Developing pheromone traps and lures for *Maruca vitrata* in Benin, West Africa

M. C. A. Downham[1,*], M. Tamò[2], D. R. Hall[1], B. Datinon[2], S. Adetonah[2] & D. I. Farman[1]

[1]*Natural Resources Institute, University of Greenwich, Central Avenue, Chatham Maritime, Chatham ME4 4TB, UK;*
[2]*International Institute of Tropical Agriculture, Biological Control Center for Africa, 08 BP 0932, Tri Postal, Cotonou, Republic of Benin*

Accepted: 4 November 2003

Key words: trap design, blend purity, monitoring (*E*,*E*)-10,12-hexadecadienal, (*E*,*E*)-10,12-hexadecadienol, (*E*)-10-hexadecenal, Lepidoptera, Pyralidae

Abstract

In previous work successful trapping of the legume podborer, *Maruca vitrata* Fabricius (Lepidoptera: Pyralidae), was accomplished using a synthetic pheromone blend consisting of (*E*,*E*)-10,12-hexadecadienal, (*E*,*E*)-10,12-hexadecadienol, and (*E*)-10-hexadecenal in a 100 : 5 : 5 ratio. In the present work, experiments were conducted in cowpea fields in Benin to compare different trap designs, and other aspects of the lures. A water-trap made from a plastic jerry-can was found to be superior to commercial funnel- and sticky-trap designs, and 120 cm was the optimum height for captures. Generally, lures consisted of polyethylene vials containing 0.1 mg of pheromone. Results showed that shielding the lures from the adverse effects of sunlight with aluminium foil did not increase trap catches of *M. vitrata*. The degree of isomeric purity of the (*E*,*E*)-10,12-hexadecadienal and (*E*,*E*)-10,12-hexadecadienol blend components, in the range 73–99%, had no significant effect on captures, while lures of 80% isomeric purity showed no loss of effectiveness for up to 4 weeks. Similar results were observed with lures from a commercial source containing 0.46 mg of pheromone in the blend ratio 100 : 11 : 6 and 95% isomeric purity. Residue analysis showed that vial lures exposed for 2 weeks in the field still contained 73% of the initial amount of (*E*,*E*)-10,12-hexadecadienal, compared to rubber septa dispensers, which only retained 22%. Females comprised 11–50% of total catches, confirming earlier, unexpected results for synthetic lures. The observations that effective traps can be made from locally available plastic containers, and that pheromone blend composition and purity are not critical, should reduce costs and improve the feasibility of traps as practical monitoring tools for *M. vitrata*.

Introduction

Cowpea, *Vigna unguiculata* (L.) Walp. (Leguminosae), is a highly important grain legume crop grown in semi-arid and dry savannah areas of the tropics (Singh & van Emden, 1979). It provides a cheap source of dietary protein for low-income populations (Rachie, 1985), and forms a vital cattle forage crop in many farming systems (Mortimore et al., 1997). Africa produces 75% of world production, of which the majority comes from West Africa (Coulibaly & Lowenberg-Deboer, 2002, derived from FAOSTAT, 2000).

The legume podborer, *Maruca vitrata* Fabricius (syn. *M. testulalis*) (Lepidoptera: Pyralidae), is a key pest of cowpea (Jackai, 1995) as well as other legume crops. The larvae attack flower buds, flowers, and young pods (Singh & Jackai, 1988), and yield losses have been reported in the 20–80% range (Singh et al., 1990).

Insecticides can control cowpea insect pests and raise yields several-fold (Afun et al., 1991; Amatobi, 1995; Asante et al., 2001). However, in West Africa, their expense limits insecticide use (Alghali, 1991; Bottenberg, 1995). Careful timing of application is required because the webs produced by young *M. vitrata* larvae, and their tendency to bore into flowers and pods, help to protect them from insecticides (Lateef & Reed, 1990). Afun et al. (1991) demonstrated the effective use of action thresholds, based on flower infestation rates, to time insecticide applications. Potentially, catches in pheromone-baited traps for *M. vitrata* could be used by cowpea farmers to determine the most

*Correspondence: E-mail: m.c.a.downham@gre.ac.uk

effective time to treat their crops. Such an approach has been developed for pests of other tropical crops such as rice (Kojima et al., 1996) and cotton (Reddy & Munjunatha, 2000).

The use of pheromone traps for monitoring the activity and movements of adult *M. vitrata* could also assist researchers in developing new pest management strategies. Bottenberg et al. (1997) provided some data on the population dynamics and migration of *M. vitrata* in West Africa, based on light trap catches. However, pheromone traps could be deployed more easily, cheaply, and in greater numbers in order to generate this kind of information. Moreover, pheromone traps are specific to the species of interest.

Okeyo-Owuor & Agwaro (1982) trapped male *M. vitrata* moths in water traps baited with virgin females in Kenya, thus suggesting that a sex pheromone of the female *M. vitrata* was produced. Later, Adati & Tatsuki (1999) reported (*E*,*E*)-10,12-hexadecadienal (EE10,12-16:Ald) to be an electroantennogramm-active component of the extract from female *M. vitrata* abdominal tips. Synthetic EE10,12-16:Ald was shown to be attractive to male moths in laboratory bioassays, although only at high levels of isomeric purity. The corresponding alcohol (*E*,*E*)-10,12-hexadecadienol (EE10,12-16:OH) was found to be present at 3–4% relative to the aldehyde, but not tested. Recently, Downham et al. (2003) confirmed the presence of EE10,12-16:Ald and EE10,12-16:OH as major and minor blend components, respectively, together with a third component that laboratory and field bioassays suggested was probably (*E*)-10-hexadecenal (E10-16:Ald). In field experiments in Benin, traps baited with a blend of EE10,12-16:Ald, EE10,12-16:OH, and E10-16:Ald in a 100 : 5 : 5 ratio caught significantly more males than traps baited with the major component alone, either two-component blend, or virgin female moths. In an almost unprecedented finding, significant numbers of female *M. vitrata* moths, in variable proportions of up to 50% of the total catches, were trapped with synthetic blends but not with virgin females. All laboratory and field experiments employed blends in which the isomeric purity of the EE10,12-16:Ald major component was >99%. Downham et al. (2003) found no significant differences in catches using polyethylene vials or rubber septa, or between lures containing 0.01 and 0.1 mg of pheromone, but considered 0.1 mg polyethylene vials to be the lures of choice due to their greater expected longevity under field conditions.

This paper reports experiments developing an effective trap for *M. vitrata* and exploring the effects of lure age and blend purity on catches of both sexes, with a view to the sustainable use of traps by farmers in West Africa for optimising control of *M. vitrata*. We also report some analysis of pheromone lures exposed under field conditions.

Materials and methods

Experimental sites

Experiments were carried out between 1998 and 2001, in cowpea fields planted with the local Kpodjiguègué variety (Tamò & Baumgärtner, 1993) at the International Institute of Tropical Agriculture research station near Cotonou, Republic of Benin (6°25.1′N, 2°19.7′E, 21 m altitude). At this location, rainfall is bimodal in pattern, with a long rainy season from April to July and a short one from mid-September to November. Cowpea is cultivatable at any time from May to December. *Maruca vitrata* may be present at any time during this period, depending on the flowering of its wild hosts (leguminous tree species such as *Lonchocarpus* spp. and *Pterocarpus* spp.), but normally appears most strongly during the latter half of the cropping cycle. All the trapping experiments were conducted over 2–3 months within the period June–December. Fields of cowpea were grown specifically for the experiments. Traps were set out in fields 20–30 days after sowing, i.e., before flowering, and were continued until after harvesting. The crops received no artificial irrigation, only rain, and no pesticides were sprayed in the fields.

General trapping methods

Traps were suspended from wooden sticks using wire; unless otherwise noted this was at a height of approximately 1.0–1.2 m. Lures were replaced every 2 weeks and were shielded from sunlight to minimize isomerization by wrapping aluminium foil around them to leave only the lower-most surface exposed. Trap catches were counted daily and trapped moths discarded at that time.

Each experiment was carried out to a randomised complete-block design with five replications. Traps within a replicate block were set out in lines or rectangular formations, the exact layout depending on the number of treatments being compared. Individual traps were positioned 20 m apart. Blocks were at least 50 m apart, and were usually situated in separate fields. With this arrangement, it was possible that some interactions between traps occurred as individual pheromone plumes overlapped and the moths, initially attracted by the plume of one trap, passed on to the plumes of others nearby. This would have acted to blur treatment differences. However, the random positioning of treatments within blocks and variations in wind direction would have greatly reduced, if not eliminated, any systematic biases.

Trap optimisation experiments

Six trap designs were used during the course of two experiments. The first compared two commercially available designs with a water-pan trap made from a green plastic

bowl (5 cm depth × 20 cm diameter) and an up-turned plate (20 cm diameter) held 5 cm apart with steel wire, with the plate uppermost. The commercial traps (Agrisense-BCS, Pontypridd, UK) were white sticky delta traps (28 cm long × 20 cm floor width × 14 cm sloping side) and green plastic funnel-traps (22 cm high × 15 cm outside diameter). In the delta trap, sticky card inserts that were replaced on a weekly basis served to trap the moths; in the funnel trap DDVP insecticide strips inside killed any trapped moths. Delta traps were fixed in such a way as to prevent them turning in the wind. Dilute detergent solution was placed in the water-pan traps to 1–2 cm below the trap openings. A little vegetable oil was added to this to reduce evaporation. The detergent solution was topped-up or entirely replaced 2–3 times each week, as necessary.

The second experiment compared the same delta trap with three more water-trap designs. These included one from a 1.5-l clear plastic bottle (formerly used as a container for mineral water; 30 × 8 cm) in which two windows (6 × 4 cm) were cut on opposite sides, with the lower edge of the window being 9.5 cm from the bottom of the bottle. The two other water-traps were made from 2-l yellow and 5-l white, plastic jerry-cans (formerly used as vegetable oil containers; 26 × 17 × 13 cm) of rectangular cross-section. These designs were very similar to those described by Smit et al. (1997). Four windows, one on each side, each positioned with the lower edge 8 cm above the bottom of the trap, were cut in each trap (two each of 8 × 9 cm and 8 × 6 cm for the 5-l trap; four of 4 × 6.5 cm for the 2-l trap). As in the water-pan trap, dilute detergent solution acted as the trapping agent in the bottle and jerry-can traps. In addition, a trap height comparison was carried out using funnel traps suspended so that the trap openings were at 20, 70, 120, and 170 cm above ground.

Previous observations have consistently noted zero catches for unbaited control traps where the delta and funnel trap designs were used (Downham et al., 2003). In the case of the water-trap designs, occasional control catches have been noted, but these have not exceeded one individual per trap over a cropping season (T. Adati and M.C.A. Downham, unpubl. obs.). In consequence, unbaited control traps were not included in any of the present experiments.

Lure optimisation experiments

The lures used in all trapping experiments consisted of polyethylene vial dispensers (23 × 9 × 1.5 mm thick; Just Plastics, London E10 7PY, UK). White rubber septa (Aldrich Chemical Co. Ltd, Gillingham, Dorset UK; catalogue number Z10,072-2) were also used in the quantitative residue experiment. Unless noted otherwise, all lures contained 0.1 mg of EE10,12-16:Ald, EE10,12-16:OH, and E10-16:Ald in a 100 : 5 : 5 ratio. They were produced at the Natural Resources Institute, UK, by adding the pheromone, and an equal weight of 2,6-di-*tert*-butyl-4-methylphenol (BHT) as an antioxidant, dissolved in 0.1 ml petroleum spirit (b.p. 40–60 °C) and allowing the solvent to evaporate. The pheromone components were prepared as described by Downham et al. (2003). The EE10,12-16:Ald and EE10,12-16:OH were of >99% isomeric purity, unless otherwise noted, and the E10-16:Ald was of >99% stereochemical purity. Lures were suspended within the centre of each trap using a small wire paper-clip.

Rubber septa and polyethylene vial dispensers, initially containing EE10,12-16:Ald alone or with one or both of the EE10,12-16:OH and E10-16:Ald minor components, were exposed under field conditions for 2 weeks in sticky delta traps during August 1998. Duplicate samples of each of the eight blend/dispenser combinations were retrieved, wrapped in aluminium foil and stored in a refrigerator at 4 °C prior to determination of the residual amount of EE10,12-16:Ald remaining. Lures were extracted individually overnight at room temperature in hexane (5 ml) containing 0.1 mg of pentadecyl acetate as an internal standard. The resultant solutions were analysed by gas chromatography using a fused silica capillary column (30 m × 0.32 mm i.d.) coated with CP Wax52CB (Carbowax equivalent; Chrompack, London, UK). The carrier gas was helium (0.5 kg cm^{-2}) and the oven temperature was programmed at 60 °C for 2 min then at 6 °C min^{-1} to 230 °C. Injection was in splitless mode (1 µl; 200 °C) and data were captured and processed with EZChrom 6.0 (Aston Scientific, UK) hardware and software. Under these conditions, good separation was obtained for E10-16:Ald and the four isomers each of EE10,12-16:Ald and EE10,12-16:OH, and these were quantified by a direct comparison of peak area with that of the internal standard without applying a response factor.

Four trapping experiments were carried out examining age and blend purity. In the first, six treatments, i.e., the combinations of shielded and unshielded lures with the age ranges 0–2, 2–4, and 4–6 weeks, were compared in delta traps. The older two ranges were produced by pre-ageing the lures for 2 or 4 weeks in delta traps situated at least 100 m from the experimental fields. These, together with fresh lures were placed in the respective traps at the start of each 2-week lure replacement period. In a second experiment unshielded lures in the age ranges 0–1, 1–2, 2–3, and 3–4 weeks were compared in 5-l jerry-can traps. In this case the older lures were produced by pre-ageing for 1, 2, or 3 weeks, using a similar procedure to that for the age/shielding experiment. In this experiment, the lures were changed on a weekly basis.

The effect of the isomeric purity of the two diene compounds EE10,12-16:Ald and EE10,12-16:OH, was determined in a further experiment using funnel traps. The four purity levels tested were 73%, 80%, 91%, and >99%. These levels of purity reflected those typically achieved after zero, one, two, and three serial recrystallizations from the equilibrium mixture of *E,E : Z,E : E,Z : Z,Z* isomers during manufacture of the compounds (see Downham et al., 2003).

The combined effects on catches of lure age and pheromone purity, in unshielded lures, were further investigated in 5-l jerry-can traps. Three lure types were compared: two produced at the Natural Resources Institute, of >99% and 80% isomeric purity with respect to the diene components and a third, commercially produced type (International Pheromone Systems, Ellesmere Port, L65 4EH, UK), hereafter termed IPS lures. In these lures, the initial quantity of pheromone was 0.46 mg and the component ratio (EE10,12-16:Ald; EE10,12-16:OH; E10-16:Ald) was 100 : 11 : 6, while the isomeric purity of the diene components was 95–96%. These three lures were each compared in two age ranges, 0–2 and 2–4 weeks old (the latter produced by an appropriate pre-ageing procedure as described above), to produce six treatments in all.

Statistical analysis

For a statistical analysis of the trapping experiments, total catches by each trap during the respective trapping periods were used. Before a statistical analysis, the data were transformed to square-root (trap height experiment) or $\log_{10}(x)$ (trap design, lure age, blend purity, and age/purity experiments). Analysis of variance was carried out using Genstat 5 for Windows© (release 4.1). Where this indicated statistically significant effects, treatment means were separated using the least significant difference (LSD) at the 5% level.

Results

General observations

Rates of capture of *M. vitrata* moths, males and females combined, were low in absolute terms, ranging from less than 10 to almost 30 individuals per trap throughout an experiment (less than one individual trap^{-1} night^{-1}). The proportion of females caught varied from 11 to 50% of the total.

Trap optimisation experiments

Significant treatment effects were observed in both the trap design experiments ($P < 0.05$, F-ratio, ANOVA). In the first, the delta trap attracted the fewest moths of both sexes (Table 1). The Agrisense-BCS funnel trap captured most males, but the locally constructed water-pan trap was most effective in capturing females. However, the different capture rates of the water-pan and funnel traps were not significant for either sex (LSD, $P > 0.05$). In the second experiment the 5-l and 2-l jerry-can designs captured significantly more males than both the delta trap and the 1.5-l bottle design (LSD, $P < 0.05$) (Table 2). A similar trend was evident in captures of females; the 5-l jerry-can caught significantly more females than the delta trap and the 1.5-l bottle design, but the difference between the 2-l jerry-can and the 1.5-l bottle design was not significant. The overall percentage captures of females in the two experiments were 46% and 35%.

During the trap height experiment, more males were captured at 120 cm than at other heights (Table 3). Mean catches of males at this height were significantly greater than at 20 and 170 cm (LSD, $P < 0.05$), although not at 70 cm. Catches of females were relatively low in this experiment (11% of the total) and there were no significant differences with respect to trap height.

Table 1 Mean catches/trap of *Maruca vitrata* in the first trap design experiment at IITA, Cotonou, Benin using lures containing 0.1 mg of EE10,12-16:Ald, EE10,12-16:OH, and E10-16:Ald in a 100 : 5 : 5 ratio (five replicates; October–December 1998)

	Males		Females	
Trap design	Mean	SE	Mean	SE
Delta	3.0 b	1.6	3.2 b	1.5
Water-pan	7.6 ab	3.4	9.0 a	3.5
Funnel	11.0 a	4.0	6.4 ab	2.7

Means within a column followed by the same letter were not significantly different ($P > 0.05$, LSD following ANOVA).

Table 2 Mean catches/trap of *Maruca vitrata* in the second trap design experiment, at IITA, Cotonou, Benin using lures containing 0.1 mg of EE10,12-16:Ald, EE10,12-16:OH, and E10-16:Ald in a 100 : 5 : 5 ratio (five replicates; September–November 1999)

	Males		Females	
Trap design	Mean	SE	Mean	SE
Delta	4.0 b	0.8	1.4 c	0.5
1.5-l bottle	5.0 b	1.1	2.8 bc	0.6
2-l jerry	10.8 a	2.0	6.0 ab	1.7
5-l jerry	13.0 a	1.8	7.4 a	1.3

Means within a column followed by the same letter were not significantly different ($P > 0.05$, LSD following ANOVA).

Table 3 Mean catches/trap of *Maruca vitrata* in funnel traps at different heights above ground, at IITA, Cotonou, Benin using lures containing 0.1 mg of EE10,12-16:Ald, EE10,12-16:OH, and E10-16:Ald in a 100 : 5 : 5 ratio (five replicates; July–October 1999)

	Males		Females	
Height	Mean	SE	Mean	SE
20 cm	5.6 bc	1.2	0.2 a	0.2
70 cm	6.8 ab	0.6	1.4 a	0.4
120 cm	10.4 a	1.4	0.6 a	0.4
170 cm	3.4 c	1.3	1.2 a	1.0

Means within a column followed by the same letter were not significantly different ($P > 0.05$, LSD following ANOVA).

Lure optimisation experiments

The results of the quantitative residue experiment were that the amounts of EE10,12-16:Ald remaining in the polyethylene vials averaged 73% of the initial value compared to 22% in the rubber septa. There was some variation in the amount of EE10,12-16:Ald remaining with pheromone blend, particularly in the polyethylene vials, but this may reflect a low replication at the level of individual blends. These results were reflected in a two-way analysis of variance, showing the effect of dispenser type to be highly statistically significant (ANOVA, d.f. = 1, $P < 0.001$). Pheromone blend was not a significant factor (ANOVA, d.f. = 3, $P = 0.08$), but the interaction of blend and dispenser type was (ANOVA, d.f. = 3, $P = 0.04$).

Results of the age and shielding experiment (Table 4) showed highly significant effects of lure age upon captures of both sexes (ANOVA, d.f. = 2, $P < 0.01$). Four to 6-week-old lures were significantly less attractive to males than 0–2 and 2–4 week old lures (LSD, $P < 0.05$), but there was no difference in catches for lures of the two lower age ranges. Zero to 2-week-old lures were significantly more attractive to females than both older sets of lures (LSD, $P < 0.05$). Male captures were not influenced by shielding of the lures (ANOVA, d.f. = 1, $P = 0.75$), but this factor did affect captures of females (ANOVA, d.f. = 1, $P < 0.01$), catches being higher with shielded lures. The interaction of age lure and shielding was not significant for males or females (ANOVA, d.f. = 2, $P > 0.38$). Captures of female moths made up 14% of the total in this experiment. In the comparison of unshielded lures up to 4 weeks old, lure age had no effect on captures of males or females (ANOVA, d.f. = 3, $P = 0.26$). Mean captures were in the range of 4–6 individuals per trap for each age range, for both males and females. Females comprised 50% of captures.

Table 4 Mean catches/trap of *Maruca vitrata* in delta traps with lures of different age ranges and shielded or unshielded from sunlight, at IITA, Cotonou, Benin using lures containing 0.1 mg of EE10,12-16:Ald, EE10,12-16:OH, and E10-16:Ald in a 100 : 5 : 5 ratio (five replicates; August–November 1999)

	Males		Females	
Lure characteristic	Mean	SE	Mean	SE
0–2 weeks old	11.9 a	1.0	2.7 a	0.5
2–4 weeks old	10.6 a	1.1	1.2 b	0.4
4–6 weeks old	6.3 b	0.9	0.9 b	0.3
Shielded	9.4 a	1.0	2.2 a	0.4
Unshielded	9.8 a	1.0	1.0 b	0.2

Means within a column followed by the same letter were not significantly different ($P > 0.05$, LSD following ANOVA); means for different age ranges averaged across both shielding classes and vice versa.

For the experiment on the effect of isomeric purity of the diene components using shielded lures, there was also no effect of treatment in males or females (ANOVA, d.f. = 3, $P = 0.39$). Mean captures were in the range of 4–8 individuals per trap for each purity level, for both males and females. Females made up 47% of total captures in this case.

The experiment on the combined effect of lure age and blend purity (unshielded lures) confirmed the earlier results for these factors individually. Lure age, of up to 4 weeks, did not affect the catches of males or females (ANOVA, d.f. = 1, $P = 0.64$) neither did the type of lure (NRI, high or low blend purity, or IPS) (ANOVA, d.f. = 2, $P = 0.85$). There was no interaction between the two factors for either sex (ANOVA, d.f. = 2, $P = 0.14$). Captures of males and females for each treatment were 21–22 and 6–7 individuals per trap, respectively. Thus, 24% of catches were of females during this experiment.

Discussion

Our results are similar to many previous reports with other species in demonstrating significant effects of trap-design and height on insect captures (e.g., Bradshaw et al., 1983; Smit et al., 1997). Earlier work has shown that trap design can affect capture rates through its effect on pheromone plume structure (Lewis & Macaulay, 1976), and hence on the approach behaviour of insects (Foster et al., 1991, 1995). Diffuse plumes reduce the number and accuracy of approaches by diminishing the insects' ability to orient upwind. For radially asymmetric designs such as the delta trap, a cross-wind orientation tends to reduce approaches and captures, at least partly for this reason. Visual cues and physical accessibility of the trap interior are also probably important, as well as the ability of the trap to retain insects

that have entered (Foster et al., 1991, 1995). Thus we can speculate that the delta trap performed relatively poorly during our own comparisons (Tables 1 and 2) because it was inappropriately oriented with respect to the wind for much of the time, or because approaching *M. vitrata* found it difficult to locate the trap entrances. Although the 1.5-l bottle was cylindrical in cross-section, a similar argument can be made for this, as it only had two entry windows and these may often have been misaligned with the wind. In contrast, the 2-l and 5-l jerry-can designs, with four windows each, were similar to the funnel trap in being almost omni-directional.

In general, an optimal trap height can reflect the preferred natural activity zone of a species, but height may also affect catch in other ways. For example, Gregg & Wilson (1990) reported that traps for *Heliothis* spp. (Lepidoptera: Noctuidae) should be just above crop height in order to prevent obstruction of the plume. In our experiments (Table 3), the crop canopy would have been well above 20 cm for most of the trapping period, and therefore plumes from traps at this height would not have carried far. The optimal trap height of 120 cm corresponded roughly to a distance of 60–90 cm above canopy, depending on the phenological stage of the plant and season. Traps at 170 cm were presumably too far above the crop for their plumes to be encountered frequently by flying *M. vitrata*.

The lure age and shielding experiment showed that male catches were unaffected by shielding of the lures from direct sunlight with aluminium foil or by lure age of up to 4 weeks (Table 4). We considered that the design of the delta trap might have provided some protection of the lures, but similar results with respect to lure age were obtained with unshielded lures in two later experiments which used the 5-l jerry-can trap. In this design, the lures were more exposed to sunlight due to the larger trap entrances and the translucent nature of the trap's walls. Results with respect to females were somewhat conflicting. In the lure age and shielding experiment, captures were significantly lower with successive lure age groups and were also affected by lure shielding. However, there was no effect of a lure age of up to 4 weeks in 5-l jerry-can traps in the other two experiments in which this factor was investigated.

The first purity experiment showed no effect on trap catches of isomeric purity of the diene components, in the range 73–99%, for lures up to 2 weeks old. The combined purity and age experiment confirmed this for lures of 80% and 99% purity up to 4 weeks old. These are slightly surprising results, as incomplete or 'off' blends typically greatly reduce the attraction of moths to sources (e.g., Willis & Baker, 1988; Witzgall, 1990). They run contrary to those of Adati & Tatsuki (1999) for *M. vitrata*, in which EE10,12-16:Ald of even 92% isomeric purity failed to attract males of Ghanaian origin in laboratory bioassays, in contrast to material of 99% purity. The reported results were obtained with EE10,12-16:Ald alone, although it was noted without supporting data that attraction rates to the pure EE10,12-16:Ald were not improved by the addition of EE10,12-16:OH. Our results can only be reconciled with those of Adati & Tatsuki (1999) if it is supposed that deficiencies in the isomeric purity of the major component can be off-set by the presence of both minor blend components.

Generally, trap-catches decline with lure age as a result of a falling release-rate or a shift away from the optimal pheromone blend caused by isomerisation or another reaction of one or more components. It is now possible to say that, within quite wide limits, catches of *M. vitrata* are relatively unaffected by several factors relating to blend quality and lure dose or release-rate. Downham et al. (2003) found no effect from varying the proportions of the two minor blend components over a 1–50% range, and the present work indicates that a wide variation in the isomeric purity of the main component similarly had no effect. Downham et al. (2003), did not observe any differences in catches with lures containing 0.01 or 0.1 mg, at least up to 2 weeks of age, or between polyethylene vial or rubber septa dispensers (despite the large difference in pheromone longevity within these dispensers that was shown by the quantitative residue experiment). From the present work we note that catches with IPS lures (containing 0.46 mg pheromone) in the combined purity and lure age experiment were very similar to those with NRI lures (0.1 mg). It may be argued that the IPS lures also differed in the blend ratio (100 : 11 : 6) and isomeric purity of the main component (95%) and therefore the comparison is not strictly valid. However, the previous findings with respect to these factors (above) suggest that these would not have affected catches, and a comparison can therefore reasonably be made in terms of lure dose. In any event, results with the IPS lures indicate that the commercially produced lures were as effective as those produced at the NRI.

From the results of the trap and lure optimisation experiments, for the first time an effective and practical trapping system for *M. vitrata* has now been developed. The 0.1 mg polyethylene vials showed no loss of attractiveness for up to 4 weeks under field conditions, although the precise dose, blend ratio, or isomeric purity of the EE10,12-16:Ald and EE10,12-16:OH components were not critical in achieving catches in the field. The isomeric purity results were significant from a practical view-point because the eventual cost of commercially produced lures would be heavily determined by the extent of purification required. If, as appears possible, a lower level of purity could be used

without a marked loss of attractiveness, this will help to ensure the economic viability of pheromone trap monitoring of *M. vitrata* by farmers and extension workers. The best trap height is 120 cm and the most effective traps are those produced from locally available plastic jerry-cans. Not only are these relatively much cheaper than imported, commercial ones, they are easy to construct and robust in use, as Smit et al. (1997) also found for traps for sweet potato weevils. To utilise traps at a practical level, some quantitative or qualitative relation now needs to be established between trap-catches of adults and the incidence of larval attack in cowpea fields. This is the subject of ongoing work, initial results of which are positive (M.C.A. Downham unpubl. obs.; Rurema, 2001) and indicate that larval infestations generally commence several days after the first trap captures.

The capture of female moths in all of the experiments confirmed earlier observations of this phenomenon by Downham et al. (2003). Possible explanations include an incomplete identification of the natural pheromone and a direct attraction of females to the synthetic lures or to previously trapped males. We consider the first of these unlikely, partly because of the extensive identification work done with strains of *M. vitrata* of different geographical origins (Downham et al., 2003), but particularly because incomplete pheromone blends generally produce lower catches of males, rather than a co-attraction of both sexes. Captures of female *Trichoplusi ni* in traps baited with synthetic pheromone lures have been shown to be due to the attraction of females to the pheromone produced by previously trapped males (Heath et al., 1992; Landolt, 1995). However, for *M. vitrata* neither this, nor a direct attraction of females to the lures, occurred in laboratory investigations by Mondhe (2001), although further work would be merited.

As demonstrated by the present results, the variability in the proportion of females captured needs to be explained. One possibility is that environmental factors, such as host plant volatiles, modulate female responses. Whatever the cause, it may still be argued that catches of both sexes are a better indicator of population events than catches of males alone, so that the predictive power of the traps is increased.

Acknowledgements

This publication is an output from project R7441 funded by the Crop Protection Programme of the UK Department for International Development (DFID) for the benefit of developing countries. The views expressed are not necessarily those of the DFID. We are grateful to Dr David Jeffries, University of Greenwich, for his help and advice with some of the statistical analyses.

References

Adati T & Tatsuki S (1999) Identification of the female sex pheromone of the legume pod borer, *M. vitrata* and antagonistic effects of geometrical isomers. Journal of Chemical Ecology 25: 105–115.

Afun JVK, Jackai LEN & Hodgson CJ (1991) Calendar and monitored insecticide application for the control of cowpea pests. Crop Protection 10: 363–370.

Alghali AM (1991) Studies on cowpea farming practices in Nigeria, with emphasis on insect pest control. International Journal of Pest Management 37: 71–74.

Amatobi CI (1995) Insecticide application for economic production of cowpea grains in the Northern Sudan Savanna of Nigeria. International Journal of Pest Management 41: 14–18.

Asante SK, Tamò M & Jackai LEN (2001) Integrated management of cowpea insect pests using elite cultivars, date of planting and minimum insecticide application. African Crop Science Journal 9: 655–665.

Bottenberg H (1995) Farmers' perceptions of crop pests and pest control practices in rain-fed cowpea in Kano, Nigeria. International Journal of Pest Management 41: 195–200.

Bottenberg HM, Tamò D, Arodokoun LEN, Jackai BB, Singh & Youm (1997) Population dynamics and migration of cowpea pests in northern Nigeria: implications for integrated pest management. Advances in Cowpea Research (ed. by BB Singh, DR Mohan Raj, KE Dashiell & LEN Jackai), pp. 271–284. Co-publication of International Institute of Agriculture (IITA) and Japan International Center for Agricultural Sciences (JIRCAS). IITA, Ibadan, Nigeria.

Bradshaw JWS, Baker R, Longhurst C, Edwards JC & Lisk JC (1983) Optimization of a monitoring system for the pine beauty moth, *Panolis flammea* (Denis & Schiffermüller), using sex attractants. Crop Protection 2: 63–73.

Coulibaly O & Lowenberg-Deboer J (2002) The economics of cowpea in West Africa. Challenges and opportunities for enhancing sustainable cowpea production. Proceedings of the World Cowpea Conference III held at the International Institute of Tropical Agriculture (IITA), Ibadan, Nigeria, 4–8 September 2000 (ed. by CA Fatokun, SA Tarawali, BB Singh, PM Kormawa & M Tamò), pp. 351–366. IITA, Ibadan, Nigeria.

Downham MCA, Hall DR, Chamberlain DJ, Cork A, Farman DI, Tamò M, Dahounto D, Datinon B & Adetonah S (2003) Minor components in the sex pheromone of the legume podborer, *Maruca vitrata* (F.) (Lepidoptera: Pyralidae): development of an attractive blend. Journal of Chemical Ecology 29: 989–1011.

FAOSTAT (2000) FAO Production Yearbook, 2000. FAO (Food and Agriculture Organisation), Rome.

Foster SP, Ayers RH & Muggleston SJ (1995) Trapping and sex pheromone-mediated flight and landing behaviour of male *Ctenopseustis obliquana*. Entomologia Experimentalis et Applicata 74: 125–135.

Foster SP, Muggleston SJ & Ball RD (1991) Behavioral responses of male *Epiphyas postvittana* (Walker) to sex pheromone-baited delta trap in a wind-tunnel. Journal of Chemical Ecology 17: 1449–1468.

Gregg PC & Wilson (1990) Trapping methods for adults. *Heliothis*: Research Methods and Prospects (ed. by MP Zalucki), pp. 30–48 Springer-Verlag, New York.

Heath RR, Landolt PJ, Dueben BD, Murphy RE & Schneider RE (1992) Identification of male cabbage looper sex pheromone attractive to females. Journal of Chemical Ecology 18: 441–453.

Jackai LEN (1995) Integrated pest management of borers of cowpea and beans. Insect Science and its Application 16: 237–250.

Kojima A, Yamashiro C & Arisaka M (1996) Regional control threshold of rice stem borer, *Chilo suppressalis* Walker (Lepidoptera: Pyralidae), indicated by adult catch with sex-pheromone trap. Applied Entomology and Zoology 40: 279–286.

Landolt PJ (1995) Attraction of female cabbage looper moths (Lepidoptera: Noctuidae) to males in the field. Florida Entomologist 78: 96–100.

Lateef SS & Reed W (1990) Insect pests on pigeon pea. Insect Pests of Tropical Legumes (ed. by SR Singh), pp. 193–242. John Wiley & Sons, Chichester, UK.

Lewis T & Macaulay EDM (1976) Design and elevation of sex-attractant traps for pea moth, *Cydia nigricana* (Steph.) and the effect of plume shape on catches. Ecological Entomology 1: 175–187.

Mondhe M (2001) Anomalous response of female *Maruca vitrata* (Fabricius) (Lepidoptera: Pyralidae) moths to synthetic sex pheromone. MSc Thesis, University of Greenwich, UK.

Mortimore MJBB, Singh F, Harris F & Blade SF (1997) Cowpea in traditional cropping systems. Advances in Cowpea Research (ed. by BB Singh, DR Mohan Raj, KE Dashiell & LEN Jackai), pp. 99–113. Co-publication of International Institute of Agriculture (IITA) and Japan International Center for Agricultural Sciences (JIRCAS). IITA, Ibadan, Nigeria.

Okeyo-Owuor JB & Agwaro PO (1982) Studies on the legume podborer, *Maruca testulalis* Geyer – III. The use of a pheromone trap in population studies. Insect Science and its Application 3: 233–235.

Rachie KO (1985) Introduction. Cowpea Research Production and Utilization (ed. by SR Singh & KO Rachie), pp. xxi–xxviii. John Wiley & Sons, London.

Reddy GVP & Munjunatha M (2000) Laboratory and field studies on the integrated pest management of *Helicoverpa armigera* (Hübner) in cotton, based on pheromone trap catch threshold level. Journal of Applied Entomology 124: 213–221.

Rurema D-G (2001) Dynamique des populations de *Maruca vitrata* (fabricius) (syn. *Maruca testulalis* Geyer) (Lepidoptere, Pyralidae) dans les cultures de niébé (*Vigna unguiculata*) (L) Walp.: Relation entre infestations larvaires et les volumes des adultes sous l'attrait de pheromones. Diplome d'Etudes Superieures Specialisées en Amènagement et Gestion des Ressources Naturelles. Université Nationale du Bénin.

Singh SR & Jackai LEN (1988) The legume pod-borer, *Maruca testulalis* (Geyer): past, present and future research. Insect Science and its Application 9: 1–5.

Singh SR, Jackai LEN, Dos Santos JHR & Adalla CB (1990) Insect pests of cowpeas. Insect Pests of Tropical Legumes (ed. by SR Singh), pp. 43–90. John Wiley & Sons, UK.

Singh SR & van Emden HF (1979) Insect pests of grain legumes. Annual Review of Entomology 24: 255–278.

Smit NEJM, Downham MCA, Odongo B, Hall DR & Laboke PO (1997) Development of pheromone traps for control and monitoring sweet potato weevils, *Cylas puncticollis* (Bohe.) and *C. brunneus* (F.) in Uganda. Entomologia Experimentalis et Applicata 85: 95–104.

Tamò M & Baumgärtner J (1993) Analysis of the cowpea agroecosystem in West Africa: I. A demographic model for carbon acquisition and allocation in cowpea. Ecological Modelling 65: 95–121.

Willis MA & Baker TC (1988) Effects of varying sex pheromone component ratios on the zigzagging flight movements of the oriental fruit moth, *Grapholia molesta*. Journal of Insect Behavior 1: 357–371.

Witzgall P (1990) Attraction of *Cacoecimorpha pronubana* male moths to synthetic sex pheromone blends in the wind tunnel. Journal of Chemical Ecology 16: 1507–1515.