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Male and Female Noctuid Moths Attracted to Synthetic Lures in Europe

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Abstract In field tests in Europe, traps baited with a blend of isoamyl alcohol, acetic acid, and isobutanol (compounds previously found attractive to a number of noctuids in North America) caught the following noctuid moths: *Agrotis segetum* Schiff., *Agrotis crassa* Hbn., *Agrotis exclamationis* L., *Amathes (Xestia) c-nigrum* L., *Apatele rumicis* L., *Amphipyra pyramidea* L., *Dipterygia scabriuscula* L., *Discestra trifolii* Hfn., *Euxoa aquilina* Schiff., *Euclidia glyphica* L., *Mamestra brassicae* L., *Mamestra oleracea* L., *Mamestra suasa* Schiff., *Mythimna albipuncta* Den. & Schiff., *Mythimna l-album* L., *Noctua pronuba* L., and *Trachea atriplicis* L. A substantial percentage of the catch of each species of moths was females. The presence of isobutanol in the mixture was important for catching *A. rumicis, D. trifolii*, and *E. glyphica*. The addition of 3-methyl-1-pentanol to the ternary mixture did not increase trap captures of any of the moths. Traps baited with the floral attractant phenylacetaldehyde alone caught several species of noctuid moths. However, when phenylacetaldehyde was added to the isoamyl-alcohol ternary blend, no increases in catches of any of the species, relative to the ternary blend or phenyacetaldehyde alone, were observed, with catches of most species being depressed. Comparing the noctuid species attracted to the phenylacetaldehyde- and isoamyl alcohol-based lures showed that phenylacetaldehyde attracted predominantly Plusiinae and Melicleptriinae spp., while isoamyl alcohol-based lures attracted species mostly from the Noctuinae or Hadeninae subfamilies.

Keywords Female attractant · Isoamyl alcohol · Isobutanol · Acetic acid · Phenylacetaldehyde · Lepidoptera · Noctuidae

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Introduction

The Noctuidae is one of the largest and most important families of Lepidoptera, both by total number of species and by economic importance of agricultural pests. The detection and monitoring of flight activity of adult males of many pest noctuid species is performed routinely by using traps baited with sex pheromone. Such sex pheromone-baited traps have proven to be highly sensitive and selective, but they have the inherent weakness for pest control of attracting only male moths. Traps catching female moths would potentially provide more valuable information for pest control decisions. Isoamyl alcohol (3-methyl-1-butanol) or 3-methyl-1-pentanol (naturally occurring in fermenting molasses), in combination with acetic acid, has been found to attract females of several noctuid pests in North America (Landolt 2000; Landolt and Alfaro 2001; Landolt and Highbee 2002). The related isobutanol (2-methyl-1-propanol), in combination with acetic acid, also is known to attract yellowjacket spp. (Hymenoptera, Vespidae) (Landolt 1998; Landolt et al. 1999, 2000). Furthermore, phenylacetaldehyde is a well-known floral compound that attracts both sexes of several noctuid species, as well as other Lepidoptera (e.g., Creighton et al. 1973; Cantelo and Jacobson 1979).

The principal objective of this study was to test the above compounds for ability to attract European noctuid species, with a particular application as female attractants in pest control programs. Also, we aimed to determine whether there were any synergistic interactions, in attraction to noctuid species, between the various alcohols/acid, produced by fermenting molasses and the floral attractant phenylacetaldehyde.

Methods and Materials

Traps The standard CSALOMON® VARL + funnel traps, produced by the Plant Protection Institute, HAS (Budapest, Hungary) (Tóth et al. 2000, 2002; Subchev et al. 2003) were used. This trap consists of an opaque plastic funnel (top opening, 13 cm o.d., funnel-hole diam., 3 cm, height of funnel, 16 cm), with a 20 × 20 cm flat, plastic roof, and a transparent plastic round container (ca 1 l, held in place by a rubber band). Photos of the trap can be viewed at <www.julia-nki.hu/traps>. The lure was suspended from the middle of the roof and positioned slightly above the level of the upper edge of the large funnel opening. A small piece (1 × 1 cm) of household anti-moth strip (Chemotox®, Sara Lee, Temana Intl. Ltd, Slough, UK; active ingredient 15% dichlorvos) was placed in the container to kill captured insects.

Baits Isoamyl alcohol, isobutanol (2-methyl-1-propanol), 3-methyl-1-pentanol, phenylacetaldehyde, and acetic acid were obtained from Sigma-Aldrich Kft. (Budapest, Hungary) and were stated by the suppliers to be >95% pure. The compounds were loaded onto a 1-cm piece of dental roll (Celluron®, Paul Hartmann Ag. Heidenheim, Germany), and placed inside a polyethylene bag (ca 1.0 × 1.5 cm; 0.02 mm-thick polyethylene foil). The lure dispensers were heat sealed and attached to 8 × 1 cm plastic strips for easy handling when assembling the traps. Lures were wrapped singly in pieces of aluminum foil and stored at−18°C until used. One or three lures were used in the traps to test for effect of lure concentration. Lures in traps were changed at 2–3 wk intervals, as previous experience with similar lures showed that they may lose activity after this period (Tóth et al. 2002).

Trapping Tests were conducted at several sites in Hungary. Traps were suspended at a height of ca 1.0–1.5 m. One replicate of each treatment was incorporated into a block, so that treatments were 8–10 m apart, and blocks were 30–50 m apart.

Experiment 1 was a preliminary, unreplicated test, run at Debrecen, Hajdú-Bihar County, May 3–October 18, 2001. Treatments included binary blends of isoamyl alcohol with acetic acid, isobutanol with acetic acid, and the ternary mixture of all three compounds. Each compound was loaded at 200 mg.

Experiment 2 studied the addition of 10, 30, and 100 mg of isobutanol to the binary isoamyl alcohol: acetic acid mixture (1:1, 100 mg each). Unbaited traps were included as a control. Site: Debrecen, July 1–October 10, 2003, with 4 blocks of traps.

Experiment 3 checked the addition of 3-methyl-1-pentanol (200 mg) to the ternary isoamyl alcohol + acetic acid mixture + isobutanol (1:1:1, 200 mg each) mixture. Unbaited traps were used as a control. Site: Debrecen, July 1–October 10, 2002, with 4 blocks of traps.

Experiment 4 compared the activity of the ternary isoamyl alcohol + acetic acid + isobutanol mixture (1:1:1, 200 mg each) against phenylacetaldehyde (200 mg). Unbaited traps were used as a control. Site: Túrkeve, Jász-Nagykun-Szolnok county, May 2–September 22, 2003, with 5 blocks of traps.

Experiments 5–6 compared the activities of the ternary isoamyl alcohol + acetic acid + isobutanol mixture (1:1:1, 200 mg each), phenylacetaldehyde (200 mg), or the combination of the two baits inside one trap. Unbaited traps were included in the tests as a control. Both tests were run with 5 blocks of traps, Experiment 5: Csenger, Szabolcs-Szatmár County, May 14–September 20, 2004; Experiment 6: Debrecen, May 11–October 11, 2004.

Experiments 7–8 compared the activity of the ternary isoamyl alcohol + acetic acid + isobutanol female-targeted lure (1:1:1, 200 mg each) with that of the respective sex pheromone baits for *Agrotis segetum* Schiff., *Mamestra brassicae* L. and *M. oleracea* L. Pheromone baits used were commercially available lures (Plant Protection Institute, HAS, Budapest, Hungary) Both tests were run with 3 blocks of traps. Experiment 7: Tiszavasvári, Hajdú-Bihar County, May 13–September 25, 2002; Experiment 8: Hajdúnánás, Hajdú-Bihar County, May 14–June 11, 2002.

Statistics The catches (number of insects caught / trap / inspection) from field trapping tests were transformed by $(x+0.5)^{1/2}$ (Tukey 1949, 1955) and analyzed by ANOVA. When the ANOVA showed a significant effect, treatment means were separated by a Games-Howell Test (Games and Howell 1976; Jaccard et al. 1984). In experiments in which one of the treatments caught no insects, the Bonferroni-Dunn test (Dunn 1961) was used to check whether mean catches in other treatments were significantly different from zero or not. All statistical procedures were conducted using the software packages StatView® v4.01 and SuperANOVA® v1.11 (Abacus Concepts, Inc., Berkeley, CA, USA).

Results

In a preliminary test (Experiment 1), substantial numbers of nine noctuid spp. (data not shown, but see Tables 1 and 2 for typical species caught) were caught in traps containing isoamyl alcohol plus acetic acid or the ternary combination with isobutanol. The combination of isobutanol + acetic acid caught few moths. Thus, further experiments concentrated on the isoamyl alcohol/acetic acid mixture. Percentages of females in the traps ranged from 10 to 100%.

Addition of increasing amounts of isobutanol to the isoamyl alcohol + acetic acid blend (Experiment 2), had little effect on catches of *Agrotis exclamationis* L., *Agrotis segetum* Schiff., *Agrotis crassa* Hbn., *Amathes (Xestia) c-nigrum* L., *Euxoa aquilina* Schiff, *Mamestra brassicae* L., *Mamestra oleracea* L., *Mamestra suasa* Schiff., and *Noctua pronuba* L., relative to traps baited with the binary mixture of isoamyl alcohol + acetic acid (Table 1). However, for *Apatele rumicis* L., *Discestra trifolii* Hufn., and *Euclidia glyphica* L., increasing amounts of isobutanol resulted in increased catches (Table 1). Traps baited with the binary mixture of isoamyl alcohol + acetic acid caught significantly more moths for the majority of species than did unbaited traps (Table 1). Again, sizeable percentages of the catches were females, ranging from 18% (for *A. exclamationis*) to 58% (for *M. brassicae*).

The addition of 3-methyl-1-pentanol to the ternary isoamyl alcohol + acetic acid + isobutanol mixture (Experiment 3), had no effect on trap catches of *A. exclamationis, A. segetum, Am. c-nigrum, D. trifolii, M. brassicae, M. oleracea, Mythimna albipuncta* (Denis & Schiff) *Mythimna. l-album* L., *N. pronuba*, or *Trachea atriplicis* L., but resulted in a decreased catch of *Dipterygia scabriuscula* L, relative to catches in traps baited with the ternary blend (Table 2). Traps with the ternary mixture caught significantly more moths of all species than did unbaited traps. The percentages of female moths caught in these traps ranged from 39% (*A. segetum*) to 75% (*M. oleracea*).

Traps baited with the ternary isoamyl alcohol + acetic acid + isobutanol mixture caught significantly more *A. exclamationis, A. segetum, Amphipyra pyramidea* L., *Apatele rumicis* L., *Am. c-nigrum, M. brassicae, M. oleracea*, and *M. suasa* moths than did traps baited with phenylactaldehyde or unbaited controls (Experiment 4**;** Fig. 1). In contrast, traps baited with phenylacetaldehyde caught more moths of *Autographa gamma* L., *Helicoverpa*

Table 1 Mean catches of noctuid moths in field tests in traps baited with mixtures of isoamyl alcohol, acetic acid, and differing amounts of isobutanol, and unbaited (**Experiment 2**). Means with same letter within a given species are not significantly different (P=0.05; ANOVA, followed by Games-Howell or Bonferroni-Dunn *post-hoc*)

Species caught	Mean catch/trap/inspection by blends (isoamyl alcohol: acetic acid: isobutanol (amounts in mg)					Total No. caught	% of females
	0 : 0 : 0	100 : 100 : 0	100 : 100 : 10	100 : 100 : 30	100 : 100 : 100		
Agrotis exclamationis	0.00a	0.28b	0.38b	0.32b	0.45b	114	18
Agrotis segetum	0.07a	1.57b	2.02b	2.46b	2.12b	1360	40
Agrotis crassa	0.03a	0.60b	0.40b	0.80b	0.77b	78	50
Amathes c-nigrum	0.01a	0.55b	0.54b	0.78b	0.85b	328	34
Apatele rumicis	0.00a	0.07ab	0.03a	0.21bc	0.36c	67	34
Discestra trifolii	0.04a	0.21b	0.21b	0.41bc	0.58c	195	33
Euclidia glyphica	0.01a	0.11ab	0.28bc	0.34bc	0.43c	93	20
Euxoa aquilina	0.06a	0.37ab	0.29ab	0.40b	0.29ab	92	29
Mamestra brassicae	0.00a	0.13b	0.12b	0.20b	0.21b	66	58
Mamestra olearcea	0.00a	0.25b	0.19b	0.40b	0.38b	160	53
Mamestra suasa	0.00a	0.35b	0.28b	0.34b	0.42b	194	54
Noctua pronuba	0.02a	0.25b	0.32b	0.23ab	0.29b	72	50

Table 2 Mean catches of noctuids in field tests in traps baited with a ternary isoamyl alcohol + acetic acid + isobutanol lure, a quaternary lure (with 3-methyl-1-pentanol added), or unbaited (**Experiment 3**). Means with same letter within a given species are not significantly different (P=0.05; ANOVA, followed by Games-Howell or Bonferroni-Dunn *post-hoc*)

Species caught	Mean catch/trap/inspection			Total No. caught	% of females
	unbaited	ternary blend	quaternary blend		
Agrotis exclamationis	0.00a	0.25b	0.38b	70	39
Agrotis segetum	0.00a	1.79b	1.62b	382	39
Amathes c-nigrum	0.00a	0.21b	0.13b	38	58
Dypterygia scabriuscula	0.00a	1.20c	0.49b	189	49
Discestra trifolii	0.00a	0.14b	0.13b	31	71
Mamestra brassicae	0.00a	0.23b	0.15b	43	49
Mamestra olearcea	0.00a	0.12b	0.17b	32	75
Mythimna albipuncta	0.00a	0.41b	0.33b	83	47
Mythimna l-album	0.00a	0.13b	0.14b	31	61
Noctua pronuba	0.00a	0.25b	0.12b	41	46
Trachea atriplicis	0.00a	0.97b	0.77b	195	49

armigera Hn., *Macdunnoughia confusa* Steph., and *Meristris trigrammica* Hufn. than did traps baited with the ternary mixture or the unbaited controls. *E. glyphica* moths were caught in similar numbers in traps baited with either phenylacetaldehyde or the ternary blend, but catches were significantly higher than those in unbaited traps only for traps baited with 3 dispensers of the ternary mixture. Traps with 3 dispensers of the ternary mixture showed a general tendency of catching more than those with a single dispenser for all species, but the difference was significant only for *A. exclamationis* (Fig. 1). The effect of increased catches with increased number of dispensers was similar for traps baited with phenylacetaldehyde, with only a significant difference for *M. confusa* catches. Female percentages in traps with the ternary mixture ranged from 45% (*E. exclamationis*) to 65% (*M. brassicae*), while in those with phenylacetaldehyde from 11% (*Me. trigrammica*) to 57% (*H. armigera*) (Fig. 1).

In Experiments 5 and 6, traps with both the ternary mixture and phenylacetaldehyde caught significantly fewer moths of *A. exclamationis, A. segetum, Am. c-nigrum, M. brassicae, M. oleracea*, and *M. suasa* than did those baited with only the ternary mixture (Fig. 2). Traps with both phenylacetaldehyde and the ternary mixture also tended to

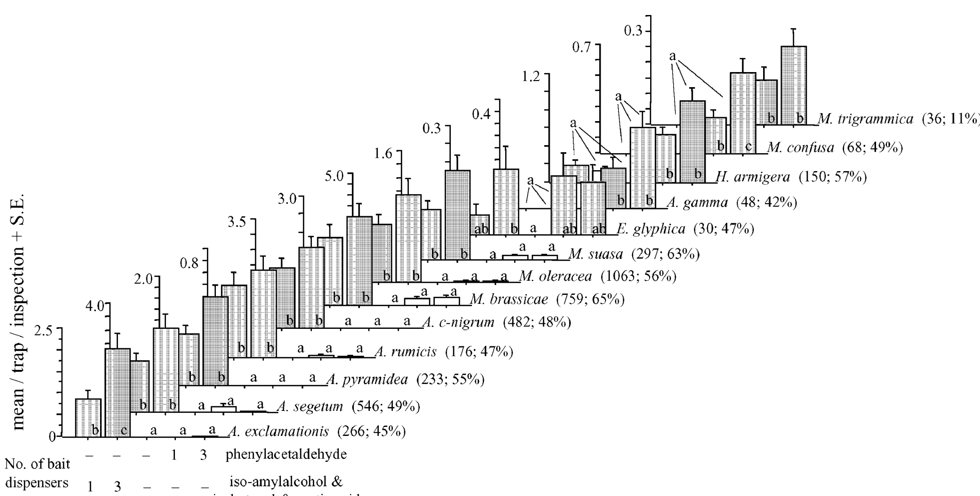

Fig. 1 Mean catches of various noctuid species in field tests in traps baited with one or three dispensers of, a ternary isoamyl alcohol + acetic acid + isobutanol lure, a phenylacetaldehyde lure, or unbaited (Experiment 4). Columns with the same letter within a given species are not significantly different (P<0.05; ANOVA, followed by Games-Howell or Bonferroni-Dunn *post-hoc* tests). Numbers in parentheses after the species show total number of moths caught and % of females in the catch. Species caught were: *Agrotis exclamationis, A. segetum, Amathes c-nigrum, Amphipyra pyramidea, Apatele rumicis, Autographa gamma, Euclidia glyphica, Heliothis armigera, Mamestra brassicae, M. oleracea, M. suasa, Meristris trigrammica*, and *Macdunnoughia confusa*. L

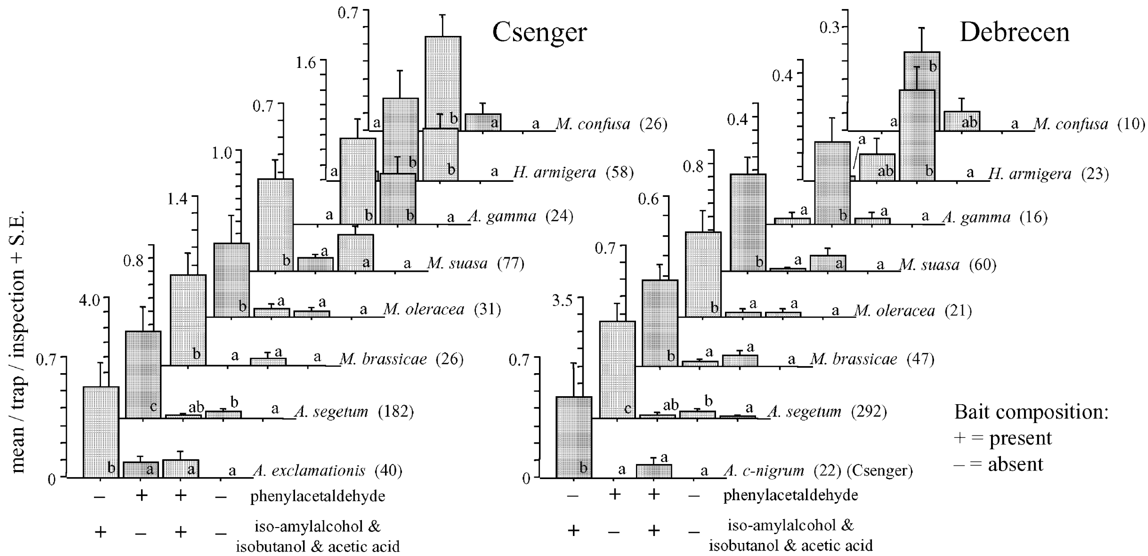

Fig. 2 Mean catches of noctuids in field tests in traps baited with a ternary isoamyl alcohol + acetic acid + isobutanol lure, a phenylacetaldehyde lure, the two types of lures together, or unbaited, at Csenger (Experiment 5) and Debrecen (Experiment 6). Columns with same letter within a given species are not not significantly different ($P<0.05$; ANOVA, followed by Games-Howell or Bonferroni-Dunn *post-hoc* tests). Numbers in parentheses after the species show total number of moths caught. Species caught were: *Agrotis exclamationis, A. segetum*, *Amathes c-nigrum, Autographa gamma*, *Heliothis armigera*, *Mamestra brassicae, M. oleracea*, *M. suasa,* and *Macdunnoughia confusa*

catch fewer moths of *Au. gamma* and *M. confusa* than did traps with phenylacetaldehyde alone, but the difference was significant in only one out of two tests for each species (respectively, Debrecen and Csenger). Traps with phenylacetaldehyde alone or with both types of baits caught similar numbers of *H. armigera*.

In Experiments 7 and 8, the respective sex pheromone-baited traps caught significantly more males of *A. segetum, M. brassicae*, and *M. oleracea* (although the pheromone data were lost for this species in Experiment 7) than did traps baited with the ternary blend of isoamyl-alcohol + acetic acid + isobutanol (which caught ca 5-7%, 25–26%, and 20% of the total amount in the pheromone traps for the respective species). Traps baited with the ternary mixture generally caught more moths of both sexes than did unbaited traps (Table 3).

Discussion

In the present experiments, the blend of isoamyl alcohol, acetic acid, and isobutanol was attractive to male and female moths of 16 species of European noctuids. Previously, isoamyl alcohol, or 3-methyl-1-pentanol, with acetic acid had been shown to attract a North American population of *Am. c-nigrum* (Landolt 2000; Landolt and Alfaro 2001). In this study, we confirmed the attraction of a European population of *Am. c-nigrum* to isoamyl alcohol plus acetic acid. Isoamyl alcohol and acetic acid in a binary mixture was attractive to 13 of the noctuid species, while the presence of isobutanol was important for catching the three additional spp. The addition of 3-methyl-1-pentanol to this ternary mixture did not increase captures of any of these moths. Importantly, the ternary blend attracted a significant proportion of female moths of all the species.

In a study of the species of North American Lepidoptera captured in traps baited with isoamyl alcohol plus acetic acid, Landolt and Hammond (2001) recorded specimens belonging to ca 60 species, 90% of which were Noctuidae. Combined with our European results, this shows that isoamyl alcohol plus acetic acid are probably widely exploited as attractants to food in Noctuidae. The presence of acetic acid and short-chain alcohols generally is attributed to a fermentation process, and may indicate the presence of a carbohydrate source for feeding (Landolt et al. 1999, 2007; Landolt 2000).

We also demonstrated attraction of four noctuid species to phenylacetaldehyde. Phenylacetaldehyde is a floral scent constituent of many flowers (Knudsen et al. 1993), and is known as an attractant of several species of Lepidoptera (e.g., Creighton et al. 1973; Cantelo and Jacobson 1979). Our study confirmed the previously reported attraction of *H. armigera* to this compound (Pawar et al. 1983) or blends containing this compound (Bruce and Cork 2001; Bruce et al. 2002). To our knowledge, the attraction of the other species (*Me. trigrammica*, *M. confusa*, *Au. gamma*) to phenylacetaldehyde has not been reported previously, although the closely related plusiines, *Autographa californica* Speyer and *Trichoplusia ni* Hbn., respond to lures containing this compound (Landolt et al. 2001, 2006).

Table 3 Mean catches of *Agrotis segetum*, *Mamestra brassicae,* and *Mamestra oleracea* in field tests in traps baited with a ternary isoamyl alcohol + acetic acid + isobutanol lure, or the respective pheromone lures (**Experiments 5–6**). Means with same letter within a given species are not significantly different (P=0.05; ANOVA, followed by Games-Howell or Bonferroni-Dunn *post-hoc*)

Species caught	Mean catch/trap/inspection								Total No. caught (both sexes)
	ternary lure		*A. segetum* pheromone		*M. brassicae* pheromone		*M. oleracea* pheromone		
	males	females	males	females	males	females	males	females	
Exp. 7									
A. segetum	0.51b	1.50B	9.59c	0.00A	0.00a	0.00A	not av.	not av.	750
M. brassicae	0.17b	0.57B	0.00a	0.00A	1.83c	0.00A	not av.	not av.	101
M. olearcea	3.57b	3.20B	0.00a	0.00A	0.00a	0.00A	not av.	not av.	465
Exp. 8									
A. segetum	1.46b	1.79B	23.17c	0.00A	0.00a	0.00A	0.00a	0.00A	634
M. brassicae	0.25a	1.46B	0.00a	0.00A	6.29b	0.00A	0.00a	0.00A	192
M. olearcea	14.96b	18.83B	0.00a	0.00A	0.00a	0.00A	160.50c	0.00A	4663

not av. not available, as several of the traps from this treatment were missing

The species caught in greatest numbers in the study of Landolt and Hammond (2001) in North America belonged to the subfamilies Amphipyrinae, Hadeninae, and Noctuinae. Similarly, the majority of species caught in our study in traps baited with isoamyl alcohol-based lures also belonged to these subfamilies. In contrast, the moths caught in traps baited with phenylacetaldehyde belonged to the subfamilies Plusiinae (2 spp.), Melicleptriinae (1 sp.) and Amphipyrinae (1 sp.). The different subfamily distribution of species that respond to isoamyl alcohol- and phenylacetaldehyde-based lures may reflect general differences in feeding habits of the respective noctuids. It has long been known to moth collectors that *Autographa* (Plusiinae) and *Helicoverpa* (Melicleptriinae) spp. frequent and feed on flowers, while *Agrotis* (Noctuinae) or *Mamestra* (Hadeninae) spp. do not (e.g., Abafi-Aigner 1907; Balachowsky 1972). Interestingly, we found traps containing both isoamyl alcohol- and phenylacetaldehyde-based baits tended to catch fewer moths than traps with the respective single baits. The reason for this negative interactive effect of the two types of compounds is unknown.

Among the species captured in the present study, *Au. gamma*, *A. segetum, A. crassa, A. exclamationis, Am. c-nigrum, D. trifolii, E. aquilina, H. armigera, M. brassicae, M. oleracea, M. suasa,* and *N. pronuba* are regarded as agricultural pests, with, *Au. gamma, A. segetum, H. armigera, M. brassicae,* and *M. oleracea* among the most important economic noctuid pests in Europe (e.g., Balachowsky 1972; Mészáros 1993). In experiments (7 and 8) that compared the isoamyl alcohol-based lures against pheromone lures, relatively high percentages (20–25% of catches in the respective pheromone traps) of *M. brassicae* and *M. oleracea* moths were caught in traps baited with isoamyl alcohol-based lures. Therefore, for these species, especially with further optimization of lures, these isoamyl alcohol-based attractants could become a useful tool. For instance, they could be used to attract both females and males in a lure and kill strategy, thus lowering both the adult moth population as well as the potential offspring of the female. A previous study that used phenylacetaldehyde and a sucrose-methomyl toxicant yielded promising results with mortality of 61% (females) and 44% (males) of released *T. ni* moths (Landolt et al. 1991). However, for *A. segetum* trapped in Experiments 7 and 8, very low percentages of moths (only 5–7% of the numbers in pheromone traps) were caught in traps baited with the isoamyl alcohol-based lures, suggesting that these lures may not be suitable for practical usage for this species.

In summary, isoamyl alcohol-based lures show promise as male and female noctuid moth attractants. A characteristic of the lures tested in this present study is that they attract a number of species, and thus are more general attractants than species-specific sex pheromones. Use of such a single lure would allow several important pests to be trapped in an agricultural system, thereby minimizing monitoring efforts. However, this lack of specificity also can be a disadvantage in that non-target, or even rare and endangered species of moths could be caught. The advantages and disadvantages of the use of such a method should, therefore, be evaluated according to the actual scenario.

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