Field Evaluation of Traps and Lures for Monitoring Plum Curculio (Coleoptera: Curculionidae) in Alabama Peaches

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ABSTRACT The plum curculio, *Conotrachelus nenuphar* (Herbst) (Coleoptera: Curculionidae), is a key pest of peaches, *Prunus persica* (L.) Batsch, in North America. We evaluated the effectiveness of two widely used trap types (pyramid versus Circle traps) and commercially available synthetic lures for monitoring the pest in two peach orchards in Alabama during 2008 and 2009. The lures evaluated alone or in combinations included benzaldehyde (BZ) (a component of fruit odor), plum essence (PE) (a mixture of fruit odor extracted from food grade plum), and grandisoic acid (GA) (a male-produced aggregation pheromone of plum curculio). In general, pyramid traps captured more plum curculio adults than Circle traps, particularly during the first generation. Trap performance was improved numerically by the addition of BZ, PE, or GA alone (single lures) and was significantly enhanced by the addition of the combined BZ + PE lure. In both first and second generations, the combined BZ + PE lure increased plum curculio captures (significant in some trials) over unbaited traps and traps baited with single lures by ≈ 1.5–21-fold and had the highest response indices (RIs), which is indicative of high attractiveness. The combined BZ + GA lure and the three-component BZ + PE + GA lure also captured numerically more plum curculio adults than unbaited traps or traps baited with single lures but the differences were rarely significant. Analysis of ratios of interaction suggests the possibility of synergistic interactions between BZ and PE and between BZ and GA; however, additive effects were concluded due to high sample errors. These results are discussed in relation to the physicochemical properties of the lures and the potential of using baited monitoring traps to aid plum curculio management decisions in peach orchards.

KEY WORDS plum curculio, pyramid trap, Circle trap, benzaldehyde, grandisoic acid

The plum curculio, *Conotrachelus nenuphar* (Herbst) (Coleoptera: Curculionidae), is a key pest of tree fruit in eastern North America (Chapman 1938), and one of the most serious economic pests of peaches, *Prunus persica* (L.) Batsch, in the southeastern United States (Horton and Ellis 1989, Horton et al. 2008). Peach growers in Alabama and many other parts of the southeastern United States typically manage plum curculio by using a calendar-based insecticide program involving six to 12 sprays of broad-spectrum organophosphate and/or pyrethroid insecticides per growing season (Foshee et al. 2008). However, recent cancellations or restrictions of some common fruit insecticides by the Environmental Protection Agency have necessitated development of alternatives to the calendar-based insecticide program for plum curculio. Ongoing research by our program suggests that targeted insecticide spray programs in which insecticide sprays are timed to coincide with key phenological stages of plum curculio may provide a cost-effective and environmentally sound alternative to the calendar-based program by significantly reducing the number of plum curculio sprays per season. However, the success of a targeted spray approach is highly dependent on the ability to effectively detect and monitor plum curculio activity in the field.

In Alabama and other peach-growing regions, plum curculio adults are known to overwinter in wooded lots adjacent to orchards from where they immigrate into peach orchards in the spring beginning around bloom (Snapp 1930, 1940; Yonce et al. 1995, Johnson et al. 2002). This movement pattern underscores the need for effective monitoring systems, which can detect activity of plum curculio spring immigrants and track the development and activity of their progeny in orchards throughout the season. Studies in some fruit-producing regions in the United States have identified candidate traps for monitoring plum curculio. The two most popular traps are black pyramid trap (also called Tedders trap) and "Circle" or screen trap (Tedders and Wood 1994; Mulder et al. 1997; Prokopy and Wright 1998; Prokopy et al. 1999a,b, 2000, 2002; Leskey and Prokopy 2002). The pyramid trap mimics tree trunks and are usually deployed in the orchard border or in between tree rows where crawling or flying plum curculio adults are visually attracted to the traps (Tedders and Wood 1994, Prokopy and Wright 1998, Les-

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key and Wright 2004b). In contrast, the Circle trap, named after Edmund Circle, a Kansas pecan grower is a "passive trap," that is encircled around the tree trunk to intercept crawling plum curculio adults (Mulder et al. 1997, Prokopy and Wright 1998, Prokopy et al. 1999b, Johnson et al. 2002).

The search for semiochemical attractants for plum curculio has resulted in the identification of various plant-based volatiles, the most attractive of which include benzaldehyde (BZ) and foliar and woody tissue of plum trees (Leskey and Prokopy 2000, 2001; Prokopy et al. 2001; Leskey et al. 2005). Grandisoic acid (GA), a male-produced aggregation pheromone of plum curculio, also was identified as attractive to both sexes of plum curculio (Eller and Bartelt 1996). To date, a synergistic lure composed of BZ and GA, developed in Massachusetts remains the most widely used attractant for monitoring plum curculio in apple (*Malus* spp.) orchards in the northeast (Piñero and Prokopy 2003, Piñero and Prokopy 2006), and in peach orchards in the mid-Atlantic (Piñero et al. 2001, Leskey and Wright 2004b, Leskey et al. 2005). Prokopy et al. (2003, 2004a,b) also developed the trap-tree approach, a simple and effective integrated pest management (IPM) tool that allows growers to determine need for and timing of insecticide applications based on occurrence of fresh oviposition injury by plum curculio to apple fruit that are monitored on a perimeter-row trap tree. The effectiveness of this approach to monitor oviposition activity of plum curculio has been demonstrated recently in seven northeastern states (Piñero et al. 2006), but not in the southern states. Plum essence (PE), a commercially available synthetic mixture of plant essence, has recently been shown to be effective in attracting plum curculio in apple orchards (Coombs 2001, Whalon et al. 2006). Despite the above-mentioned efforts, no truly effective and practical attractant-based monitoring systems are currently available for plum curculio. This is due to several factors including competition from natural odors from host plants and lack of adequate knowledge of the effect of environmental factors on plum curculio trap capture.

The majority of the research on evaluation of monitoring traps and lures for plum curculio have been conducted in apple orchards in the northeastern United States (Piñero and Prokopy 2003; Leskey and Wright 2004a,b; Leskey et al. 2005). Very little has been done to evaluate the performance of traps and lures for monitoring plum curculio in peach orchards in Alabama and other parts of the southeastern United States. An exception to this was the study by Johnson et al. (2002) that evaluated pyramid versus Circle traps baited with GA for monitoring plum curculio in peach orchards in Arkansas and Oklahoma. The authors concluded that captures of plum curculio in baited traps can be used in combination with fruit damage to time insecticide applications against plum curculio (Johnson et al. 2002). Because regional conditions differ considerably across the continental United States and because most volatile lures depend on temperature-driven mechanisms of release of attractant molecules (Leskey and Zhang 2007), it is imperative that lures are evaluated on a regional and perhaps local basis before recommendation for grower use. Furthermore, it is possible that the two geographical strains of plum curculio in the United States, the northern univoltine strain and the southern multivoltine strain (Smith 1957, Hoffmann et al. 2004), may differ in their responses to traps and semiochemicals.

The objective of this study was to evaluate the effectiveness of two widely used trap types (pyramid versus Circle traps) and commercially available lures (synthetic fruit volatiles and aggregation pheromone) for monitoring populations of plum curculio in Alabama peaches. Data from this study, in addition to a degree-day model being developed (unpublished data) may aid the development of an effective IPM program for this pest in the region.

Materials and Methods

Study Sites. This 2-yr study was conducted during the 2008 and 2009 in two unsprayed peach orchards located at Clanton, Chilton County, AL. The predominant peach variety in each orchard was 'David Sun' (early season variety harvested in early to mid-June) and 'Loring' (midseason variety harvested in early to mid-July), respectively. The two orchards were 500 m apart, each with row spacing of 6.7 m and tree spacing of 4.9 m. The peach trees were ≈12 yr old, with an average height of 4 m. The David Sun variety orchard (henceforth referred to as David Sun orchard) was bordered to the south by a stretch of woods across the breadth of the entire orchard ≈30 m from the perimeter row. On the west and east sides were two orchards of different cultivars. The west side was bordered by 'Rich May' variety that matured and was harvested earlier than David Sun, whereas the east side was bordered by 'Fireprince', which matured later than David Sun variety. The north side was an open field with no trees or shrubs. The Loring variety orchard (henceforth referred to as Loring orchard) was bordered to the north and south by open grassland with the closest peach orchard being ≈100 m away, to the west by a wheat field, and to the east by a wood lot. In the David Sun orchard, the first bloom was observed in mid-March, whereas bloom was recorded in late March in the Loring orchard. Except for the application of a fungicide (Bravo 720 or Captan 50W) early in the season, no systemic or foliar pesticides were applied in both orchards during this study. However, the orchards were conventionally managed in the years preceding this study. Routine orchard floor maintenance was performed during this study by mowing the understory periodically to aid in trap placement and maintenance, and data collection.

Evaluation of Traps and Lures. Two trap types (black pyramid versus Circle) unbaited or baited with various types and combinations of commercially available lures were evaluated. All traps tested in this study were purchased from Great Lakes IPM Inc. (Vestaburg, MI). Trap placement followed that of Prokopy and Wright (1998) and Prokopy et al. (2003). In brief, pyramid traps were placed ≈ 0.6 m from a tree trunk. Circle traps, with a string for attachment were wrapped around the main tree trunk of selected trees. The two trap types were alternated on every other tree along a peach row, which resulted in an ≈10-m distance between two traps. Four replicated plots (blocks) were set up in each orchard and blocks were separated apart by at least 24 m.

The following synthetic lures were evaluated singly (alone) or in combinations: BZ, PE, and GA. The following lure treatments were compared in David Sun orchard in both years: 1) BZ only, 2) PE only, 3) GA only, 4) BZ + PE, 5) BZ + GA, 6) BZ + PE + GA, and 7) control (no lure). However, only five treatments (treatments 1, 4, 5, 6, and 7) were evaluated in Loring orchard in both years because of its smaller size (i.e., the single PE and GA lure treatments were not tested). The BZ dispenser was a small polyethylene vial containing ≈5 ml of lure consisting of BZ formulated with 1, 2, 4-trichlorobenzene (TCB) at a ratio of 9:1 (BZ:TCB). The TCB was used as a stabilizing agent to prevent the hydrolysis of BZ to *trans*-stilbene and benzoic acid under UV light and oxidation processes (Leskey et al. 2005). The PE lure was a blend of plant essences (Great Lakes IPM Inc.). The PE lure dispenser was a transparent polyethene sachet with a small cotton thread (≈6.5 cm in length) through which the lure is released. The GA lure dispenser consisted of a heat-sealed polymer membrane release device obtained from ChemTica International (San Jose, Costa Rica). The position of each lure treatment within a block was rerandomized biweekly (fortnightly) to minimize potential effect of treatment location on trap capture. All lures were replaced (with fresh lures) every 2–3 wk depending on field conditions. For the pyramid traps, a single BZ dispenser was placed in the plastic, funnel shaped top attached to the tip of the trap. The PE and GA dispensers were each attached separately at random positions on the top corner of the pyramid trap using a small push pin or binder clip. In all cases plum curculio adults were captured in a boll weevil trap top attached to the top of the pyramid trap. Similar procedures were used for installing lures on the Circle traps, which also contained boll weevil trap tops for capturing beetles. Trap and lure treatments were deployed on 29 February (during bud swell) and checked weekly for plum curculio adult captures until 24 July (2–3 wk after harvest) of each year. The date of first plum curculio capture was noted for each trap/lure treatment combination.

Estimation of Release Rates of Lures. The release rates of the BZ and PE lures were determined gravimetrically in the Loring orchard in 2008 and 2009 using the methods described by Leskey and Wright (2004b). In brief, five fresh lures of each type (BZ or PE) were weighed on a balance (Acculab VI-6 kg model, Precision Weighing Balances, Bradford, MA) to determine initial weight. Each lure was then attached to a pyramid trap and placed in the test orchard. The weight of each lure was determined weekly to estimate release rate per day under variable field conditions. The daily average temperatures were recorded to determine any relationship between temperatures and lure release rates. The release rate of the GA lure (25 mg) was not evaluated because it was determined by the manufacturer and in a previous study (Leskey and Wright 2004b) to be ≈1 mg/d. The mean field release rate (milligrams per day) of BZ increased from 8.9 in early to mid-April to 13.5 in late May to early June. Similarly, mean field release rate (milligrams per day) of PE increased from 244 in early to mid-April to 648 in late May to early June. The mean daily average temperature within the period ranged from 12.7 ± 4.8°C in early to mid-April to 25.2 ± 3.5°C in late May to early June. In general, similar release rates were recorded in 2009.

Statistical Analyses. Data for each orchard and year were analyzed and presented separately. Trap capture data were not normally distributed and thus were transformed by using the $\sqrt{x + 0.5}$ transformation method. Because two distinct plum curculio generations were recorded in central Alabama in both years, the first (spring) generation from early March to late May and the second (summer) generation from early June to mid September, trap captures were compared by generation. Data were first analyzed by using standard least square analysis of variance (ANOVA) (JMPIN version 7.0.1, SAS Institute 2007) to test for effects of trap, lure, and interactions among both factors on plum curculio trap capture. Seasonal mean trap captures were then calculated for each lure treatment (data for each trap type analyzed separately by generation) and analyzed with ANOVA followed by Tukey–Kramer honestly significant difference (HSD) test to determine significant effects of lures and blocks (replicates). To measure the attractiveness of each lure, a response index (RI) (Phillips et al. 1993, Leskey and Prokopy 2000, Leskey et al. 2001) was calculated by subtracting the total number of plum curculio responding to an unbaited control trap (C) from the total number responding to its corresponding baited trap (BT) dividing by the total number of plum curculio captured by the C and BT traps, and multiplying by 100. Thus, $RI = [(BT - C)/BT + C)] \times 100$. RI was calculated for each replicate and this was used to calculate the mean RI for each lure. A lure was considered attractive only if it had a mean RI value of ≥25 (Leskey and Prokopy 2000). Ratios of interaction (ROIs) were calculated as described by Hammack (1996) and Piñero and Prokopy (2003) to determine the type of interactions (additive, inhibitory, or synergistic) among single and multiple component lure treatments in the David Sun orchard (single lure treatments were not evaluated in Loring orchard). The ROIs, calculated for each replicate, was based on the following relationship: $ROI = [(A + GA) + control]/[(A) + GA)]$, where (A) represents plum curculio captures by traps baited with a particular fruit volatile or combinations of fruit volatiles, GA represents captures by traps baited with GA alone, (A + GA) represents captures in traps baited with either single or double fruit volatiles, and control represents the trap capture numbers in unbaited traps. We adopted the rule of thumb that ROI values significantly <1 indicate inhibitory effect, equal to one indicate additive or neutral effect, and significantly >1 indicate synergistic interaction between lures (Piñero and Prokopy 2003). ROI values significantly less or >1 were established by using Student's *t*-test (JMPIN version 7.0.1, SAS Institute, 2007). The specific interactions examined were between BZ and GA, BZ and PE, and BZ, PE, and GA for the David Sun orchard in both years. Interactions between PE and GA could not be examined because there was no PE + GA treatment. For all data, differences between/among treatments were considered significant at $P < 0.05$.

Results

In 2008, 78 and 52 plum curculio adults in total were captured in the David Sun and Loring orchards, respectively. Higher trap captures were recorded in 2009, totaling 345 and 264 plum curculio adults in the David Sun and Loring orchards, respectively. Standard least square ANOVA revealed a significant effect of trap on adult captures in the David Sun orchard during the first ($F = 25.13$, df = 1, $P < 0.0001$) and second ($F = 10.37$, df = 1, $P = 0.0025$) generations in 2008, and during the second ($F = 4.93$, df = 1, $P = 0.0319$) generation in 2009. Standard least square ANOVA also showed a significant effect of lure on trap captures of plum curculio adults in the David Sun orchard during the first generation ($F = 4.90$, df = 6, $P = 0.0007$) in 2008 and during the first ($F = 5.62$, df = 6, $P = 0.0002$) and second ($F = 4.46$, df = 6, $P = 0.0014$) generations in 2009. In the Loring orchard, lure had a significant effect on adult trap captures during the second generation ($F = 10.32$, df = 4, $P < 0.0001$) in 2008 and during the first generation ($F = 3.48$, df = 4, $P < 0.0189$) in 2009. In general, the interaction between trap and lure (trap × lure) was not significant in six out of eight cases. A significant trap × lure interaction was recorded only during second generation in the Loring orchard in 2008 ($F = 10.32$, df = 4, $P < 0.0001$) and during second generation in the David Sun orchard in 2009 ($F = 2.97$, df = 6, $P = 0.0166$). Because a significant trap × lure interaction was not recorded in most cases, captures of adults in pyramid versus Circle traps (data pooled for all lures) were compared for each generation in each orchard and year by using Student's *t*-test analysis.

In 2008, significantly greater number of plum curculio were captured in pyramid traps than in Circle traps in the David Sun orchard during the first ($t = 17.73$, df = 1, $P = 0.0001$) and second ($t = 11.16$, df = 1, $P = 0.0016$) generations (Fig. 1A). Similar results were obtained in the Loring orchard in 2008 with significantly more plum curculios captured in pyramid traps than in Circle traps during the first ($t = 6.50$, df = 1, $P = 0.0153$) and second ($t = 5.19$, df = 1, $P = 0.0289$) generations (Fig. 1B). In 2009, no significant differences in trap captures were recorded between pyramid traps and Circle traps in the David Sun orchard during the first ($t = 0.02$, df = 1, $P = 0.8923$) and second ($t = 3.18$, df = 1, $P = 0.0806$) generations (Fig. 1A). In the Loring orchard in 2009, significantly more plum curculio adults were captured in pyramid traps than in Circle traps during the first generation ($t = 6.16$, df = 1, $P = 0.0180$) but not during the second ($t = 0.14$, df = 1, $P = 0.7097$) generation (Fig. 1B). In general, ≈ 2–5 times plum curculio adults were captured in pyramid traps than in Circle traps (Fig. 1). In 2008, no significant effects of block (replication) were recorded on plum curculio captures during the first (David Sun: $t = 1.15$, df = 3, $P = 0.3396$; Loring: $t = 0.80$, df = 3, $P = 0.5008$) and second (David Sun: $t = 1.38$, df = 3, $P = 0.2584$; Loring: $t = 0.50$, df = 3, $P = 0.6875$) generations. Similarly in 2009, no significant effects of block (replication) were recorded on plum curculio captures during the first (David Sun: $t = 0.33$, df = 3, $P = 0.8065$; Loring: $t = 0.17$, df = 3, $P = 0.9136$) and second (David Sun: $t = 1.62$, df = 3, $P = 0.1969$; Loring: $t = 2.41$, df = 3, $P = 0.0834$) generations.

Lure treatments had significant effect on plum curculio trap captures in both orchards and years of the study (Tables 1 and 2). Significant differences among lure treatments were observed only in pyramid traps in both orchards and years (Tables 1 and 2). In general, more plum curculio adults were captured in pyramid traps baited with the combined BZ + PE lure or the three-component BZ + PE + GA lure than traps baited with single lure or unbaited traps (Tables 2 and 3). Analyses of RI further confirmed that the combined BZ + PE lure was the most attractive odor treatment for plum curculio, particularly during the first generation (Tables 3 and 4). This was true for both trap types, although significant trap captures were recorded only in pyramid traps. Pyramid traps baited with BZ + PE had the highest RIs during the first generation in both orchards and years (Tables 3 and 4). In contrast, traps baited with BZ + PE + GA had the highest RIs during the second generation in both orchards in 2008, but not in 2009 (Tables 3 and 4).

The ROIs were calculated using the pooled data for the two generations per year, because the aim was to simply determine the type of interactions among single and multiple component lure treatments. In both years in the David Sun orchard, high ROI values were recorded for the combined BZ + PE (ROI ≈2) and BZ + GA (ROI ≈2.4) baits in both pyramid and Circle traps (Table 5). However, these values were not significantly different from 1 due to high sample errors. Thus, *t*-test showed only an additive effect of combining BZ and PE and BZ and GA. The ROI values for the three-component BZ + PE + GA lure ranged from 0.75 to 1.1 in both traps and years (Table 5), suggestive of a weak additive effect at best.

The seasonal captures of plum curculio in pyramid traps baited with BZ + PE is presented in Fig. 2 to illustrate the seasonal phenology of the pest in central Alabama. The first plum curculio captures were recorded around the same time (90% bloom) in the different treatments within each orchard. In 2009, plum curculio adults were recorded in the traps earlier in the David Sun orchard (13 March) than in the Loring orchard (20 March), possibly due to early blooming of the David Sun peach variety.

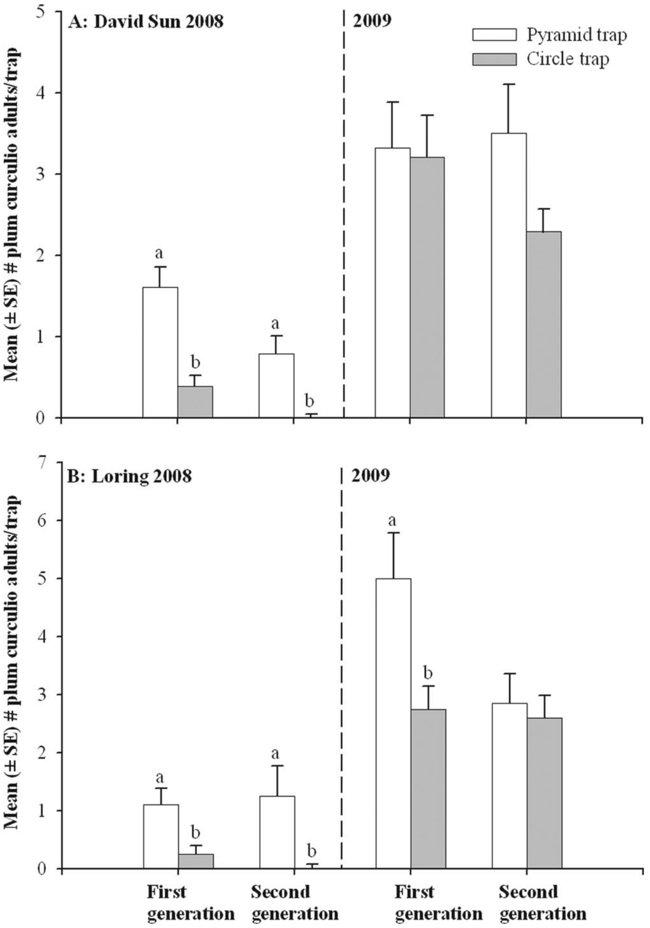

Fig. 1. Mean ± SE total captures of plum curculio adults in pyramid versus Circle traps during the first and second generations in David Sun orchard (2008 and 2009) (A) and Loring orchard (2008 and 2009) (B). Means for each generation having no letter in common are significantly different between trap types (ANOVA, *t*-test, $P < 0.05$).

Discussion

The results showed that pyramid traps captured more plum curculio adults than Circle traps. Trap performance was improved at least numerically by the addition of host plant volatile lures (BZ or PE) and the male-produced aggregation pheromone (GA) of plum curculio. Among the lures, the combined BZ + PE lure increased plum curculio captures over unbaited traps by up to 21-fold. In both orchards and years, pyramid traps baited with the combined BZ + PE

Table 1. Mean ± SE total number of plum curculio adults captured in pyramid and Circle traps baited with synthetic formulations of BZ, PE, or GA singly or in combinations, versus unbaited (control) traps during the first and second generations in David Sun peach orchard (Clanton, AL) in 2008 and 2009

Lure treatment	2008				2009			
	First generation		Second generation		First generation		Second generation	
	Pyramid	Circle	Pyramid	Circle	Pyramid	Circle	Pyramid	Circle
BZ	1.00 ± 0.12b	0.00 ± 0.07	0.50 ± 0.34	0.00 ± 0.00	1.25 ± 0.36b	2.50 ± 0.74	1.75 ± 1.42b	1.50 ± 0.87
PE	1.50 ± 0.61ab	0.25 ± 0.19	0.00 ± 0.28	0.00 ± 0.00	2.75 ± 0.91b	1.75 ± 0.26	4.50 ± 0.84ab	3.50 ± 0.79
GA	1.00 ± 0.50b	0.00 ± 0.07	0.50 ± 0.30	0.00 ± 0.00	1.00 ± 0.45b	1.50 ± 0.78	1.00 ± 0.60b	1.75 ± 0.17
BZ + PE	3.75 ± 0.41a	1.25 ± 0.48	1.50 ± 1.16	0.00 ± 0.00	5.50 ± 1.65ab	5.00 ± 1.95	8.25 ± 1.39a	2.75 ± 0.38
BZ + GA	1.50 ± 0.48ab	0.50 ± 0.32	0.50 ± 0.37	0.00 ± 0.00	7.25 ± 1.30a	5.50 ± 1.17	2.00 ± 0.85b	3.00 ± 0.50
BZ + PE + GA	1.75 ± 0.67ab	0.50 ± 0.28	1.50 ± 0.13	0.00 ± 0.00	3.75 ± 1.01ab	4.75 ± 1.21	5.50 ± 1.29ab	2.50 ± 1.29
Control	0.75 ± 0.51b	0.25 ± 0.19	1.00 ± 0.81	0.00 ± 0.00	1.75 ± 1.22b	1.50 ± 0.54	1.50 ± 0.81b	1.50 ± 0.22
F	3.49	2.27	0.81	0.00	4.04	2.37	5.37	1.01
P	0.0182	0.0832	0.5756	0.000	0.0097	0.0733	0.0025	0.4513

Means within the same column having no letter in common are significantly different (ANOVA, Tukey–Kramer HSD, $P < 0.05$, df = 6, 18).

Table 2. Mean ± SE total number of plum curculio adults captured in pyramid and Circle traps baited with synthetic formulations of BZ, PE, or GA singly or in combinations, versus unbaited (control) traps during the first and second generations in Loring peach orchard (Clanton, AL) in 2008 and 2009

Lure treatment	2008				2009			
	First generation		Second generation		First generation		Second generation	
	Pyramid	Circle	Pyramid	Circle	Pyramid	Circle	Pyramid	Circle
BZ	0.50 ± 0.41	0.00 ± 0.13	0.75 ± 0.39b	0.00 ± 0.00	1.50 ± 0.68	2.50 ± 0.86	1.25 ± 0.85	2.00 ± 0.23
BZ + PE	1.75 ± 0.40	0.75 ± 0.37	5.25 ± 1.29a	0.00 ± 0.00	7.00 ± 1.19	3.25 ± 0.44	3.75 ± 0.42	2.75 ± 1.16
BZ + GA	1.50 ± 0.91	0.25 ± 0.29	0.00 ± 0.39b	0.00 ± 0.00	6.50 ± 1.99	3.00 ± 0.56	4.25 ± 2.00	4.00 ± 1.04
BZ + PE + GA	1.25 ± 0.73	0.25 ± 0.14	0.50 ± 0.22b	0.00 ± 0.00	6.75 ± 1.99	3.75 ± 0.82	2.50 ± 0.77	2.75 ± 0.188
Control	0.50 ± 0.32	0.00 ± 0.13	0.25 ± 0.29b	0.00 ± 0.00	3.25 ± 0.33	1.25 ± 0.79	2.50 ± 0.77	1.50 ± 0.41
F	0.74	1.36	11.90	0.00	2.49	1.42	0.92	1.04
P	0.5829	0.3036	0.0004	0.0000	0.0991	0.2871	0.4850	0.4272

Means within the same column having no letter in common are significantly different (ANOVA, Tukey–Kramer HSD, $P < 0.05$, df = 4, 12).

lure captured more plum curculio adults than traps baited with single component lures of BZ, PE, or GA. The combined BZ + GA lure and the three-component BZ + PE + GA lure also captured numerically more plum curculio adults than unbaited traps or traps baited with the single components lures but the differences were rarely significant. The response index data also supported the above-mentioned results, which generally hold true for both generations of plum curculio.

Our results agree with previous studies which reported the superiority of pyramid traps over Circle traps and other trap types for monitoring plum curculio adults in fruit orchards (Le Blanc 1982, Le Blanc et al. 1984, Yonce et al. 1995, Mulder et al. 1997, Johnson et al. 2002, Lafleur et al. 2007). In contrast, Johnson et al. (2002) reported similar plum curculio captures in pyramid versus Circle traps in most of their samples. However, Circle traps deployed on tree trunks with circumference <38 cm had significantly lower plum curculio captures than pyramid traps. The length of the Circle trap bottom used in that study was 38 cm, which overlapped on circumferences >38 cm, thus reducing plum curculio captures (Johnson et al. 2002). Leskey and Wright (2004b) also reported that Circle traps captured significantly more plum curculio adults than pyramid traps in unsprayed orchards. Although not discussed by the authors, this result also may also be due to larger tree circumference in the unsprayed orchards. The length of the Circle trap bottom used in the current study was ≈ 33 cm, which is smaller than the circumference of most trees in the test orchards (the trees were >12 yr old). Thus, the lower plum curculio trap captures in Circle traps compared with pyramid traps recorded in the current study may not be explained by smaller tree circumferences.

Our data on lure performance are also consistent with previous reports which showed that the combined BZ + GA lure was more effective than single lures for monitoring plum curculio (Piñero and Prokopy 2003, Leskey and Wright 2004b, Leskey et al. 2005). However, it is difficult to completely compare our data with those reported by the above authors because PE was not evaluated in the studies. We recorded no significant differences in plum curculio trap captures among any of the single lures (BZ, PE, or GA), or between traps baited with any of the single lures versus unbaited traps. These results are generally similar to those reported by Leskey and Wright (2004b). Among the combined lures, BZ + PE attracted numerically more plum curculio adults than did BZ + GA or BZ + PE + GA. The data which showed no significant effect of combining BZ with GA agree with those of Leskey (2006), who reported that the combined BZ + GA lure was more effective in apples than in peach orchards.

The results on lure performance may be related to the physicochemical properties of the lures including release rates. We obtained an average field release rate of ≈11 mg/d for BZ, which is similar to the 10 mg/d reported by Piñero et al. (2001). For PE, we obtained

Table 3. Response indices of the various lure treatments evaluated in David Sun peach orchard (Clanton, AL) in 2008 and 2009

Lure treatment	2008				2009			
	Pyramid		Circle		Pyramid		Circle	
	First generation	Second generation	First generation	Second generation	First generation	Second generation	First generation	Second generation
BZ	0.00	−8.33	−25.00	0.00	−6.68	−16.68	27.50*	−33.35
PE	20.82	−25.00*	0.00	0.00	29.18*	47.23*	25.83*	38.33*
GA	−25.00	10.00	−25.00	0.00	−20.00	30.00*	−5.83	5.00
BZ + PE	67.50*	25.00*	50.00*	0.00	57.48*	66.88*	45.00*	18.33
BZ + GA	12.50	10.00	25.00*	0.00	55.78*	20.00	65.90*	27.38*
BZ + PE + GA	8.33	66.68*	25.00*	0.00	37.78*	59.23*	63.90*	−10.48
Control	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

* Asterisk denotes response index ≥25, which is significantly more attractive than control.

Table 4. Response indices of the various lure treatments evaluated in Loring peach orchard (Clanton, AL) in 2008 and 2009

Lure treatment	2008				2009			
	Pyramid		Circle		Pyramid		Circle	
	First generation	Second generation	First generation	Second generation	First generation	Second generation	First generation	Second generation
BZ	−16.68	0.00	0.00	0.00	−48.93	−36.68	6.67	−6.68
BZ + PE	45.83*	9.45	50.00*	0.00	33.58*	4.20	35.85*	23.23
BZ + GA	8.33	−25.00	25.00*	0.00	24.65	23.50	40.83*	13.23
BZ + PE + GA	15.00	25.00*	25.00*	0.00	26.78*	0.83	24.53	16.68
Control	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

* Asterisk denotes response index ≥25, which is significantly more attractive than control.

an average field release rate of 405 mg/d, which is ≈36 times higher than for BZ. Although not determined in this study, the release rate of GA is ≈1 mg/d (Prokopy et al. 2004a,b; Leskey and Wright 2004b). It is not surprising that the PE lure had a higher release rate than the BZ lure because both lures had different components with different viscosities. The PE lure is composed of ethanol with viscosity of 1.07 cp at 25°C, whereas the BZ lure consisted of BZ and TCB with viscosities of 1.4 cp at 25°C and 1.89 cp at 25°C, respectively. Viscosity has a direct relationship with evaporation; compounds with high viscosity tend to be released more slowly than those with low viscosity. Given this, the higher viscosity of the lure might have contributed to its slower release compared with PE. Thus, the comparatively higher release rate of PE under orchard conditions may explain in part the enhancement of captures of plum curculio in traps baited with BZ + PE. Further studies are necessary to confirm this prediction.

The data from the analysis of ROIs suggest a trend for synergistic interactions between BZ and PE and between BZ and GA in both trap types but the data were not significant due to large standard errors, hence we concluded additive effects. Piñero and Prokopy 2003 reported a synergistic interaction between BZ and GA, a finding consistent with the general view that aggregation pheromones enhance the attraction of beetles to host volatiles (Landolt 1997, Landolt and Phillips 1997). The numerically lower plum curculio trap captures in the three-component BZ + PE + GA bait compared with the two-component BZ + PE bait, plus the <1 ROI values obtained for the three-component lure in 2009, suggest the possibility of an inhibitory effect of combining BZ + PE + GA. Although an inhibitory interaction cannot be concluded due to lack of statistical significance, further studies are necessary to confirm this possibility. Nevertheless, our results provided no economic or scientific basis for using the three-component (BZ + PE + GA) lure to monitor plum curculio in Alabama peach orchards.

The low plum curculio trap captures recorded in this study are fairly typical of studies in commercial fruit orchards (Johnson et al. 2002, Leskey and Wright 2004b) and are not surprising given that the test orchards were conventionally managed (including routine applications of conventional insecticides) in the years preceding this study. Overall plum curculio trap captures seemed lower in 2008 than in 2009, but the difference was not statistically tested because this study was not designed to compare years. We recorded no significant block (replication) effects on plum curculio trap captures, contrary to previous a report by Leskey et al. (2001) in which the effect of replications was significant, which was suggestive of a border effect. The lack of a block effect in the current study may suggest that a significant proportion of plum curculio adults overwintered in the test orchards instead of in adjacent wood-lots, thus diluting potential border effect due to immigration of plum curculio adults. Other authors also have reported that plum curculio adults are capable of overwintering within fruit orchards (Lafleur et al. 1987, Leskey and Wright 2004b, Piñero and Prokopy 2006).

In summary, this study demonstrated the potential utility of pyramid traps baited with the combined BZ and PE lure for monitoring plum curculio in peach orchards in Alabama and other parts of the region.

Table 5. Type of interaction found between single and combined attractants (synthetic fruit odors and grandisoic acid) when evaluated as baits in pyramid and Circle traps in David Sun peach orchard (Clanton, AL) in 2008 and 2009

Trap type	Lure type	2008		2009	
		ROI (Mean ± SE)	Type of interaction	ROI (mean ± SE)	Type of interaction
Pyramid	BZ + GA	2.0 ± 0.8*	Additive	2.1 ± 0.7*	Additive
Circle	BZ + GA	N/A[a]	N/A	2.4 ± 0.9*	Additive
Pyramid	BZ + PE + GA	1.1 ± 0.1	Additive	0.96 ± 0.1	Additive
Circle	BZ + PE + GA	0.9 ± 0.3	Additive	0.75 ± 0.3	Additive

* Asterisk denotes high mean ROIs which could be indicative of synergistic interaction but not significant due to high sample errors.
[a] N/A, ROI was not calculated due to zero trap captures.

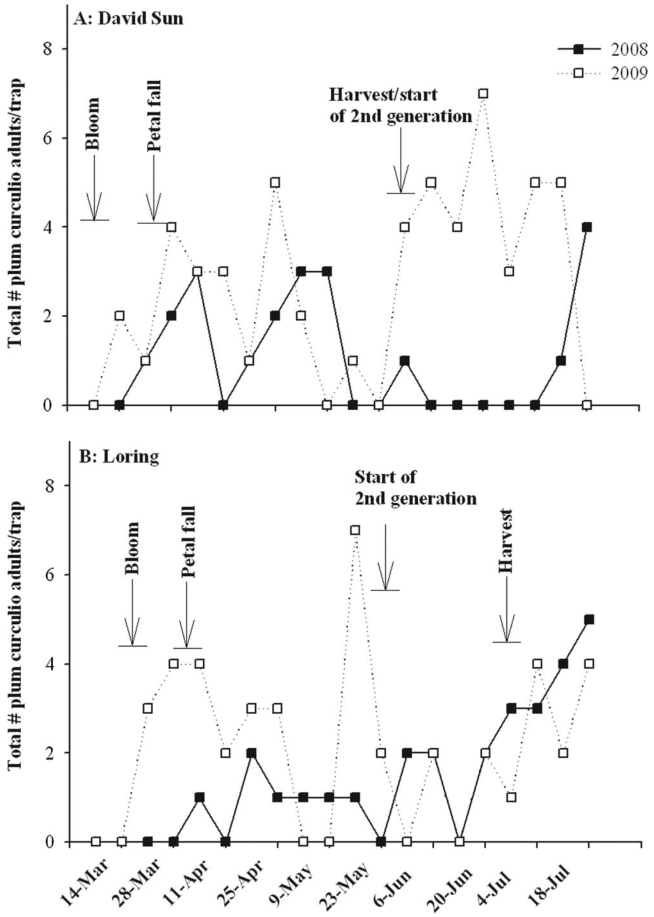

Fig. 2. Captures of plum curculio adults in pyramid traps baited with BZ+ PE in David Sun (A) and Loring orchards (Clanton, AL) (B), in relation to peach phenology in 2008 and 2009.

The results that showed the efficacy of baited pyramid traps in detecting activity of plum curculio spring immigrants suggest a role for this monitoring system in the development of a targeted insecticide spray and IPM program for plum curculio. Future studies are necessary to confirm the efficacy of PE established in this study, investigate factors affecting response of plum curculio adults to the lures, and test the ability of baited traps to predict fruit injury by plum curculio.

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