J Chem Ecol (2009) 35:111–117
DOI 10.1007/s10886-008-9580-6

Development of an Efficient Pheromone-Based Trapping Method for the Banana Root Borer *Cosmopolites sordidus*

G. V. P. Reddy · Z. T. Cruz · A. Guerrero

Received: 2 July 2008 / Revised: 25 November 2008 / Accepted: 15 December 2008 / Published online: 13 January 2009

Abstract The banana root borer *Cosmopolites sordidus* (Germar) (Coleoptera: Curculionidae) is a major pest of bananas throughout the world. Chemical control is both undesirable and expensive, where biological control alternatives are limited, and pheromone-based trapping results in low captures. In this study, several important factors that affect pheromone-based catches, such as trap type, trap dimensions, and color and position of the traps, were optimized. Ground traps were found to be superior to ramp and pitfall traps, and larger traps (40×25 cm and above) were more efficient than smaller ones (30×15 cm). In a color-choice test, the banana weevil clearly preferred brown traps over yellow, red, gray, blue, black, white, and green, with mahogany being more attractive than other shades of brown. In addition, pheromone baited ground traps positioned in the shade of the canopy caught significantly more adults than those placed in sunlight. Therefore, mahogany-brown ground traps 40×25 cm appear to be the most efficient at catching *C. sordidus* adults and have the greatest potential for use in mass trapping and programs for eradication of this pest.

Keywords Aggregation pheromone · Traps · Color preference · Banana root borer · *Cosmopolites sordidus* · Coleoptera · Curculionidae

G. V. P. Reddy (✉) · Z. T. Cruz
Western Pacific Tropical Research Center,
College of Natural and Applied Sciences, University of Guam,
Mangilao, GU 96923, USA
e-mail: reddy@uguam.uog.edu

A. Guerrero
Department of Biological Organic Chemistry,
Institute of Chemical and Environmental Research (CSIC),
Jordi Girona 18-26,
08034 Barcelona, Spain

Introduction

The banana root borer *Cosmopolites sordidus* (Germar) (Coleoptera: Curculionidae) is native to Malaysia and Indonesia but is now a major pest in most banana-growing regions of the world (Gold et al. 2001), particularly those producing dessert and cooking bananas (Sikora et al. 1989). In recent times, this borer has become a serious problem in Guam and other parts of Micronesia, raising concern among local authorities because all varieties of bananas appear to be attacked, and losses may reach 100% if the pest is left uncontrolled (Koppenhöffer et al. 1994).

Budenberg et al. (1993) provided the first evidence of a male-produced aggregation pheromone in *C. sordidus*, and Beauhaire et al. (1995) detected six male-specific compounds that elicited electroantennogram activity in vapor form, including the male pheromone (sordidin; 1S,3R,5R, 7S-1-ethyl-3,5,7-trimethyl-2,8-dioxabicyclo[3.2.1]octane). The structure and absolute stereochemistry of the natural attractant were confirmed by synthesis (Mori et al. 1996; Fletcher et al. 1997) and racemic sordidin proved attractive to both sexes (Ndiege et al. 1996; Jayaraman et al. 1997). Sordidin, formulated by ChemTica Internacional, S.A., San José, Costa Rica, is used to monitor the banana borer (Tinzaara et al., 2002, 2003) in Costa Rica (Alpizar et al. 1999; Oehlschlager et al. 2000) and Uganda (Tinzaara et al. 2000). In the Caribbean, four baited pitfall traps/hectare reduced corm damage (to <10%) and increased bunch weights (by 10–20% over a crop cycle) in commercial plantations (Alpizar et al. 1999, 2000). However, in Africa, the use of sordidin was ineffective for mass trapping (Tinzaara et al. 2005). Therefore, there is an urgent need for an efficient semiochemical-based trapping method for the control of *C. sordidus*. Here, we report a study directed toward improving trapping methods to control the pest and also toward a better understanding of the pheromone ecology of the pest.

Methods and Materials

Trap Types Three different types of traps—ground, ramp, and pitfall—were evaluated. The ground trap (Fig. 1A) was constructed in our laboratory from a 120×60×0.5-cm piece of white corrugated plastic board, with a 50×8-cm slit baffle fitted at the top to prevent borers from escaping (Reddy et al. 2005). Traps were sealed in all four corners and along edges with marine adhesive sealant, and water, mixed with a dishwashing liquid detergent (1–3%), was put in the bottom container to retain adults. The lower outer edges of the ground traps were covered with earth to prevent weevils from crawling under the traps.

The ramp trap used was commercially available from ChemTica Internacional S.A. (San José, Costa Rica; Fig. 1B). It was made of durable polyethylene and consisted of two box-shaped components, each 14 cm wide by 4 cm high (inside dimensions). Four sloping ramps led from the four cardinal directions into the sides of one of the open boxes. Each ramp was 4 cm high, 13 cm long, and 12 cm wide and slid into a slot in the floor of the box component. The other box had four corner ridges (6 cm high) that extended downward into the bottom box. As in the ground trap, the bottom container was filled partially with soapy water to retain attracted borers.

Pitfall traps were cylindrical, translucent white plastic cups (10-cm diameter, 1.5-L capacity; Fig. 1C). Four drainage holes (24-mm diameter) were drilled at 90° from each other in the sides of the cup, at least 5 cm from the bottom. The pheromone lure was suspended from the top of the cup on a vinyl-clad steel wire (12 cm long) threaded through a 3-mm hole. Traps were placed in holes dug 10 cm into the ground so that the upper edge of the cup was at the level of the soil.

Pheromone Lures Pheromone lures (Cosmolure), sealed in a polymer membrane release device and optimized for *C. sordidus*, were obtained from ChemTica Internacional S.A. (San José, Costa Rica). The lure packs, each containing 90 mg of pheromone and having a release rate of 3 mg/day (Tinzaara et al. 2005), were stored at 4°C until use. Lures were hung on 2-cm wires suspended across the tops of the ground and pitfall traps. In the case of the ramp trap, a hook-shaped wire with the lure was inserted (2 cm) through a hole in the top side of the trap. The lures were changed when the transparent container with the pheromone appeared empty, usually once or twice a month, although occasionally more frequent changes were necessary.

Effect of Trap Type on Capture Efficiency Ground, ramp, and pitfall traps with synthetic pheromone lures were

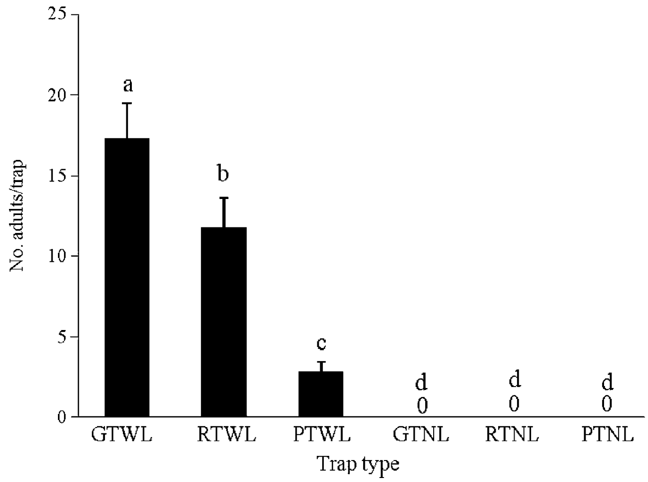

Fig. 2 Mean (± SE) numbers of adult *Cosmopolites sordidus* caught in ground, ramp, and pitfall traps baited with pheromone lures and in unbaited controls. *Different lower-case letters* indicate significant differences between treatments (one-way ANOVA using Poisson model, Least Square Means, $P<0.001$). *GTWL* ground trap with lure; *RTWL* ramp trap with lure; *PTWL* pitfall trap with lure; *GTNL* ground trap without lure; *RTNL* ramp trap without lure; *PTNL* pitfall trap without lure

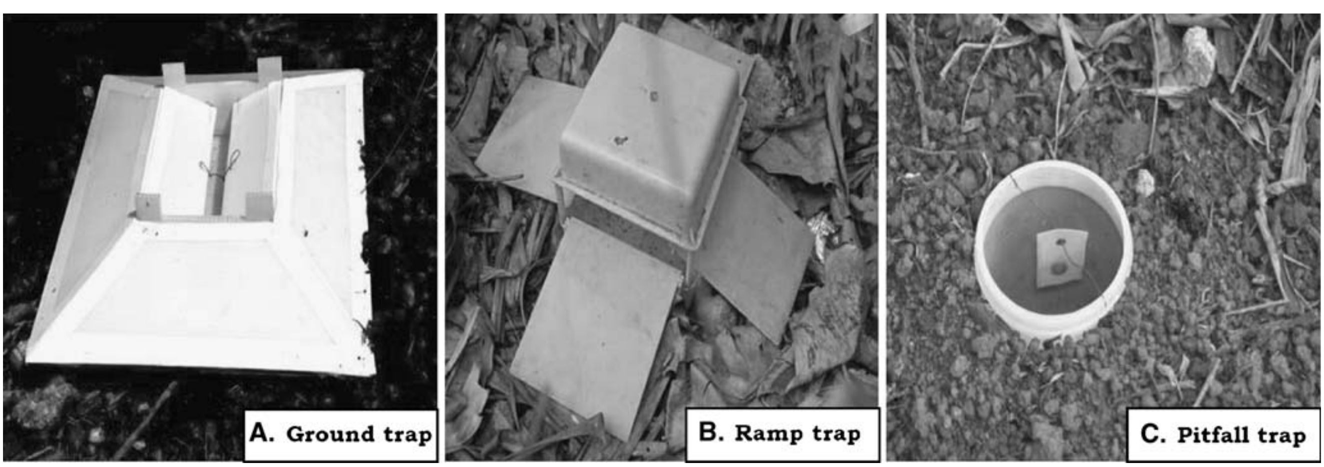

Fig. 1 **A**–**C** Design of the three traps used in experiments on *Cosmopolites sordidus*

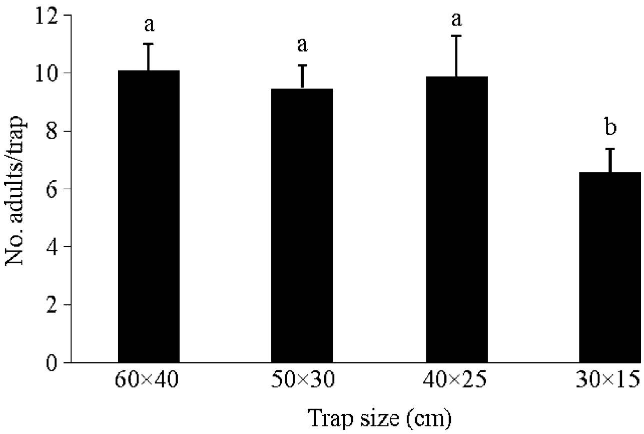

Fig. 3 Mean (± SE) numbers of adult *Cosmopolites sordidus* caught in pheromone-baited ground traps of different sizes. *Different lowercase letters* indicate significant differences between treatments (one-way ANOVA using Poisson model, Least Square Means, $P<0.05$)

placed at randomly chosen locations about 5 m apart on the ground of banana plantations in the villages of Dededo, Yigo, Agaña, and Yoña (Guam, USA; replicated ×4 at each site). Every week, the banana root borers trapped were removed and counted. Traps were washed and rinsed, and new detergent water was added. We randomized the traps across the field to avoid any possible trap-placement effect. Traps without lure were used as controls. The experiment was carried out from January to March 2007.

Effect of Trap Size The relative efficacy of four different sized ground traps (60×40, 50×30, 40×25, and 30×15 cm) was investigated. The ground trap was selected because it caught significantly more weevils than the ramp and pitfall traps. In each village, one trap of each size was set up, and their position rotated every week to prevent any location effect. The experiment was conducted from April to June 2007.

Effect of Trap Color Brown-, black-, gray-, yellow-, red-, white-, green-, and blue-colored vinyl tapes were adhered to all sides of 40×25-cm ground traps and tested independently (one trap of each color per location). The experiment was carried out from July to August 2007. The hue angle (h°) and chroma (C*) and the average of three readings for each color were determined by using a Konica Minolta CR-410 Chromameter (Minolta Instrument Systems, Ramsey, NJ, USA). The hue angle indicates the sample color, whereas the chroma provides a measure of the color intensity, and these were calculated by using the equations of Wrolstad et al. (2005). The hue angle is expressed on a 360° grid where 0°=red, 90°=yellow, 180°=green, and 270°=blue, respectively.

Effect of Shade of Brown Brown traps caught significantly more adults than traps of other colors so ground traps of different shades of brown (dark brown, mahogany brown, russet brown, saddle brown, and light brown) were evaluated (one trap of each shade in each village). The experiment was conducted from September to November 2007.

Relative Effects of Visual and Olfactory Cues To determine the relative importance of the visual and olfactory components of attraction, we repeated the experiment with mahogany brown ground traps baited with pheromone lures or unbaited. There were four replicates in each village, tested from December 2007 to February 2008.

Effect of Trap Shading Baited mahogany brown ground traps were placed in the shade and in sunlight, with four replicates in each village from March to May 2008. During the experiments, the color of the trap was measured by using a chromameter in the morning (0830 hours), noon (1200 hours), and afternoon (1600 hours). The data were averaged, and means were compared. Similarly, the

Table 1 Color measurements of traps used in the trapping of *C. sordidus* in Guam

Trap color	L*	a*	b*	Chroma (C)	Hue angle (h°)
Black	30.44±0.06	0.42±0.03	−1.08±0.04	1.16±0.05	–
Brown	35.26±0.18	3.98±0.03	3.94±0.02	5.60±0.03	44.66±0.11
Gray	39.83±0.11	−0.17±0.02	−2.23±0.01	2.24±0.01	85.64±0.47
Yellow	82.57±0.02	−2.92±0.03	84.02±0.27	84.07±0.27	91.99±0.02
Red	42.84±0.11	49.88±0.28	19.44±0.20	53.54±0.34	21.29±0.09
White	92.29±0.03	1.34±0.01	−2.59±0.04	2.91±0.03	–
Green	43.50±0.08	−27.32±0.03	1.72±0.09	27.37±0.03	176.39±0.19
Blue	36.02±0.10	15.19±0.10	−35.82±0.12	38.91±0.14	292.98±0.08

Data represent means of three observations

*L** indicates lightness of the color and it runs through the center of the color chart, where 100 at the top represents white and zero at the bottom represents black, *a** runs left to right on the color chart, and indicates a red shade when greater than zero (positive) and a green shade when lower than zero (negative), *b** runs vertically through the color chart, and indicates a yellow shade when positive and a blue shade when negative

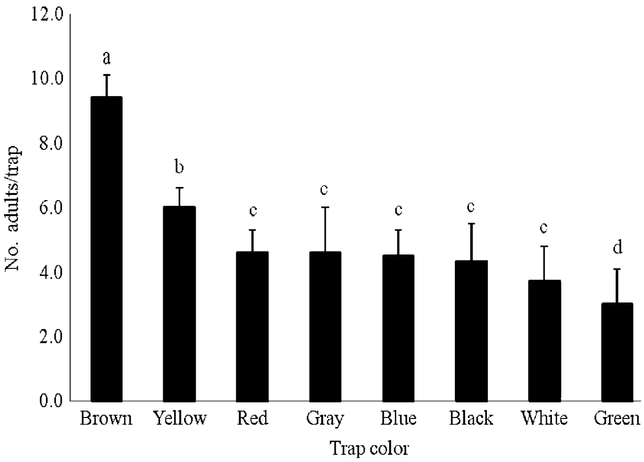

Fig. 4 Mean (± SE) numbers of adult *Cosmopolites sordidus* caught in pheromone-baited ground traps of different colors. *Different lower-case letters* indicate significant differences between treatments (one-way ANOVA using Poisson model, Least Square Means, $P<0.001$)

temperature within the different traps was recorded using a pocket weather meter (Kestrel®3000, Boothwyn, PA, USA).

Statistical Analysis Because all the response variables used in the experiments are count variables, a one-way Poisson analysis of variance model was fitted using the GLIMMIX Procedure SAS Version 9.13 (SAS Institute Inc. 2004). The Least Square Means test was used to make multiple comparisons for significant differences between treatments.

Results

Effect of Trap Type Baited ground traps captured more adult borers than baited ramp or pitfall traps ($F=48.88$, $df=2$, $P<0.001$; Fig. 2). Control traps captured no adult borers.

Effect of Trap Size The three larger trap sizes performed equally ($F=3.59$, $df=3$, $P<0.05$) but were significantly better than the smallest one (mean of 10.1±0.9, 9.5±0.8 and 9.9±1.4 adults/trap for 60×14, 50×30, and 40×25 cm, respectively; Fig. 3). For economy and ease of handling, 40×25-cm traps were chosen for further study.

Effect of Trap Color Trap color measurement values (L*, a*, b*, chroma, and hue angle) are given in Table 1. Brown ground traps were more attractive to banana borers than those of any other color tested ($F=6.74$, $df=7$, $P<0.001$; Fig. 4). There was a significant difference ($P<0.001$) between yellow and red colors. For the other colors, yellow attracted more banana borers than red, gray, blue, black, white, and green.

Effect of Shade of Brown Trap color measurement values (L*, a*, b*, chroma, and hue angle) for the different shades of brown are given in Table 2. The shade of brown affected adult catches in ground traps ($F=7.31$, $df=4$, $P<0.001$; Fig. 5), with mahogany brown traps catching significantly more adult borers than other shades. Dark brown, russet brown, and light brown did not differ significantly, whereas saddle brown traps were the least attractive.

Relative Effects of Visual and Olfactory Cues Mahogany brown ground traps baited with pheromone lures caught significantly more adults than those without ($F=33.32$, $df=1$, $P<0.001$; Fig. 6).

Effect of Trap Shading Pheromone-baited mahogany brown ground traps positioned in the shade of banana plants caught more adults than did similar traps placed in sunlight ($F=9.27$, $df=1$, $P<0.05$; Fig. 7). There was no significant difference in the color measurements of the mahogany brown traps placed in the sun (L=34.4, a=4.2, b=4.4, hue angle=46.7, and chroma=6.1) and shade (L=34.5, a=4.0, b=4.3, hue angle=46.5, and chroma=5.9). Similarly, only a marginal difference (<1°C) was observed among the temperatures of the different traps placed in both locations.

Table 2 Color measurements of the different shades of brown tested in the trapping of *C. sordidus* in Guam

Trap color	L*	a*	b*	Chroma (C)	Hue angle (h°)
Dark brown	35.26±0.18	3.98±0.03	3.94±0.02	5.60±0.03	44.66±0.06
Mahogany brown	35.91±0.01	5.44±0.02	4.35±0.03	6.97±0.03	38.65±0.13
Russet brown	38.99±0.03	11.37±0.05	9.00±0.01	14.51±0.03	38.37±0.07
Saddle brown	48.37±0.01	9.25±0.06	20.62±0.05	22.60±0.03	65.83±0.10
Light brown	61.13±0.03	4.50±0.02	21.87±0.02	22.33±0.01	78.38±0.03

Data represent means of three observations

*L** indicates lightness of the color and it runs through the center of the color chart, where 100 at the top represents white and zero at the bottom represents black, *a** runs left to right on the color chart, and indicates a red shade when greater than zero (positive) and a green shade when lower than zero (negative), *b** runs vertically through the color chart, and indicates a yellow shade when positive and a blue shade when negative

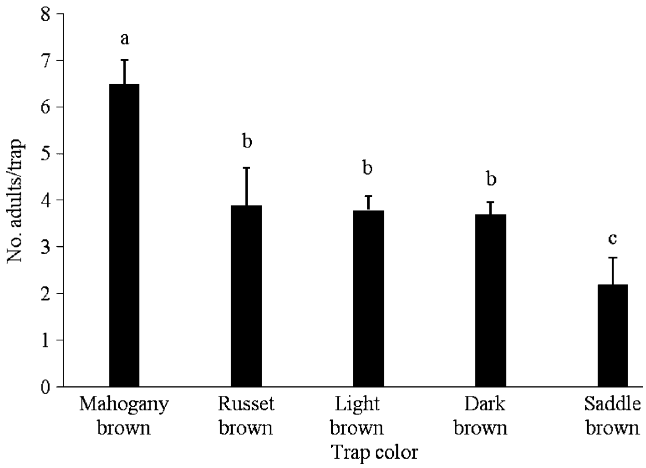

Fig. 5 Mean (± SE) numbers of adult *Cosmopolites sordidus* caught in pheromone-baited ground traps of different shades of brown. *Different lower-case letters* indicate significant differences between treatments (one-way ANOVA using Poisson model, Least Square Means, $P<0.001$)

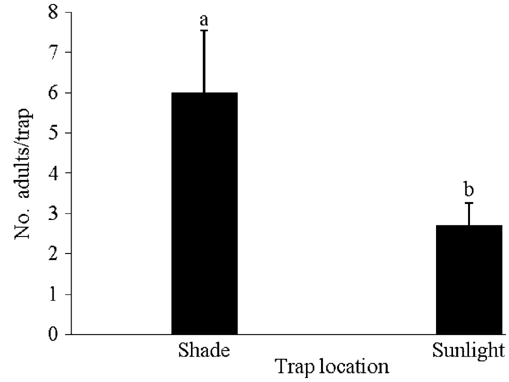

Fig. 7 Mean (± SE) numbers of adult *Cosmopolites sordidus* caught in pheromone-baited ground traps placed in shade and in sunlight. *Different lower-case letters* indicate significant differences between treatments (one-way ANOVA using Poisson model, Least Square Means, $P<0.05$)

Discussion

Pseudostem trapping was recommended for reducing populations of the banana borer (Gold et al. 2002; Koppenhöffer et al. 1994) but proved impractical and labor intensive (Gold et al. 2002). In Uganda, use of baited pitfall traps caught up to 18 times as many adults as pseudostem traps probably because they lasted longer (1 month vs. 3–7 days, Gold et al. 2001). While there have been several reports of successful trapping of banana borers with pheromone lures (Ndiege et al. 1996; Jayaraman et al. 1997; Alpizar et al. 1999), pheromone traps were not effective in reducing *C. sordidus* populations in Cameroon (Messiaen 2001). Tinzaara et al. (2005) failed to catch >3% of adults at either low or high trap density, and there was no reduction in damage to the plants (Tinzaara et al. 2005). Moreover, our recent studies indicate that, although ramp traps baited with Cosmolure are useful for monitoring *C. sordidus*, they do not reduce corm damage at several locations in Guam (G. V. P. Reddy, personal observation).

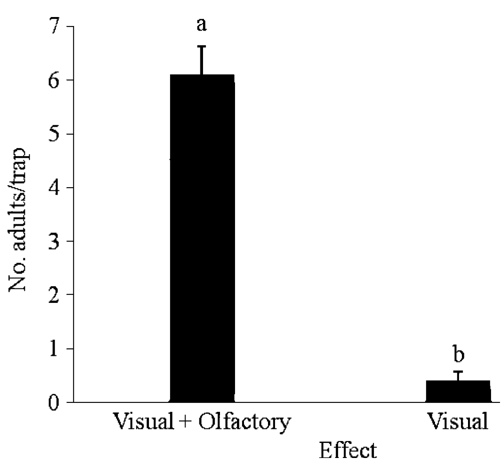

Fig. 6 Mean (± SE) numbers of adult *Cosmopolites sordidus* caught in mahogany-brown ground traps with and without pheromone lures. *Different lower-case letters* indicate significant differences between treatments (one-way ANOVA using Poisson model, Least Square Means, $P<0.001$)

Trap type is known to influence adult catches of many insects (Wyatt 1998; Reddy et al. 2005), yet no systematic study of trap features for more effective trapping of the banana borer had been conducted previously. Clearly, ground traps are superior to both ramp and pitfall traps under field conditions, as well as being cheaper and easier to use (Reddy 2007). Previous studies have shown that efficacy of traps for beetles can be strongly affected by their position (Lanier et al. 1976), color (Lanier et al. 1976; Ladd and Klein 1986; Smart et al. 1997), height above ground (Cuthbert and Peacock 1975), and surface texture (Lie and Bakke 1981), but few reports have been published on the effect of trap size. Tilden et al. (1979) found that larger traps caught significantly more western pine beetles *Dendroctonus brevicomis* than smaller traps. The same was reported for the European elm bark beetle, *Scolytus multistriatus* (Lanier et al. 1976), but not for the old-house borer, *Hylotrupes bajulus* (Reddy 2007).Trap diameter affected catches of spiders and ants (Brennan et al. 1999; Borgelt and New 2005), so it was surprising to find no difference between the three larger traps tested.

Some insects use visual pheromone cues to find a mate (Thornhill and Alcock 1983; Reddy et al. 2002), and these may act in combination (Carlton and Cardé 1990; Fukaya et al. 2004; Reddy and Guerrero 2004). Color has been shown to influence the efficacy of pheromone traps, and our results for the banana weevil show that not only is brown preferred over the other colors tested but also that mahogany is preferred to other shades of brown. The borer's preference for mahogany brown did not obviate the need for a chemical attractant; however, pheromone-baited traps caught significantly higher numbers of adults than unbaited ones.

Finally, we studied the effect of shading on trap catches as placement is an important factor affecting trap efficacy (Blackmer et al. 2008). Although few reports address the effect of shade or sunlight on trap catches, our results are consistent with those of Arbogast et al. (2007), who reported a marked preference of the small hive beetle, *Aethina tumida* (Murray) (Coleoptera: Nitidulidae), for shaded traps over those placed in sunshine. As there were no significant differences in the temperature of traps placed in the shade or in the sun, it is unlikely that differences in trap catch were related to differential emission rates of the pheromone. Furthermore, as we recorded no differences in either the hue angle or chroma of the traps in sun and shade, it would appear that the differences were not related directly to the color properties of the traps, although this needs to be investigated. The most likely explanation relates to a behavioral preference for shade, possibly because beetles are subject to desiccation in sunlight.

In summary, we have shown that 40×25-cm mahogany brown ground traps baited with pheromone lures and placed in shaded areas of the banana plantation are an efficient tool for catching adult male and female banana borers. Although our experiments were conducted on a small Pacific island, we expect the new trap design to be useful for monitoring and mass trapping of this important pest in larger banana plantations in the mainland.

Acknowledgements This research was supported by Grant #98-34135-6786 from the Tropical and Subtropical Agricultural Research (TSTAR), Special Grants, CSREES, USDA. We thank Mr. Raymond Gumataotao and Ms. Nakita Braganza for help in constructing the traps.

References

Alpizar, D., Fallas, M., Oehlschlager, A. C., Gonzalez, L. M., and Jayaraman, S. 1999. Pheromone-based mass trapping of the banana weevil and the West Indian sugarcane weevil in plantain and banana, 5th International Conference on Plant Protection in the Tropics, Malaysian Plant Protection Society, Kuala Lumpur, Malaysia, March 15–18, 1999.

Alpizar, D., Fallas, M., Oehlschlager, A. C., Gonzalez, L. M., and Jayaraman, S. 2000. Pheromone-based mass trapping of the banana weevil, *Cosmopolites sordidus* (Germar) in plantain and banana, Assoc. for Coop. in Banana Research in the Caribbean and Tropical America bi-annual conference, San Juan, Puerto Rico, July 25–31, 2000.

Arbogast, R. T., Torto, B., Van Engelsdorp, D., and Teal, P. E. A. 2007. An effective trap and bait combination for monitoring the small hive beetle, *Aethina tumida* (Coleoptera: Nitidulidae). *Fla. Entomol.* 90:404–406.

Beauhaire, J., Ducrot, P.-H., Malosse, C., Rochat, D., Ndiege, I. O., and Otieno, D. O. 1995. Identification and synthesis of sordidin, a male pheromone emitted by *Cosmopolites sordidus*. *Tetrahedron Lett* 36:1043–1046.

Blackmer, J. L., Byers, J. A., and Rodriguez-saona, C. 2008. Evaluation of color traps for monitoring *Lygus* spp.: design, placement, height, time of day, and no-target effects. *Crop Prot.* 27:171–181.

Borgelt, A., and New, T. R. 2005. Pitfall trapping for ants (Hymenoptera, Formicidae) in mesic Australia: the influence of trap diameter. *J. Insect Conserv.* 9:219–221.

Brennan, K. E. C., Majer, J. D., and Reygaert, N. 1999. Determination of an optimal pitfall trap size for sampling spiders in a Western Australian jarrah forest. *J. Insect Conserv.* 3:297–307.

Budenberg, W. J., Ndiege, I. O., and Karago, F. W. 1993. Evidence for volatile male-produced pheromone in the banana weevil *Cosmopolites sordidus*. *J. Chem. Ecol.* 19:1905–1916.

Carlton, R. E., and Cardé, R. T. 1990. Orientation of male gypsy moths, *Lymantria dispar* (L.), to pheromone sources: the role of olfactory and visual cues. *J. Insect Behav.* 3:443–469.

Cuthbert, R. A., and Peacock, J. W. 1975. Attraction of *Scolytus multistriatus* to pheromone baited traps at different heights. *Environ. Entomol.* 4:889–890.

Fletcher, T. M., Moore, J. C., and Kitching, W. 1997. Absolute configuration of sordidin and 7-episordidin emitted by the banana weevil, *Cosmopolites sordidus*. *Tetrahedron Lett.* 38:3475–3476.

Fukaya, M., Arakaki, N., Yasui, H., and Wakamura, S. 2004. Effect of colour on male orientation to female pheromone in the black chafer *Holotrichia loochooana loochooana*. *Chemoecology* 14:225–228.

Gold, C. S., Karamura, E. G., and Peña, J. E. 2001. Biology and integrated pest management for the banana weevil *Cosmopolites sordidus* (Germar) (Coleoptera: Curculionidae). *Int. Pest Manage. Rev.* 6:79–155.

Gold, C. S., Okech, S. H., and Nokoe, S. 2002. Evaluation of pseudostem trapping as a control measure against banana weevil, *Cosmopolites sordidus* (Coleoptera: Curculionidae) in Uganda. *Bull. Ent. Res.* 92:35–44.

Jayaraman, S., Ndiege, I. O., Oehlschlager, A. C., Gonzalez, L. M., Alpizar, D., Fallas, M., Budenberg, W. J., and Ahuya, P. 1997. Synthesis and analysis and field activity of sordidin, a male-produced aggregation pheromone of the banana weevil *Cosmopolites sordidus*. *J. Chem. Ecol.* 23:1145–1161.

Koppenhöffer, A. M., Seshu Reddy, K. V., and Sikora, R. A. 1994. Reduction of banana weevil populations with pseudostem traps. *Int. J. Pest Manage.* 40:300–304.

Ladd, T. L., and Klein, M. G. 1986. Japanese beetle (Coleoptera: Scarabididae) response to color traps with phenethyl propionate + eugenol + geraniol (3:7:3) and japonilure. *J. Econ. Entomol.* 79:84–86.

Lanier, G. N., Silverstein, R. M., and Peacock, J. W. 1976. Attractant pheromone of the European elm bark beetle (*Scolytus multistriatus*): isolation, identification, synthesis and utilization studies, pp. 149–175, in J. E. Anderson, and H. K. Kaya (eds.). Perspectives in Forest EntomologyAcademic Press, New York.

Lie, R., and Bakke, A. 1981. Practical results from the mass trapping of *Ips typographus* in Scandinavia, pp. 175–181, in E. E. Mitchell (ed.). Management of Insect Pests with Semiochemicals. Plenum Press, New York.

Messiaen, S. 2001. Evaluation of pheromone baited trapping systems for *Cosmopolites sordidus* Germar (Coleoptera: Curculionidae) in Cameroon. INIBAP 8, Paris.

Mori, K., Nakayama, S., and Takikawa, H. 1996. Synthesis and absolute configuration of sordidin, the male-produced aggregation pheromone of the banana weevil, *Cosmopolites sordidus*. *Tetrahedron Lett.* 37:3741–3744.

NDIEGE, I. O., JAYARAMAN, S., OEHLSCHLAGER, A. C., GONZALEZ, L. M., ALPIZAR, D., and FALLAS, M. 1996. Convenient synthesis and field activity of a male-produced aggregation pheromone for *Cosmopolites sordidus*. *Naturwissenschaften* 83:280–282.

OEHLSCHLAGER, A. C., ALPIZAR, D., FALLAS, M., GONZALEZ, L. M., and JAYARAMAN, S. 2000. Pheromone-based mass trapping of the banana weevil *Cosmopolites sordidus* and the West Indian sugarcane weevil, *Metamasius hemipterus* in banana and plantain. Abstracts XXI Int. Congress Entomol.; Iguassu Falls, Brazil.

REDDY, G. V. P. 2007. Improved semiochemical-based trapping method for old-house borer, *Hylotrupes bajulus* (Coleoptera: Cerambycidae). *Environ. Entomol.* 36:281–286.

REDDY, G. V. P., FETTKÖTHER, R., NOLDT, U., and DETTNER, K. 2005. Capture of female *Hylotrupes bajulus* as influenced by trap type and pheromone blend. *J. Chem. Ecol.* 31:2169–2177.

REDDY, G. V. P., and GUERRERO, A. 2004. Interactions of insect pheromones and plant semiochemicals. *Trends Plant Sci.* 9:253–261.

REDDY, G. V. P., HOLOPAINEN, J. K., and GUERRERO, A. 2002. Olfactory responses of *Plutella xylostella* natural enemies to host pheromone, larval frass, and green leaf cabbage volatiles. *J. Chem. Ecol.* 28:131–143.

SAS INSTITUTE INC. 2004. SAS/STAT user's guide, release 9.13. SAS Institute, Cary.

SIKORA, R. A., BAFOKUZARA, N. D., MBWANA, A. S. S., OLOO, G. W., URONU, B., and SESHU REDDY, K. V. 1989. Interrelationship between banana weevil, root lesion nematode and agronomic practices and their importance for banana decline in the United Republic of Tanzania. *FAO Plant Prot. Bull.* 37:151–157.

SMART, L. E., BLIGHT, M. M., and HICK, A. J. 1997. Effect of visual cues and a mixture of isothiocyanates on trap capture of cabbage seed weevil, *Ceutorhynchus assimilis*. *J. Chem. Ecol.* 23:889–902.

THORNHILL, R., and ALCOCK, J. 1983. The Evolution of Insect Mating Systems. Harvard University Press, Cambridge.

TILDEN, P. E., BEDARD, W. D., WOOD, D. L., LINDAHL, K. Q., and RAUCH, P. A. 1979. Trapping the western pine beetle at and near a source of synthetic attractive pheromone. *J. Chem. Ecol.* 5:519–531.

TINZAARA, W., DICKE, M., VAN HUIS, A., and GOLD, C. S. 2002. Use of infochemicals in pest management with special reference to the banana weevil, *Cosmopolites sordidus* (Germar) (Coleoptera: Curculionidae). *Insect Sci. Appl.* 22:241–261.

TINZAARA, W., DICKE, M., VAN HUIS, A., VAN LOON, J. J. A., and GOLD, C. S. 2003. Different bioassays for investigating orientation responses of the banana weevil, *Cosmopolites sordidus*, show additive effects of host plant volatiles and a synthetic male-produced aggregation pheromone. *Entomol. Exp. Appl.* 106:169–175.

TINZAARA, W., GOLD, C. S., KAGEZI, G. H., DICKE, M., VAN HUIS, A., NANKINGA, C. M., TUSHEMEREIRWE, W., and RAGAMA, P. E. 2005. Effects of two pheromone trap densities against banana weevil, *Cosmopolites sordidus*, populations and their impact on plant damage in Uganda. *J. Appl. Entomol.* 129:265–271.

TINZAARA, W., TUSHEMEREIRWE, W., and KASHAIJA, I. 2000. Efficiency of pheromones and trap type in the capture of the banana weevil *Cosmopolites sordidus* Germar in Uganda. *Uganda J. Agric. Sci.* 5:91–97.

WROLSTAD, R. E., DURST, R. W., and LEE, J. 2005. Tracking color and pigment changes in anthocyanin products. *Trends Food Sci. Tech.* 16:423–428.

WYATT, T. D. 1998. Putting pheromones to work: paths forward for direct control, pp. 445–459, in R. T. Cardé, and A. K. Minks (eds.). Insect Pheromone Research: New Directions. Chapman & Hall, New York.