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Attractiveness of binary blends of floral odorant compounds to moths in Florida, USA

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Abstract

Evaluation of combinations of flower odor compounds in the field revealed several compounds that were attractive or co-attractive with phenylacetaldehyde (PAA) to pest noctuid and pyralid moths. A number of moth species responded positively to the key floral odorant PAA. The floral odorants *cis*-jasmone, linalool, benzyl acetate, limonene, β-myrcene, methyl salicylate, and methyl 2-methoxybenzoate all increased captures of some moths when added to traps with PAA, but responses varied among the moth species that were trapped. For example, soybean looper moths, *Pseudoplusia includens* (Walker) (Lepidoptera: Noctuidae), most strongly responded to PAA + β-myrcene, but benzyl acetate, *cis*-jasmone, and limonene also increased captures of these moths when these compounds were used in traps along with PAA. Velvetbean caterpillar moths, *Anticarsia gemmatalis* Hübner (Lepidoptera: Noctuidae), responded most strongly to PAA + linalool, but β-myrcene, *cis*-jasmone, and limonene also increased captures of these moths in traps over numbers trapped with PAA. Positive responses to floral compound blends were also noted for golden looper [*Argyrogramma verruca* (F.)], grass looper [*Mocis disseverans* (Walker)], tobacco budworm [*Heliothis virescens* (F.)], southern armyworm [*Spodoptera eridania* (Stoll) (all Lepidoptera: Noctuidae)], and melonworm [*Diaphania hyalinata* (L.) (Lepidoptera: Pyralidae)]. Overall, PAA + β-myrcene appeared to be the strongest floral compound combination for pest species trapped, compared to PAA or other compound blends.

Introduction

Some species of moths are attracted to odors emitted by flowers (Haynes et al., 1991; Heath et al., 1992a; Plepys, 2001; Plepys et al., 2002; Landolt & Smithhisler, 2003; Huber et al., 2005; Dötterl et al., 2006) and probably feed on floral nectar. Volatile compounds that are emitted by some moth-visited flowers have been characterized (Knudsen et al., 2006), providing a list of putative attractants. These studies include the major floral odorants of *Abelia grandiflora* (André) Rehd. (Haynes et al., 1991), night-blooming jessamine [*Cestrum nocturnum* L. (Heath et al., 1992a)], three species of *Gaura* (Teranishi et al., 1991; Kint et al., 1993; Shaver et al., 1997), Japanese honeysuckle [*Lonicera japonica* Thunberg (Schlotzhauer et al., 1996)], *Platanthera bifolia* L. (Rich.) (Plepys, 2001), Oregon grape [*Mahonia* (= *Berberis*) *aquifolium* (Pursh) (Landolt & Smithhisler, 2003)], the orchid species *Gymnadenia conopsea* (L.) R.Br. and *Gymnadenia odoratissima* (L.) Rich. (Huber et al., 2005), and *Silene latifolia* Poiret (Dötterl et al., 2006). These floral odor blends are generally complex, with multiple compounds present.

Evidence to date indicates that species of moths that visit flowers for nectar can respond to single compounds or simple blends that may be part of much more complex aroma bouquets. Phenylacetaldehyde (PAA) is a key floral odorant important to moth attraction to flowers. Cantelo & Jacobson (1979) identified PAA as a major volatile of flowers of the bladder flower, *Araujia sericofera* Brotero, and showed that this compound increased blacklight trap capture of pest moth species by 48%. Haynes et al. (1991) demonstrated cabbage looper moth, *Trichoplusia ni* (Hübner) (Lepidoptera: Noctuidae), attraction to PAA, benzaldehyde, benzyl alcohol, and 2-phenylethanol

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emitted by *A. grandiflora* flowers, and Heath et al. (1992a) demonstrated cabbage looper moth attraction to PAA and to benzyl acetate emitted by flowers of night-blooming jessamine. Pair & Horvat (1997) demonstrated moth attraction to a blend of *cis*-jasmone, linalool, and PAA from flowers of Japanese honeysuckle, out of a list of 27 compounds provided that were isolated and identified from those flowers by Schlotzhauer et al. (1996). Lopez et al. (2000) reported moth attraction to a blend of PAA, 2-phenylethanol, limonene, methyl-2-methoxybenzoate, and methyl salicylate from flowers of *Gaura* species, out of 12 compounds reported from *Gaura drummondii* flowers by Teranishi et al. (1991) and 23 compounds from flowers of *Gaura suffulta* (Kint et al., 1993). Lilac aldehyde isomers have been found to be highly attractive to the noctuid moths *Autographa gamma* L. (Plepys et al., 2002) and *Hadena bicruris* (Hufnagel) (Dötterl et al., 2006).

Field testing of PAA, benzyl acetate, and β-myrcene in Washington State (USA) revealed the attractiveness of a small number of compounds to cabbage looper and alfalfa looper, *Autographa californica* (Speyer), moths when the compounds were tested individually (Landolt et al., 2001, 2006). In addition, several compounds improved the capture of moths when presented in traps as part of blends with otherwise attractive compounds (i.e., they were co-attractive). Of particular interest were demonstrations that β-myrcene, although weakly attractive or unattractive when presented alone, enhanced cabbage looper and alfalfa looper moth response to PAA. Most other compounds tested had little or no effect on captures of these moths in traps.

In Florida, PAA is a strong attractant for several noctuid moths from different subfamilies, but particularly for soybean looper moths, *Pseudoplusia includens* (Walker) (Meagher, 2001, 2002). We report here additional studies in Florida (USA) that evaluate responses of primarily pest moth species to PAA and to a series of two-component blends of floral odorant compounds that include PAA. These compounds were selected based on their prior isolation from the odors of moth-visited flowers, and demonstrated or hypothesized roles in moth orientation to flowers for nectar (Haynes et al., 1991; Heath et al., 1992a; Pair & Horvat, 1997; Lopez et al., 2000). Our hypothesis was that some compounds from moth-visited plants will enhance response of soybean looper moths to PAA, as was found with cabbage and alfalfa looper. We also hypothesized that a greater diversity of pest moths would be collected in Florida compared with Washington. Results of these experiments demonstrate the importance of many of these compounds as co-attractants with PAA, and indicate possible differences or preferences for floral odor blends among the moth species captured in traps. Additionally, our results suggest potential lures that might be used in the management of several highly pestiferous species of moths.

Materials and methods

The experiments evaluated compounds as attractants by their performance as lures in traps. Standard Universal Moth Traps, 'Unitraps' (Great Lakes IPM, Vestaburg, MI, USA), were used to capture attracted moths. These traps are constructed of a white bucket, a yellow cone on top of the bucket, and a dark green cover above the cone. A 2.5×2.5 cm piece of Vaportape (Hercon Environmental, Emigsville, PA, USA), releasing the pesticide dichlorvos, was stapled to a string and hung inside the bucket to kill captured moths. Lures were suspended by a wire inside the bucket of the trap. All compounds tested were dispensed from 8-ml polypropylene bottles (Nalg Nunc, Rochester, NY, USA), each with a 3-mm hole in the lid. Five ml of active ingredient was added to cotton balls in the bottom of the bottle. When two compounds were tested in a single trap, each compound was dispensed from a separate bottle. Phenylacetaldehyde (90%), β-myrcene (90%), methyl salicylate (99%), methyl 2-methoxybenzoate (99%), benzyl acetate (99%), *cis*-jasmone (85%), linalool (97%), benzaldehyde (98%), benzyl alcohol (98%), and 2-phenylethanol (99%) were purchased from Aldrich (Milwaukee, WI, USA). (*R*)-(+)-Limonene (97%) was purchased from Acros Chemical (Milwaukee, WI, USA).

Traps were placed on 1.5-m metal poles along roads and edges of 400-ha fields of peanuts (*Arachis hypogaea* L.) near Williston, FL, USA (Levy County; 29°20.5′N, 82°34.2′W). Traps were placed at least 30 m apart, and treatment order was randomized at each sample date. A randomized complete block experimental design was used, with five replicate blocks for each experiment. Lures were replaced every 2 weeks, and Vaportape was replaced every 4 weeks.

A trapping test was set up on 1 August 2005 that evaluated eight floral odor treatments. These treatments were: (i) no lure as a control, (ii) PAA, (iii) PAA + *cis*-jasmone, (iv) PAA + linalool, (v) PAA + benzaldehyde, (vi) PAA + methyl salicylate, (vii) PAA + methyl 2-methoxybenzoate, and (viii) PAA + β-myrcene. Traps were checked and insects removed on 3, 5, 8, 10, 12, 15, 18, and 24 August, and on 2 and 7 September 2005. A second trapping test was set up on 1 August 2006 that evaluated seven treatments: (i) no lure as a control, (ii) PAA, (iii) PAA + β-myrcene, (iv) PAA + benzyl acetate, (v) PAA + benzyl alcohol, (vi) PAA + limonene, and (vii) PAA + 2-phenyl ethanol. Traps were checked and insects removed on 4, 8, 11, 15, 21, 25, and 29 August, and on 15 and 25 September 2006.

Moths captured were identified to species (Kimball, 1965; Covell, 2005), and then sorted by sex. Voucher specimens are deposited in the Florida State Collection of Arthropods, Florida Department of Agriculture and Consumer Services, Division of Plant Industry, Gainesville, FL, USA. Trap catch data for each species and sex were subjected to an analysis of variance (ANOVA; PROC Mixed, SAS 9.1), where block, date (block), and block*treatment were random variables (Littell et al., 1996). If the treatment variable produced a significant F-value, treatment means were separated using simple effect differences of the least square means. Sex ratios were analyzed to determine if they were significantly different from 1.0 using a χ^2 test (GraphPad Software, San Diego, CA, USA).

Results

Trap catches in 2005

Large numbers of seven noctuid and one pyralid pest moth species were collected in traps baited with floral odors, providing data suitable for statistical comparisons of treatments. These were soybean looper (3 964) and golden looper [*Argyrogramma verruca* (F.) 1 376 (Plusiinae)], velvetbean caterpillar [*Anticarsia gemmatalis* Hübner (3884)], *Mocis latipes* (Guenée) (675), and *Mocis disseverans* (Walker) (596) (Catocalinae), tobacco budworm [*Heliothis virescens* (F.) (426) (Heliothinae)], southern armyworm [*Spodoptera eridania* (Stoll) (411) (Amphipyrinae)], and melonworm [*Diaphania hyalinata* (L.) (457) (Pyralidae)]. Smaller numbers (<100) of several other pest moth species were captured, including corn earworm [*Helicoverpa zea* (Boddie)], *Mocis marcida* (Guenée), and fall armyworm, *Spodoptera frugiperda* (J.E. Smith).

Four species, golden looper, *M. latipes*, *M. disseverans*, and southern armyworm, had higher numbers in PAA-baited traps than the unbaited traps (Table 1). All other treatments contained binary blends with PAA and showed evidence of increased attraction. β-Myrcene, *cis*-jasmone, linalool, methyl salicylate, and methyl 2-methoxybenzoate in combination with PAA captured more moths than PAA-baited traps. As expected, β-myrcene and *cis*-jasmone were strong co-attractants with PAA for soybean loopers, increasing trap catch by 5-fold and 3-fold, respectively. β-Myrcene was also a co-attractant for velvetbean caterpillar, tobacco budworm, southern armyworm, and melonworm. *Cis*-jasmone increased numbers of golden looper, tobacco budworm, southern armyworm, and melonworm when added to PAA.

Linalool was a strong co-attractant for velvetbean caterpillar, with an average of 41.8 moths per trap per week captured (total 2 091). Surprisingly, 62 velvetbean caterpillars were captured in the unbaited traps. Linalool also was a co-attractant for *M. disseverans* and melonworm. Methyl salicylate was a co-attractant for southern armyworm and melonworm, and methyl 2-methoxybenzoate was a co-attractant for *M. disseverans*, tobacco budworm, southern armyworm, and melonworm. Benzaldehyde did not add to the attractiveness of PAA for any of the moth species captured in 2005.

Trap catches in 2006

Large numbers of many of the same pest moth species were trapped again in 2006, particularly soybean looper (3 953), golden looper (691), velvetbean caterpillar (5 205), *M. disseverans* (175), and tobacco budworm (262). Fewer *M. latipes* (93), southern armyworm (76), and melonworm (90) were captured so results are not reported; however,

Table 1 Mean (± SE) numbers of pest moths captured in universal moth traps (n = 50) baited with floral compounds dispensed from polypropylene bottles, 2005, Williston, FL, USA. Moth species are soybean looper (SBL), golden looper (GL), velvetbean caterpillar (VBC), *Mocis latipes* (ML), *Mocis disseverans* (MD), tobacco budworm (TBW), southern armyworm (SAW), and melonworm (MW). Compounds tested are phenylacetaldehyde (PAA), *cis*-jasmone (CJ), linalool (LIN), benzaldehyde (BALD), methyl salicylate (MS), methyl 2-methoxybenzoate (M2MB), and β-myrcene (MYR)

Compound	SBL	GL	VBC	ML	MD	TBW	SAW	MW
Unbaited	0.0 ± 0.0d	0.06 ± 0.03d	1.3 ± 0.2c	0.0 ± 0.0b	0.02 ± 0.02d	0.0 ± 0.0e	0.02 ± 0.02d	0.0 ± 0.0d
PAA	5.1 ± 1.3cd	3.5 ± 0.5bc	3.6 ± 0.9c	1.4 ± 0.4a	1.3 ± 0.2c	0.4 ± 0.1cde	0.8 ± 0.2bc	0.5 ± 0.2cd
PAA + CJ	18.0 ± 4.4b	5.7 ± 0.9a	5.8 ± 1.6bc	1.9 ± 0.5a	1.2 ± 0.2c	1.5 ± 0.4b	1.4 ± 0.2a	1.8 ± 0.6ab
PAA + LIN	8.1 ± 1.9c	3.7 ± 0.6bc	41.8 ± 7.0a	2.5 ± 0.5a	2.4 ± 0.5a	1.1 ± 0.3bcd	0.6 ± 0.1c	1.3 ± 0.5ab
PAA + BALD	5.4 ± 1.8c	3.1 ± 0.6bc	4.0 ± 1.0c	1.9 ± 0.5a	1.7 ± 0.4bc	0.3 ± 0.1de	1.1 ± 0.2bc	0.8 ± 0.3bc
PAA + MS	9.0 ± 1.9c	4.2 ± 0.8abc	5.0 ± 1.0c	1.3 ± 0.4a	1.8 ± 0.4abc	1.2 ± 0.4bc	1.5 ± 0.3a	1.6 ± 0.5ab
PAA + M2MB	8.1 ± 1.6c	2.9 ± 0.8c	6.0 ± 1.3bc	2.2 ± 0.6a	2.1 ± 0.4ab	1.4 ± 0.4b	1.4 ± 0.3a	1.4 ± 0.4ab
PAA + MYR	26.3 ± 4.9a	4.6 ± 0.8ab	11.8 ± 2.3b	2.4 ± 0.5a	1.5 ± 0.3bc	2.6 ± 0.6a	1.5 ± 0.2a	1.9 ± 0.4a

Means within a column followed by the same letter are not significantly different (P>0.05; Contrasts, PROC Mixed).

Table 2 Mean (±SE) numbers of pest moths captured in universal moth traps (n = 45) baited with floral compounds dispensed from polypropylene bottles, 2006, Williston, FL, USA. Moth species are soybean looper (SBL), golden looper (GL), velvetbean caterpillar (VBC), *Mocis disseverans* (MD), tobacco budworm (TBW), and corn earworm (CEW). Compounds tested were phenylacetaldehyde (PAA), benzyl acetate (BAC), benzyl alcohol (BOH), limonene (LIM), 2-phenylethanol (2PE), and β-myrcene (MYR)

Compound	SBL	GL	VBC	MD	TBW	CEW
Unbaited	0.1 ± 0.07d	0.0 ± 0.0d	5.1 ± 1.2b	0.02 ± 0.02b	0.0 ± 0.0b	0.8 ± 0.1b
PAA	6.6 ± 1.0c	2.3 ± 0.3bc	7.0 ± 1.7b	0.7 ± 0.1a	0.4 ± 0.1b	0.24 ± 0.1bc
PAA + BAC	17.9 ± 2.3b	2.2 ± 0.3bc	6.2 ± 1.7b	0.6 ± 0.2a	0.8 ± 0.1b	0.78 ± 0.1ab
PAA + BOH	5.8 ± 1.1c	2.1 ± 0.4bc	14.7 ± 6.0b	0.7 ± 0.2a	0.5 ± 0.1b	0.14 ± 0.05c
PAA + LIM	13.4 ± 2.3b	1.6 ± 0.2c	37.9 ± 12.7a	0.8 ± 0.2a	0.9 ± 0.2b	0.32 ± 0.1bc
PAA + 2-PE	6.6 ± 0.9c	2.9 ± 0.5b	14.0 ± 0.6b	0.4 ± 0.1ab	0.4 ± 0.1b	0.33 ± 0.1bc
PAA + MYR	37.9 ± 4.0a	4.3 ± 0.7a	36.8 ± 10.6a	0.7 ± 0.1a	2.8 ± 0.6a	1.24 ± 0.3a

Means within a column followed by the same letter are not significantly different (P>0.05; Contrasts, PROC Mixed).

corn earworm (137) numbers were large enough to provide significant comparisons among treatments.

Three species, soybean looper, golden looper, and *M. disseverans* had higher numbers in PAA-baited traps than the unbaited traps (Table 2). β-Myrcene, benzyl acetate, and limonene in combination with PAA captured more moths than PAA-baited traps, whereas benzyl alcohol and 2-phenylethanol did not add to the attractiveness of PAA for any of the moth species captured in 2006. β-Myrcene was again a strong co-attractant for the soybean looper, increasing numbers in traps by more than 5-fold. Golden looper, velvetbean caterpillar, tobacco budworm, and corn earworm also responded well to the combination of β-myrcene added with PAA. Benzyl acetate was only a co-attractant for soybean looper and limonene was a co-attractant for soybean looper and velvetbean caterpillar.

Moth numbers across both years showed that soybean looper and velvetbean caterpillar were the most abundant pest species collected, being present in at least 13.2 and 15.6%, and as high as 60.5 and 68.0%, respectively, of all of the important floral lure combinations tested (Table 3). Golden looper moths comprised as high as 21.1% of the moths in the PAA collections in 2005. All other moth species comprised less than 10% of the collections.

Table 3 Percentage of selected pest species captured in universal moth traps baited with floral compounds dispensed from polypropylene bottles, 2005 and 2006, Williston, FL, USA. Moth species are soybean looper (SBL), golden looper (GL), velvetbean caterpillar (VBC), *Mocis disseverans* (MD), tobacco budworm (TBW), southern armyworm (SAW), and melonworm (MW). Compounds tested were phenylacetaldehyde (PAA), benzyl acetate (BAC), *cis*-jasmone (CJ), limonene (LIM), linalool (LIN), methyl 2-methoxybenzoate (M2MB), methyl salicylate (MS), and β-myrcene (MYR)

Compound	SBL	GL	VBC	MD	TBW	SAW	MW
PAA-2005	30.7	21.1	21.7	7.8	2.4	4.8	3.0
PAA-2006	37.4	13.0	39.7	4.0	2.3	0.2	0.7
PAA + BAC	60.5	7.4	21.0	2.0	2.7	1.4	1.2
PAA + CJ	48.6	15.3	15.6	3.2	4.0	3.8	4.8
PAA + LIM	23.9	2.9	67.6	1.4	1.6	0.5	0.9
PAA + LIN	13.2	6.0	68.0	3.9	1.8	1.0	2.1
PAA + M2MB	31.8	11.4	23.5	8.2	5.5	5.5	5.5
PAA + MS	35.2	16.4	19.5	7.0	4.7	5.9	6.3
PAA + MYR-2005	50.0	8.8	22.4	2.9	4.9	2.9	3.6
PAA + MYR-2006	44.6	5.1	43.3	0.8	3.3	0.6	0.4

Sex ratio

The numbers of male and female moths captured in floral lure traps were determined for moth species-floral lure combinations that were present in both years (Table 4). Soybean looper generally had a neutral sex ratio, especially when attracted in large numbers to PAA + β-myrcene. Velvetbean caterpillar males were collected in larger numbers than females in every floral lure tested; the opposite was true for *M. disseverans*, which was always female biased.

Discussion

This study provided new information on the attraction responses of several species of pest moths to compounds emitted by flowers. These responses were to PAA and to other compounds that were attractive or co-attractive when presented with PAA. The soybean looper, golden looper, grass loopers, and southern armyworm were all trapped with PAA in both years, indicating attraction to this compound. Prior studies have shown attractiveness of several moth species to PAA, including cabbage looper, alfalfa looper, soybean looper, velvetbean caterpillar, and corn earworm (Cantelo & Jacobson, 1979; Beerwinkle

Table 4 Sex ratio (number of males/number of females) of pest moths captured in universal moth traps baited with floral compounds dispensed from polypropylene bottles, 2005 and 2006, Williston, FL, USA. Moth species are soybean looper (SBL), golden looper (GL), velvetbean caterpillar (VBC), *Mocis disseverans* (MD), and tobacco budworm (TBW). Compounds tested were phenylacetaldehyde (PAA), benzyl acetate (BAC), *cis*-jasmone (CJ), limonene (LIM), linalool (LIN), methyl 2-methoxybenzoate (M2MB), methyl salicylate (MS), and β-myrcene (MYR)

Compound	SBL	GL	VBC	MD	TBW
PAA-2005	0.506[1]	1.047	2.400[1]	0.208[1]	1.500
PAA-2006	0.954	2.219[1]	4.466[1]	0.154[1]	0.900
PAA + BAC	1.235[1]	1.564[1]	3.072[1]	0.217[1]	2.000[1]
PAA + CJ	0.925	1.058	1.694[1]	0.245[1]	1.026
PAA + LIM	1.198[1]	2.000[1]	3.901[1]	0.700	1.563
PAA + LIN	0.762[1]	1.346[1]	2.681[1]	0.326[1]	1.455
PAA + M2MB	1.015	1.300	1.626[1]	0.170[1]	1.667[1]
PAA + MS	1.047	1.081	1.714[1]	0.156[1]	1.320
PAA + MYR-2005	1.056	0.957	2.253[1]	0.316[1]	1.844[1]
PAA + MYR-2006	1.160	1.553[1]	3.724[1]	0.375[1]	1.646[1]

[1]Sex ratio significantly different from 1.0 (χ^2 test, d.f. = 1, P<0.05).

et al., 1996; Landolt et al., 2001; Meagher, 2001, 2002; Landolt et al., 2006).

Other compounds tested in combination with PAA increased the response of moths to lures in these traps. However, without additional testing in Florida, we do not know if they are individually attractive, or if the response was due to some type of enhancing or synergistic effect of the combination of compounds. β-Myrcene was notable in providing greatly improved captures of seven species of moths when combined with PAA (soybean looper, golden looper, velvetbean caterpillar, tobacco budworm, corn earworm, southern armyworm, and melonworm). This compound was isolated from odors of flowers of Oregon grape, an ornamental and wild shrub in the western USA that is visited by moths, particularly the alfalfa looper (Landolt & Smithhisler, 2003). When presented alone, β-myrcene was a weak attractant for both alfalfa and cabbage loopers (Landolt et al., 2006).

Linalool was notable in providing very large increases when added to PAA in numbers of velvetbean caterpillar moths and grass looper moths. The numbers of these moths captured were somewhat surprising, as Unitraps are usually not considered a good trap for these relatively large species. The trap cone narrows to an opening of 3 cm in diameter, compared to a wingspan of 3.3–4.0 cm for velvetbean caterpillar moths and 3.3–4.3 cm for *M. latipes* (Covell, 2005). Large numbers of velvetbean caterpillar were present in the area in both years, feeding on peanut and on a local annual legume [*Indigofera hirsute* L., Fabaceae)]. Linalool has been found in many species of moth-visited flowers (e.g., Schlotzhauer et al., 1996; Honda et al., 1998; Raguso & Pichersky, 1999; Bruce & Cork, 2001; Knudsen et al., 2006). However, linalool has not been shown to be a strong attractant when delivered as a single lure (Landolt et al., 2001; RL Meagher, unpubl.). It is a component of the male pheromone of the cabbage looper moth (Heath et al., 1992b), and is attractive to cabbage looper males and females (Landolt et al., 2004).

Significant but less pronounced improvements in the capture of some species of moths were seen with the baiting of traps with *cis*-jasmone (soybean looper, golden looper, tobacco budworm, southern armyworm, and melonworm), methyl 2-methoxybenzoate (*M. disseverans*, tobacco budworm, southern armyworm, and melonworm), benzyl acetate (soybean looper), limonene (soybean looper and velvetbean caterpillar), or methyl salicylate (southern armyworm and melonworm) plus PAA, compared to PAA alone. Benzyl acetate is a component of several flower blends, and like *cis*-jasmone, is attractive to Plusiinae moths (Heath et al., 1992a; Landolt et al., 2001; Meagher, 2002). Methyl salicylate and methyl 2-methoxybenzoate have been isolated from *Gaura* spp. flowers (Teranishi et al., 1991; Shaver et al., 1997), and limonene is one of the compounds isolated from Oregon grape (Landolt & Smithhisler, 2003). Benzaldehyde, benzyl alcohol, and 2-phenylethanol did not add to the attractiveness of PAA, which has been shown in other studies with Plusiinae moths (Landolt et al., 2001; Meagher, 2002). In all cases, additional testing will be required to determine the nature of the interactions with these compounds and PAA.

There appeared to be differences or preferences for floral compound combinations among the moths responding in these experiments, in addition to overlaps in those responses. For example, significant responses were seen by southern armyworm and melonworm moths to methyl salicylate plus PAA, but not by other moth species captured in this study. *Cis*-jasmone increased capture of soybean looper, tobacco budworm, southern armyworm, and melonworm moths, but not velvetbean caterpillar or grass looper moths. It is not yet possible to determine if there are response patterns that are related to taxonomic affinities, although there are suggestions of such patterns. For example, linalool was active in this study only for velvetbean caterpillar and grass looper moths, which are related within the subfamily Catocalinae, but not for Plusiinae loopers or armyworm moths (Amphipyrinae). β-Myrcene was a powerful co-attractant for soybean looper, as it is for alfalfa looper (Landolt et al., 2006), another Plusiinae noctuid. β-Myrcene is broadly active but was a moderate co-attractant for golden looper in this study and only weakly co-attractive with PAA for cabbage looper moths (Landolt et al., 2006). Data for many additional species are needed to substantiate or dispute any taxonomic patterns to these lure preferences.

It was interesting that some noctuid moths were not collected in large numbers in floral-baited traps even though moth populations were present in the field. Although fall armyworm and corn earworm moths were collected in pheromone-baited traps (data not shown), only 131 and 209 moths, respectively, were found combined for 2005 and 2006. Perhaps these moths are attracted to other feeding source odors that are not related to flowers. Both species have been found feeding on exudates on florets of *Paspalum* spp. grass flowers (Beerwinkle et al., 1993, RL Meagher, unpubl.).

Many of the moth species collected are economic pests in diverse cropping systems. Velvetbean caterpillar and soybean looper are important defoliators of soybeans and peanuts in the southeastern USA (Herzog & Todd, 1980; Herzog, 1980). *Mocis* spp. larvae are important pests in forage and pasture grasses in the southeastern USA (Meagher & Mislevy, 2005). Tobacco budworm and corn earworm are serious pests in tobacco, cotton, and corn plantings, and southern armyworm is a pest of tomatoes and other vegetables in central and southern Florida (Webb et al., 2006). Melonworm is a foliage pest of curcubits in the southeastern USA (Pena et al., 1987). Subsequent studies with the identified binary blend attractants need to be conducted in the cropping systems where one would expect to find larger populations of the particular species of interest.

The relatively large numbers of soybean looper and velvetbean caterpillar moths captured in traps, particularly those baited with PAA + β-myrcene and PAA + linalool, suggest the possibility of using these attractants in an attract-and-kill strategy to manage moth populations (Landolt et al., 1991). Such an approach was used in an experiment demonstrating possible knockdown of populations of alfalfa looper moths, and prevention of oviposition on host plants in a screenhouse, using pesticide-coated stations baited with a floral odor-based lure (De Camelo et al., 2007). These lures are attractive to both male and female moths, including soybean looper and velvetbean caterpillar, suggesting some potential in removing females from a population before most eggs are laid. However, we do not know what percentage of the population responded to these lures, how old or reproductively active responding females are, and note the strong male bias to velvetbean caterpillar moths captured in traps baited with floral lures in this test. It is difficult to tell if large numbers trapped indicate a strong response by moths present, or a very large population density at the trapping sites.

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