Entomologia Experimentalis et Applicata **103:** 219–226, 2002.

Trapping noctuid moths with synthetic floral volatile lures

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Accepted: June 11, 2002

Key words: insect behavior, attractants, phenylacetaldehyde, trapping, *Pseudoplusia includens, Anticarsia gemmatalis*, aculeate Hymenoptera, Lepidoptera, Noctuidae

Abstract

Male and female noctuid moths were collected from plastic bucket traps that were baited with different synthetic floral chemicals and placed in peanut fields. Traps baited with phenylacetaldehyde, benzyl acetate, and a blend of phenylacetaldehyde, benzyl acetate, and benzaldehyde collected more soybean looper moths, *Pseudoplusia includens* (Walker), than benzaldehyde-baited or unbaited traps. Females comprised over 67% of the moths captured and most were mated. At peak capture, over 90 male and female moths per night were collected. In another experiment, phenylacetaldehyde delivered in plastic stoppers attracted more *P. includens* moths than traps baited using other substrates, but this chemical delivered in wax attracted more velvetbean caterpillar moths (*Anticarsia gemmatalis* Hübner). Other noctuid male and female moths collected included *Agrotis subterranea* (F.), *Argyrogramma verruca* (F.), *Helicoverpa zea* (Boddie), and several *Spodoptera* species. Aculeate Hymenoptera were collected in large numbers, especially in traps baited with phenylacetaldehyde delivered from stoppers.

Introduction

Lepidopteran pest populations in agricultural systems are monitored by collecting males in traps baited with synthetically-produced female pheromones (Mitchell, 1986). However, chemicals other than sex pheromones have been isolated, identified, and bioassayed as moth attractants. Male and female moth attraction to and feeding from blooming plants has been noted for several noctuid pest species including black cutworm, *Agrotis ipsilon* (Hufhagel) (Zhu et al., 1993), velvetbean caterpillar, *Anticarsia gemmatalis* Hübner (Gregory, 1989), corn earworm, *Helicoverpa zea* (Boddie) (Adler, 1987; Beerwinkle et al., 1993), and European grapevine moth, *Lobesia botrana* Denis and Schiffermüller (Gabel et al., 1992). As early as the 1920s, the floral compound phenylacetaldehyde was shown to attract various noctuid species in the field (Smith et al., 1943). This chemical and other volatiles have been isolated from many flowering plants and shrubs (Cantelo & Jacobson, 1979; Haynes et al., 1991; Heath et al., 1992; Shaver et al., 1997). Field bioassays have shown phenylacetaldehyde alone, or in combination with other floral chemicals, attracts many male and female loopers (Plusiinae) (Cantelo & Jacobson, 1979).

Recent laboratory and field studies tested these floral chemicals as enhancements to sex pheromone in the collection of male fall armyworm, *Spodoptera frugiperda* (J. E. Smith) (Meagher & Mitchell, 1998; Meagher, 2001a). During collection of moths in pheromone traps with and without phenylacetaldehyde, male and female soybean looper moths, *Pseudoplusia includens* (Walker), were collected (Meagher, 2001b). Phenylacetaldehyde and other floral volatile materials have the potential in agricultural systems to attract both male and female moths. The objective of this paper was to collect and identify noctuid moths attracted to floral volatile-baited field traps. An additional objective was to compare trap collection of nontarget Hymenoptera attracted to phenylacetaldehyde released from different substrates (Meagher & Mitchell, 1999).

Materials and methods

Floral volatiles. This experiment was designed to compare capture of *P. includens* moths in traps baited with various floral volatiles. Standard Universal Moth Traps, 'Unitraps' (Great Lakes IPM, Vestaburg, Michigan, USA), were placed in northwestern Alachua County, Florida, USA, along roads and edges in a 80-ha field of peanuts (*Arachis hypogaea* L.,'Georgia Green', Fabaceae). This field was surrounded by $\approx$ 400 ha of peanut, separated by roads and forested strips. All traps contained insecticide strips to kill moths that were captured (Hercon® Vaportape II containing 10% 2, 2-dichlorovinyl dimethyl phosphate, Hercon Environmental Co., Emigsville, Pennsylvania, USA).

The first lure was a blend of floral chemicals identified from the night-blooming jessamine, *Cestrum nocturnum* (L.) (Solanaceae) (Heath et al., 1992). This lure contained 155.4 mg benzaldehyde, 47.4 mg phenylacetaldehyde, and 51.6 mg benzyl acetate (all obtained from Aldrich Chemical Co., Milwaukee, Wisconsin, USA). The ratio used was similar to amounts released during the period of maximum release for each *C. nocturnum* floret (Heath et al., 1992). Other lures included each floral chemical individually delivered in hollow polyethylene stoppers (0.5 ml each) (Kimble, Vineland, New Jersey, USA, purchased through Thomas Scientific, Swedesboro, New Jersey, USA, #9713-F28). A control lure of an empty stopper completed the five treatment, four block experiment. Trap location was randomized weekly, and moths were collected from 13 until 28 September 1998. To determine mating status of female moths, each was dissected to discover if a spermatophore was present.

Release substrates. This experiment was designed to compare capture of noctuid moths baited with only phenylacetaldehyde released from different substrates. Traps were placed in 400 ha of peanuts during mid-May 1999 in southern Levy County, Florida, USA. Traps were baited with phenylacetaldehyde loaded into stoppers (0.5 ml), or mixed in a wax developed for semiochemical dispensing (Scenturion Inc., Clinton, Washington, USA). Phenylacetaldehyde was mixed at 5% (50 mg) or 20% (200 mg) w/w into the wax, poured either into stoppers, or when dried, placed as cubes into plastic baskets. Therefore, the five phenylacetaldehyde treatments were stopper, 5% wax in stopper, 20% wax in stopper, 5% cube in basket, and 20% cube in basket. Traps with no lures completed the six treatment, three-randomized block design experiment. Trap location within a replication was randomized weekly, and lures were replaced every two weeks.

Moths were identified with the aid of Kimball (1965) and Covell (1984). They were compared with identified specimens in the Florida State Collection of Arthropods, Florida Department of Agriculture and Consumer Services, Division of Plant Industry, Gainesville, Florida, USA. Captured Hymenoptera were identified and compared among treatments (Meagher & Mitchell, 1999).

Release rates. Release rates of phenylacetaldehyde in stoppers and wax were determined by the modified techniques of Heath & Manukian (1992). This system consists of a glass chamber (25.7 cm long and 7.6 cm inner diam.) constructed of Pyrex glass with a glass frit inlet, a ground-glass joint outlet, and a multiport collector base to which the collector traps were connected. Collector traps were made from a 4.0 cm long by 4.0 mm inner diam. piece of glass tubing and contained 50 mg of Super-Q® (Alltech Assoc.) as the adsorbent. Two stainless steel frits were used to contain the adsorbent. The collector traps were connected to stainless steel tubing by 0.64 cm unions and 0.64 cm inner diam. Teflon® ferrules. These traps were cleaned by soxhlet extraction with methylene chloride for 24 h and dried in a fume hood prior to use. Volatiles from the lures collected on the traps were eluted using 100 μl of high purity methylene chloride. Tetradecane was added as internal standard prior to analysis. Release rates were determined from three lures on days 1, 3, 5, 7 and 14. The lures were held in a hood without airflow between analyses.

Gas chromatographic analyses were conducted with a Hewlett-Packard Model 5890A Series II gas chromatograph equipped with a cool on-column capillary injector (septum injector) and flame ionization detector. Helium was used as the carrier gas at a linear flow of 18 cm s^{-1}. A combination of three fused silica columns connected in series by GlasSeal® connectors (Supelco Inc.) was used. A deactivated fused silica column, 8.0 cm long by 0.5 mm inner diam., was connected between the injector and the retention gap column. This column permitted the use of 0.4 mm outer diam. stainless steel needles with a septum injector for on-column injections. The retention gap column used were 10 m by 0.25 mm inner diam. deactivated fused silica and the analytical column used for analysis was a 30 m by 0.25 mm inner diam. (0.25 μm film) SE-30.

Statistics. For each experiment, moth numbers per night were compared across treatments using a split block analysis of variance (ANOVA), where treatment was the main plot and date was the subplot (Steel & Torrie, 1980). To satisfy ANOVA assumptions, counts were square root $(x + 0.5)$ transformed before analysis. Treatment means or treatment combinations were separated using a LSD mean separation test or orthogonal comparisons (PROC GLM, CONTRAST statement, SAS Institute, 1996). Untransformed means (± s.e.) are given in text and figures, whereas statistical results refer to transformed data.

Results

Floral volatiles. Traps baited with phenylacetaldehyde, the blend, and benzyl acetate collected more *P. includens* moths per night than traps baited with benzaldehyde or unbaited traps (males: $F = 41.6$; d.f. = 4, 64; $P < 0.0001$; females: $F = 5.4$; d.f. = 4, 64; $P = 0.0206$) (Table 1). Most female moths collected were mated. Of the 1479 moths collected, 1001 (67.7%) were females. Peak capture of *P. includens* occurred in mid-September, when > 90 male and female moths per night were collected in the phenylacetaldehyde-, blend-, and benzyl acetate-baited traps (Figure 1).

Release substrates. Higher release rates were achieved when phenylacetaldehyde was placed as a wax cube in baskets (mean μg h^{-1} over 14 days: 20% cube in basket 735.6 ± 58.7, 5% cube in basket 671.5 ± 50.6) compared to the stopper (469.7 ± 15.8). The lowest release rates occurred when phenylacetaldehyde was placed in wax in stoppers (20% wax in stopper 92.4 ± 3.9, 5% wax in stopper 68.3 ± 1.8). Release from all substrates remained relatively constant over the 14-day recording period (data not shown).

Different moth species were collected during different times of the season. *Anticarsia gemmatalis* and *P. includens* were collected during July and August, whereas the cutworm *Agrotis subterranea* (F.) was collected mostly in May and June (Figure 2). Peak capture of *A. gemmatalis* males was during mid-August, when almost 30 moths per night were collected. Analysis of variance showed differences among lures with both male ($F = 3.1$; d.f. = 5, 10; $P = 0.0612$) and female moths ($F = 3.6$; d.f. = 5, 10; $P = 0.0415$). Treatment contrasts showed that more moths were collected in traps baited with 5% phenylacetaldehyde wax cube in basket than the other traps (males: $F = 9.7$; d.f. = 1, 10; $P = 0.011$; female: $F = 15.3$; d.f. = 1, 10; $P = 0.0029$). For *P. includens*, significant differences among lures were found (males: $F = 7.1$; d.f. = 5, 10; $P = 0.0045$; females: $F = 6.2$; d.f. = 5, 10; $P = 0.0072$). Both sexes were collected in higher numbers in traps baited with phenylacetaldehyde released from stoppers (males: $F = 30.2$; d.f. = 1, 10; $P = 0.0003$; female: $F = 28.3$; d.f. = 1, 10; $P = 0.0003$). *Agrotis subterranea* was found in relatively lower numbers than the other two species, but differences among lures were still found (males: $F = 16.0$; d.f. = 5, 10; $P = 0.0002$; female: $F = 16.4$; d.f. = 5, 10; $P = 0.0002$). As with *P. includens*, both sexes of *A. subterranea* were collected in higher numbers in traps baited with phenylacetaldehyde released from stoppers (males: $F = 56.9$; d.f. = 1, 10; $P < 0.0001$; female: $F = 64.1$; d.f. = 1, 10; $P < 0.0001$). Other male and female moths of species in six noctuid subfamilies were collected in traps baited with phenylacetaldehyde released from stoppers (Table 2).

Aculeate Hymenoptera were collected in large numbers. Taxa with the most individuals collected included the bees *Apis mellifera* L. (186) and *Agapostemon splendens* (Lepeletier) (96), the scoliid *Campsomeris plumipes fossulana* (F.) (166), the sphecids *Larra bicolor* F. (63) and *Ammophila* spp. (101), and the vespid *Polistes* spp. (78). Differences among treatments were found with the Apoidea ($F = 9.4$; d.f. = 5, 225; $P = 0.0015$) and Scolioidea ($F = 3.8$; d.f. = 5, 225; $P = 0.0339$). Traps baited with phenylacetaldehyde delivered from stoppers collected large numbers of wasps (Figure 3).

Discussion

The floral volatiles experiment suggested that both phenylacetaldehyde and benzyl acetate were active materials that attracted *P. includens* moths. Research conducted using large screen cage traps placed next to field sites and baited with phenylacetaldehyde collected various species of Plusiinae, including *P. in-*

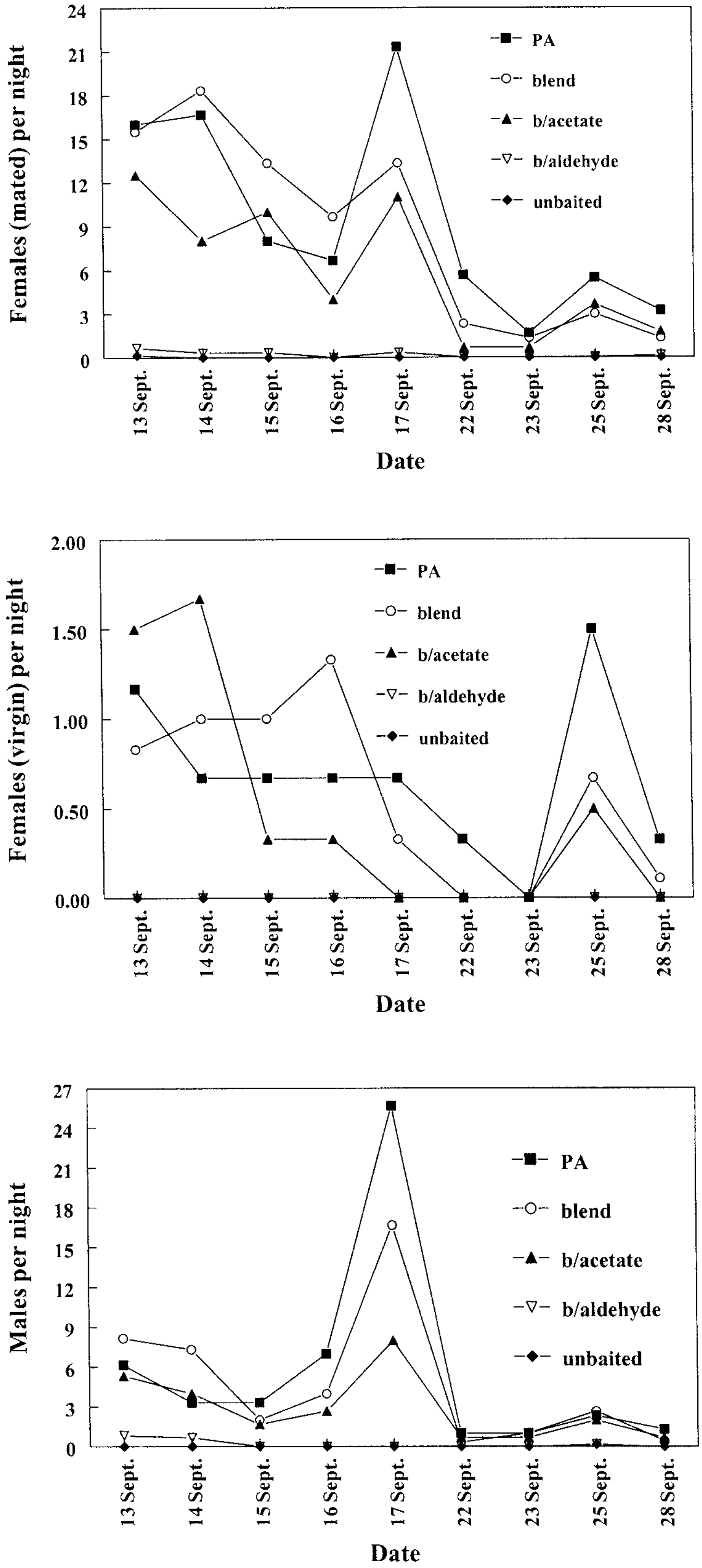

Figure 1. Collection of male and female *P. includens* in 'Unitraps' baited with phenylacetaldehyde (PA), benzyl acetate (b/acetate), benzaldehyde (b/aldehyde), or a blend of these chemicals, Alachua County, Florida, USA, 1998.

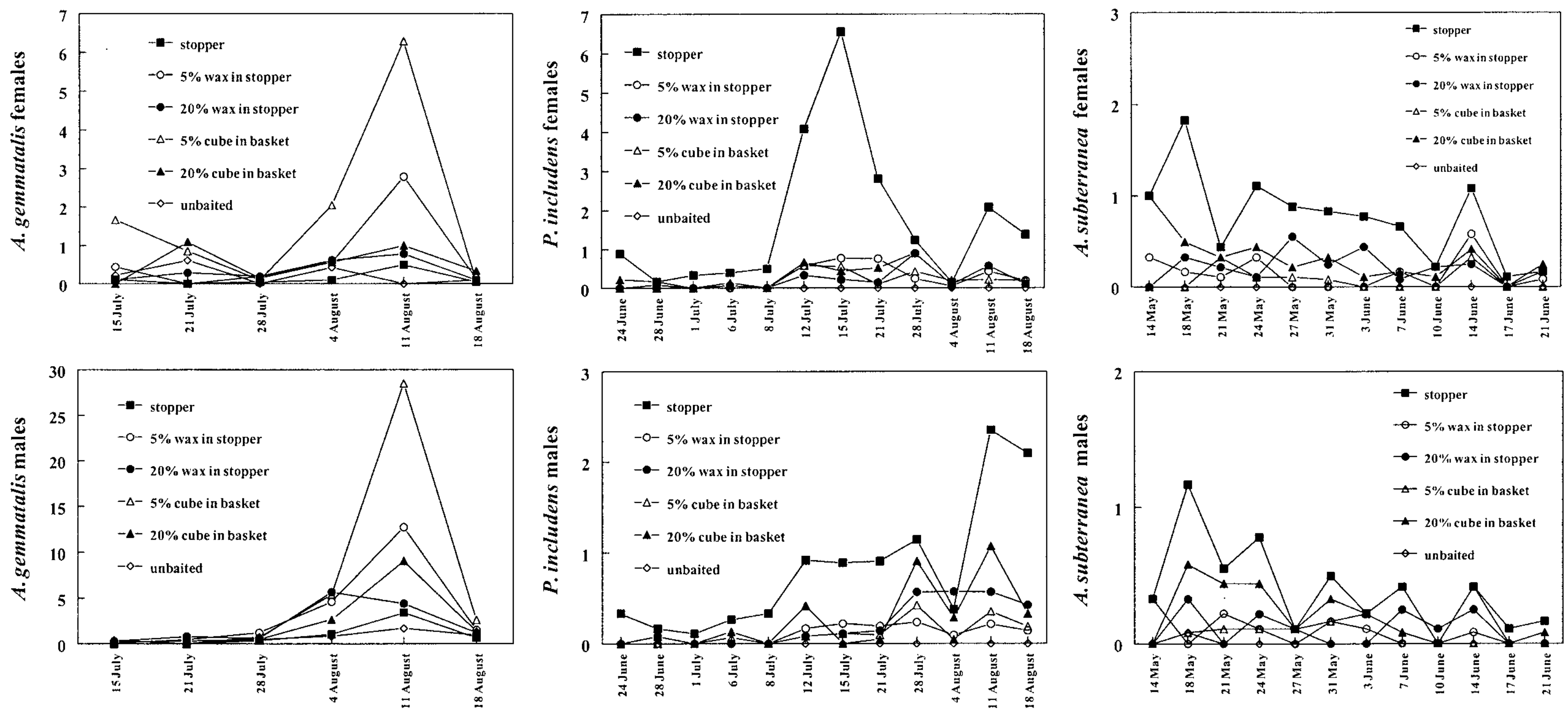

Figure 2. Collection of *A. gemmatalis*, *P. includens*, and *A. subterranea* adults per night in 'Unitraps' baited with phenylacetaldehyde released from plastic stoppers, wax cubes in plastic baskets, or wax in stoppers, Levy County, Florida, USA, 1999.

Table 1. Number of *P. includens* moths per night and total number collected in 'Unitraps' baited with different floral volatiles, September, 1998, Alachua, FL

Lure	Moths per night ± s.e. (number collected)		
	Females (mated)	Females (virgin)	Males
Phenylacetaldehyde	9.4 ± 2.1a (362)	0.7 ± 0.2a (30)	5.7 ± 1.9a (199)
'Blend'[a]	8.7 ± 1.8a (338)	0.6 ± 0.2a (29)	4.7 ± 1.1a (167)
Benzyl acetate	5.8 ± 1.7ab (215)	0.5 ± 0.2a (19)	2.9 ± 0.9a (103)
Benzaldehyde	0.2 ± 0.1bc (7)	0.0 ± 0.0b (0)	0.2 ± 0.1b (8)
Unbaited	0.02 ± 0.02c (1)	0.0 ± 0.0b (0)	0.02 ± 0.02b (1)

[a]Composed of 155.4 mg benzaldehyde, 47.4 mg phenylacetaldehyde, and 51.6 mg benzyl acetate.

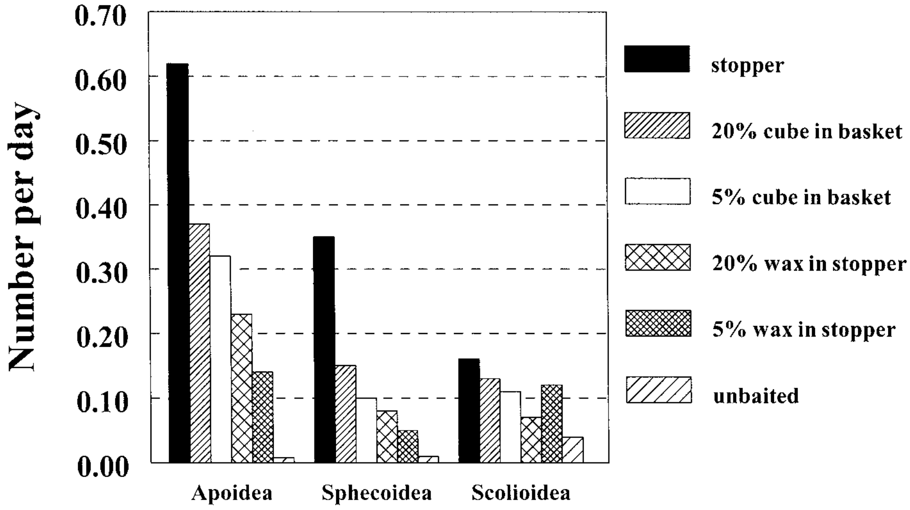

Figure 3. Number of Hymenoptera captured per day in 'Unitraps' baited with phenylacetaldehyde released from plastic stoppers, wax cubes in plastic baskets, or wax in stoppers, Levy County, Florida, USA, 1999. More Apoidea were collected in traps baited with phenylacetaldehyde in stoppers than the other substrates ($P < 0.05$).

cludens, *Trichoplusia ni* (Hübner), *Argyrogramma verruca* (F.), and *Agrapha oxygramma* (Geyer) (Smith et al., 1943; Creighton et al., 1973). Results from this and a previous study (Meagher, 2001b) showed that a variety of noctuid species could be collected in 'Unitraps' baited with phenylacetaldehyde.

The release substrate experiment was successful in providing a tenfold range of phenylacetaldehyde release rates ($\approx 65\ \mu g\ h^{-1}$–$735\ \mu g\ h^{-1}$). The release rate from stoppers found in this study ($469.7\ \mu g\ h^{-1}$) compares to what was found in a previous study ($492.9\ \mu g\ h^{-1}$) (Meagher, 2001a). Flowers release phenylacetaldehyde in blends with other volatile chemicals. Analysis of chemicals emitted by *C. nocturnum* plants suggested that a blend of benzaldehyde, phenylacetaldehyde, and benzyl acetate were released at $\approx 4\ \mu g$ per flower per hour, but that a large shrub probably releases in milligram amounts per hour (Heath et al., 1992). Another night-blooming plant, *Gaura drummondii* (Spach) Torrey & Gray, released phenylacetaldehyde at 200–300 ng $bloom^{-1}$ (Shaver et al., 1997). *Trichoplusia ni* moths responded to release rates between 20 ng h^{-1}–4 $\mu g\ h^{-1}$ in flight tunnel and small cage bioassays (Landolt et al., 1991; Heath et al., 1992). Release rates of phenylacetaldehyde from this field study are higher than rates from individual blooms, and probably correspond to what would be released from many flowers or small shrubs.

Although *P. includens* captures were highest in stopper-baited traps, *A. gemmatalis* appeared to respond more towards basket- or wax-baited traps. The lures in these traps contained both high and low phenylacetaldehyde release rates, therefore there may be an unknown factor involved in attraction of *A. gemmatalis* to traps baited with those lures.

Table 2. Number of noctuid moths collected in 'Unitraps' baited with phenylacetaldehyde delivered in stoppers, and total numbers collected in all baited 'Unitraps', 5 May – 18 August, 1999, Levy Co., FL

Subfamily/species	Stoppers		Baited traps	
	Females	Males	Females	Males
Amphipyrinae				
Spodoptera frugiperda (J. E. Smith)	2	4	7	12
Spodoptera spp.[a]	27	9	87	21
Catocalinae				
Anticarsia gemmatalis Hübner	13	95	327	1534
Mocis spp.[b]	13	7	30	10
Hadeninae				
Leucania sp.	2	0	5	3
Heliothinae				
Helicoverpa zea (Boddie)	26	43	43	84
Heliothis subflexa Guenée	3	7	5	14
H. virescens (F.)	2	8	3	13
Noctuinae				
Agrotis subterranea (F.)	100	53	198	136
Anicla infecta (Ochsenheimer)	3	4	5	7
Plusiinae				
Agrapha oxygramma (Geyer)	10	4	21	14
Argyrogramma verruca (F.)	58	38	115	93
Pseudoplusia includens (Walker)	280	160	464	312
Totals	539	432	1310	2253

[a]*S. eridania* (Cramer), *S. dolichos* (F.) and *S. latifascia* (Walker).
[b]*M. disseverans* (Walker), *M. latipes* (Guenée), and *M. marcida* (Guenée).

One appeal of using floral volatile-baited traps is the ability to collect female moths. Sex ratios varied widely with species collected, ranging from low female-biased percentages for *A. gemmatalis* (17.6%) and *H. zea* (33.9%), to equivalent percentages for *A. verruca* (55.3%), *A. subterranea* (59.3%), and *P. includens* (59.8%), to highly female-biased percentages for *Spodoptera* spp. (80.6%). It is unknown why female and male moths across species responded differently to these lures, although feeding behavior and adult movement are factors.

Sex pheromones are commercially available for most of the species collected, but they attract and capture only males. Other than light traps (Graham et al., 1964) or sugar-based lures (Landolt, 1995), few trapping systems have been developed to capture female moths in field crop systems. The proposed trapping system of phenylacetaldehyde loaded into stoppers as a lure and 'Unitraps' as a collector, appears to offer an easy, efficient technique to collect noctuid females. Trapping of female moths could be used to interfere with their host plant location, lure moths away from host plants, control populations through mass trapping (Gabel et al., 1992), improve monitoring systems by correlating adult and larval populations (Chowdhury et al., 1987), or combine floral lures with toxicants to make attracticides (Beerwinkle et al., 1993; Lingren et al., 1988). Results from the 1998 study showed that more mated females were collected than virgin females. It is not known what influence this result may have on future population monitoring or pest control research.

One potential negative result of using floral lure-baited traps is the collection of nontarget Hymenoptera. Two previous studies showed that species within Sphecoidea were collected in higher numbers in traps baited with phenylacetaldehyde than traps baited with *S. frugiperda* sex pheromone or unbaited traps (Meagher & Mitchell, 1999; Meagher, 2001a). The ecological significance of removal of these beneficials is not known, but it may be of value to study their interactions within field crop agroecosystems. Efforts should be made to develop traps and lures that are not attractive or that do not easily capture aculeate Hymenoptera, but consistently capture the target pest.

Acknowledgements

Release rate determination of the phenylacetaldehyde was conducted by B. Dueben (USDA-ARS). Technical support was provided by J. Brady, C. Dillard, C. Leander and J. Wright. N. D. Epsky (USDA-ARS), G. Leibee (University of Florida), D. L. Johanowicz (University of Florida), and J. Sivinski (USDA-ARS) provided helpful reviews of an earlier manuscript. The use of trade, firm, or corporation names in this publication is for the information and convenience of the reader. Such use does not constitute an official endorsement of approval by the United States Department of Agriculture or the Agricultural Research Service of any product or service to the exclusion of others that may be suitable.

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