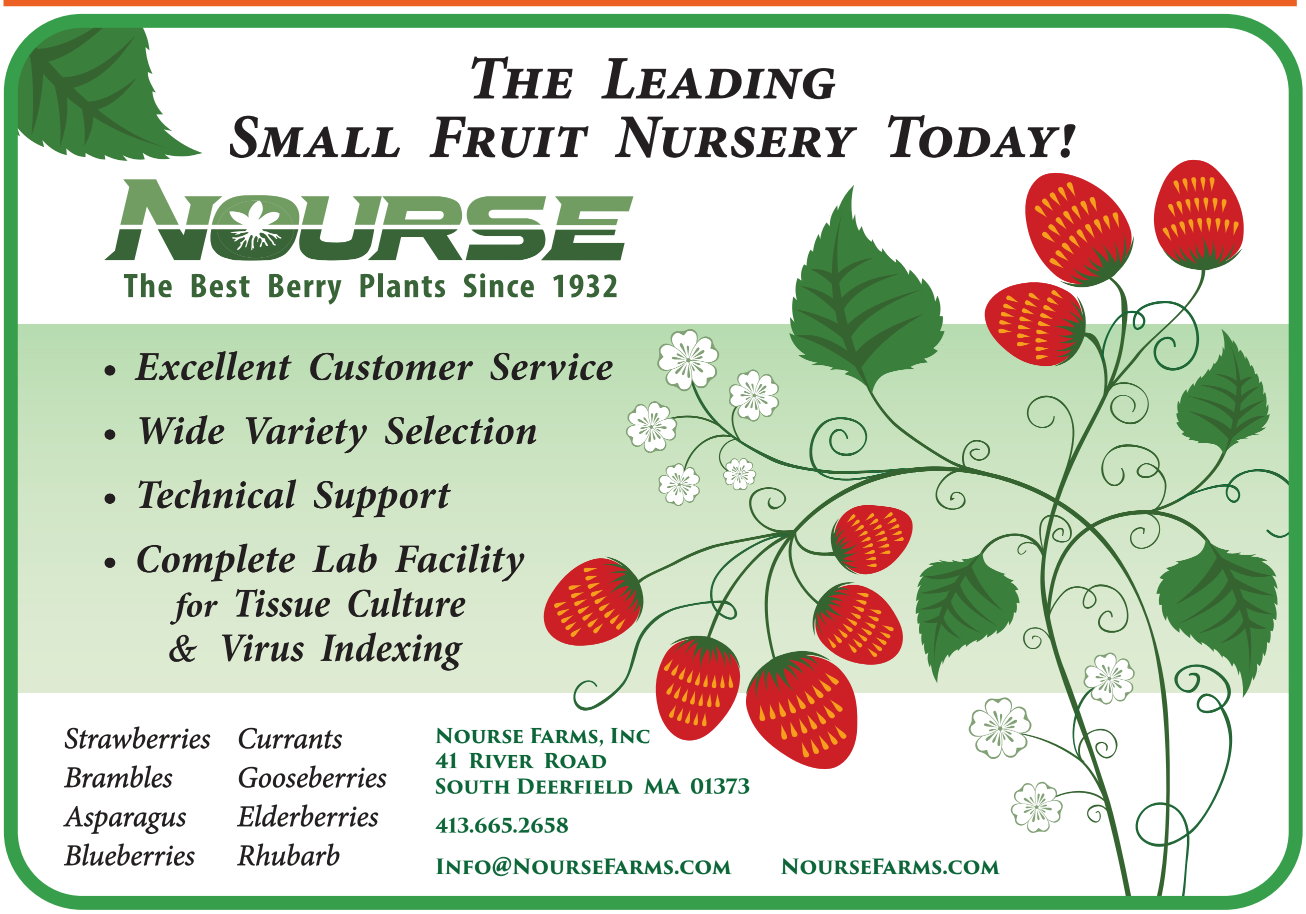
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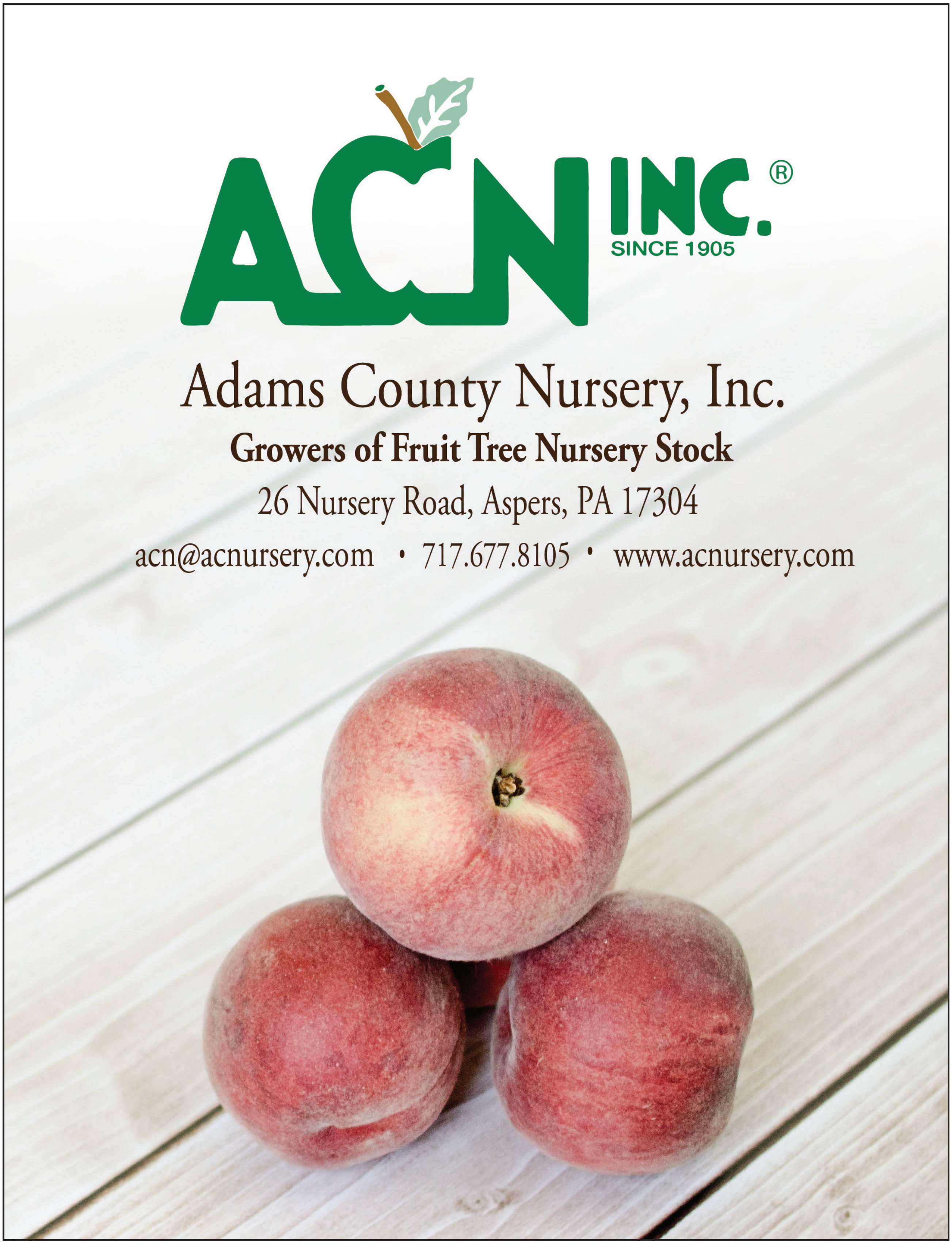
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