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Trapping of the coffee berry borer *Hypothenemus hampei* Ferr. (Col., Scolytidae) within a mesh-enclosed environment: interaction of olfactory and visual stimuli

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Abstract: Coffee berry borer (CBB) colonizing females were released within a mesh-tent and recaptured in traps to study the interaction of olfactory and visual stimuli during the flight phase. A 1 : 1 methanol–ethanol mixture was used as an attractant in traps constructed from multiple funnels of red or white. The first aim of the present experiments was to verify that the results obtained in a laboratory olfactometer, in which insects were constrained to walk and in which visual and olfactory stimuli were independently manipulated, could be extended to an outdoor arena enclosed by a net tent. The second aim was to test different emission odour rate, and finally develop a prototype trap which could be used for subsequent studies of CBB population dynamics in the field. Out of 3 000 females released, over 45% were recaptured, among which 95% were collected from traps with methanol–ethanol mixture. The red traps were more attractive than the white traps. The lower the rate of emission of odour, the greater the number of females recaptured. These results show the importance of vision and olfaction for the CBB's flight approach to the trap.

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1 Introduction

Hypothenemus hampei is considered the most important coffee pest in the world. The coffee berry borer (CBB) is present in almost all coffee-producing zones; in the past decade, its range has expanded to include Colombia and all of Central America (see WATERHOUSE and NORRIS, 1989; MATHIEU, 1995 for review). Although chemical control methods are expensive and difficult to apply, they are often the only recourse for controlling populations of this pest. Only a few insecticides provide control, since nearly the entire life cycle of the CBB is spent within coffee berries. Furthermore, CBB strains resistant to endosulfan, the insecticide most commonly used against them, were identified in the late 1980s (BRUN et al., 1989). For this reason, chemical treatment should be seen as temporary stopgap while research teams around the world develop integrated management strategies. Such rational strategies require an improved understanding of CBB population dynamics, ecology and ethology.

Experiments in the laboratory have shown that *H. hampei* locate the coffee berry using visual and olfactory cues produced by the berries during maturation. Several authors have demonstrated that vision and/or olfaction play a role in the CBB's preference for ripe (red) versus immature (green) berries (TICHELER, 1961; MENDOZA MORA, 1991; GIORDANENGO et al., 1993; MATHIEU, 1995). Our work follows up on that of MENDOZA MORA (1991), the only previous author to have carried out trials for trapping *H. hampei*. He shows that a 1 : 1 methanol–ethanol mixture can serve as an attractant in a trap constructed from multiple funnels. However, he does not establish any role for vision for CBB capture, or examine how numbers of insects captured relate to the natural populations present. Our experiments with a static olfactometer confirm the attractiveness of the methanol–ethanol mixture (MATHIEU, 1995). In the present study, two principal objectives were pursued. The first was to verify that the results obtained in a laboratory olfactometer, in which insects were constrained to walk and in which visual and olfactory stimuli were independently manipulated, could be extended to an outdoor arena enclosed by a net tent. The second objective was to develop a prototype trap which could be used for subsequent studies of CBB population dynamics in the field.

2 Materials and methods

2.1 The trap

Numerous traps are documented in the literature for the capture of forest pest scolytids. We chose a "multiple funnel" design (LINDGREN, 1983) for two reasons. First, the only previous experiments in CBB trapping had been carried out with this sort of trap (MENDOZA MORA, 1991). Second, this design has proved effective for the capture of numerous beetle species within varied experimental programmes: whereas CHENIER and PHILOGÈNE (1989a, 1989b) used this kind of trap to measure the effect of kairomones on the capture of forest coleopteran, BORDEN et al. (1987) used it for their study of the plant–insect relations associated with pheromones. Our traps, either white or red, consisted of five funnels; the second and fourth funnel were fitted with a diffuser (fig. 1). We compared three types of dispensers, which emit an ethanol–methanol mixture at rates of approximately 0.5, 1.5, and 20 g/day/dispensers, i.e. at 1 : 3 : 40 ratio.

2.2 The tent

Four traps were placed in a closed tent, which served both as a release zone for colonizing females (i.e. females emerging

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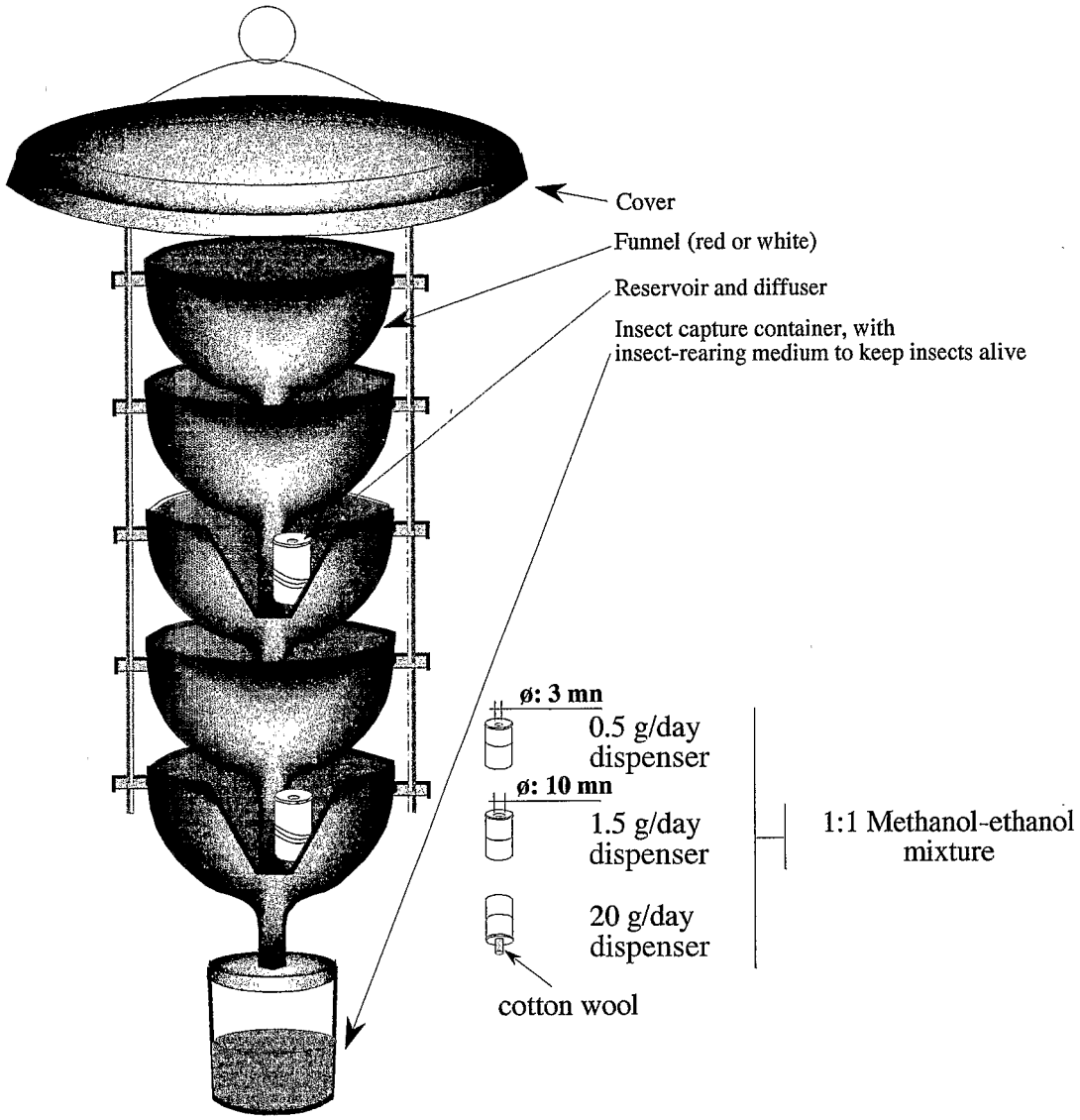

Fig. 1. Multiple funnel trap

from dry berries) and as a recapture area (fig. 2). The tent is made of light tissue similar to mosquito netting, with a mesh size permitting good ventilation, but preventing insects from escaping. Luminosity readings were taken for each of the four positions using a photoelectric cell placed in the centre of the tent (the release point for colonizing females) and oriented toward each of the traps. Trap locations P1 and P3 were near a large green tree, which constitutes a dark vegetational mass. The two other traps were more visible against their background, a white wall.

2.3 Procedure

Three hundred to 400 colonizing females were collected daily, following the protocol of GIORDANENGO et al. (1993) and released at 15.00–16.00 hours at the centre of the tent, from a point equidistant from the four traps. The trapped insects were counted at approximately 08.00 hours the following morning.

Analytical-grade (at least 99% pure) alcohols were used. The solutions were changed every 2 days.

Three factors were studied: the rate of emission of the attractive mixture (Dose); the colour of the trap (Colour); and the position of the trap within the tent (Placement). The four traps used in a tent on a given day were each different: red with odour, red without odour, white with odour, and white without odour. The analysis of the factors "Colour" and "Placement" involved a direct comparison for each day's test, while analysis of "Dose" required two steps: first, to compare the number of insects captured by the traps with odour and without odour; and second, to compare captures at each of the three rates of emission tested. The traps were rotated, such that each Colour–Dose combination was tested twice at each location. Two outcome variables were examined: the percentage of trapped insects/trap (% Trapped insects/trap) and the yield per trap (Yield) (tables 1 and 2). The analysis of each of the two outcome variables employed a three-factor analysis of variance with interaction terms (tables 1 and 2, respectively). The "Dose" factor used in the Anova in table 2 has three levels (0.5 g/day, 1.5 g/day and 20 g/day); the data from traps without odour were excluded from this analysis.

3 Results

The number of replicates, the numbers of insects captured, the percentage of insects harvested per trap, and the trapping yield are summarized in table 3. For the variable "% Trapped insects/trap", three factors, trap "Dose", "Colour" and "Placement", are all highly

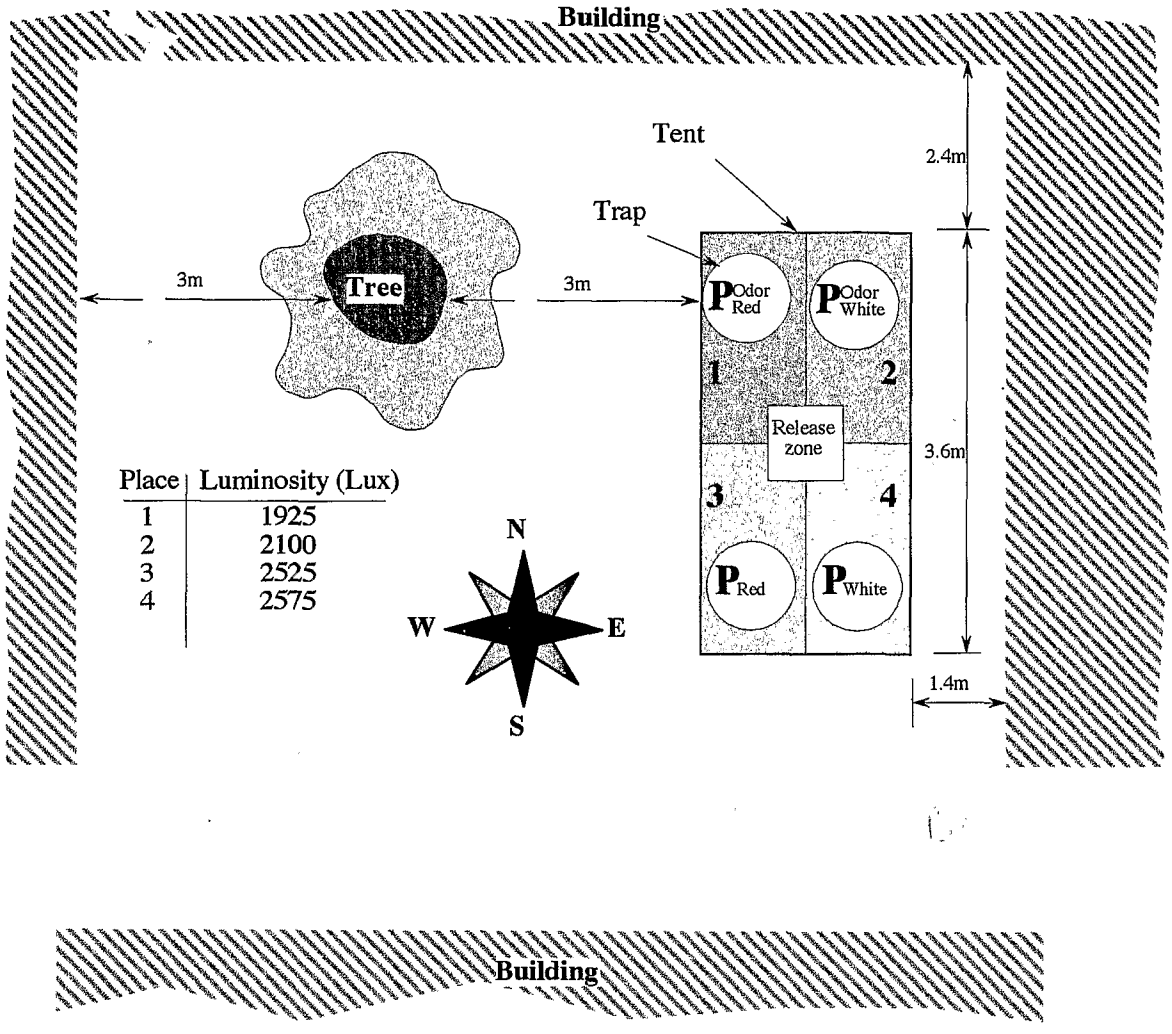

Fig. 2. Experimental layout. The luminosities at locations P1–P4 were measured with a photoelectric cell positioned in the centre of the insect release zone, at a point one metre above ground, i.e. at the average height of the traps. For each level of odour (Dose), the traps were positioned in eight configurations. Each release rate was tested against traps releasing no odour, with two replicates at each of four rotational positions. The factors of trap "Colour' and "Placement" were examined by a direct comparison of numbers of insects captured

significant (table 1). The red traps were more attractive than the white traps, and the traps with odour generally captured more insects than those without odour (table 3). The relationship between "% Trapped insects/trap" and "Placement" is less clear. Nevertheless, it appears that the CBB moved preferentially toward trap locations closest to the tree standing near the tent, i.e., to locations P1 and P3.

For the variable "Yield", the trap factors "Dose" (0.5 g/day, 1.5 g/day, and 20 g/day), "Colour", and

Table 1. *Analysis of variance of the percentage of captured* H. hampei *per trap*

Source	df	Sum of squares	Mean square	F-ratio	Prob
Dose (A)	3	37419.38	12473.13	150.59	0.00
Trap colour (B)	1	6582.32	6532.32	79.47	0.00
Trap placement (C)	3	16477.50	5492.50	66.31	0.00
AB	3	3530.40	1176.80	14.21	0.00
AC	9	1522.04	1691.56	20.42	0.00
BC	3	103.12	34.37	0.42	0.74
ABC	9	206.49	22.94	0.28	0.98
Error	64	5300.93	82.83		

Model: Factorial design with interactions.
Variable: % trapped insects/trap
Dose (A): 0 g/day, 0.5 g/day, 1.5 g/day, 20 g/day; Trap Colour (B): red and white; Trap Placement (C): P1, P2, P3 and P4.
See Figs 1, 2.

Table 2. Analysis of variance of yield per trap

Source	df	Sum of squares	Mean square	F-ratio	Prob
Dose (A)	2	12.34	6.17	25.35	0.00
Trap colour (B)	1	3.42	3.42	14.06	0.00
Trap placement (C)	3	10.37	3.46	14.21	0.00
AB	2	1.01	0.51	2.08	0.15
AC	6	4.24	0.71	2.91	0.03
BC	3	0.42	0.14	0.58	0.63
ABC	6	1.18	0.20	0.81	0.58
Error	24	965.66	40.24		

Data from traps without odour are excluded from the analysis.
Model: Factorial design with interactions.
Variable: ln (Yield + 1)
Dose (A): 0 g/day, 0.5 g/day, 1.5 g/day, 20 g/day; Trap colour (B): red and white; Trap placement (C): P1, P2, P3 and P4.
See Figs 1, 2.

"Placement" are all three highly significant (table 2). The lower the rate of emission of odour (Dose), the greater was the "Yield". The analysis confirms that the red traps captured more insects than the white ones, and that the locations P1 and P3 were more attractive than were places P2 and P4 (tables 2 and 3).

Analyses of variance reveal strong first-order interactions between the factors studied. In the ANOVA of "% Trapped insects/trap" (table 1), two of the three two-factor interactions are highly significant: "Dose" × "Colour", and "Dose" × "Placement". The interaction, "Colour" × "Placement", and the three-way interactions are not significant. In the ANOVA of "Yield", only the "Dose" × "Placement" interaction is significant. The existence of these interactions shows that the factors are dependent on each other, and thus that the variables analysed are not simply the result of linear combinations of these factors.

4 Discussion

These results show the importance of vision and olfaction for the CBB's flight approach to the trap. Of 3000 insects released, 1354 were recaptured: 1267 in traps with odour and 87 in odourless traps. At the three doses tested (0.5, 1.5, and 20 g/day), the traps with lowest emissions showed the best recapture rate. Red colour as well as the presence of a dark-coloured mass near locations P1 and P3 attracted the CBB. Once they took flight, *H. hampei* depended on olfactory and visual stimuli to get their orientation. This phase corresponds well to WOOD's "selection phase" (1982). The insects seem to become oriented toward a relatively large dark mass and toward a source of attractive odour. These results correspond to the role of olfaction and of vision for host recognition observed in walking CBB (TICHELER, 1961; MENDOZA MORA, 1991; GIORDANENGO et al., 1993; MATHIEU, 1995).

The visual stimuli studied elsewhere (MATHIEU, 1995) to play a role are different from those examined here. In MATHIEU (1995), *H. hampei* was shown to be attracted to spherical 1.5 cm diameter objects perceived from a short range. In this case, the stimulus consisted of conical forms lined up along a metre-long vertical axis. This silhouette was perceived from a distance ranging from 1 m to several cm, depending on the position of the insects in the tent. While the first case corresponds to the beetles' perception of coffee from a very short distance or upon contact, the second is difficult to transpose to nature. The dark coloration representing the dark mass of a tree may be attractive; the vertical silhouette representing the form of a tree or a branch may also be attractive. In both cases, the insect moves toward a dark-coloured zone or object. SCHÖNHERR (1977) observed that similar stimuli attract the scolytids, *Ips montanus* and *Dendroctonus ponderosae*, and showed that they are attracted by vertical motifs. Likewise, CHENIER and PHILOGÈNE (1989b) suggest that the vertical silhouette of tube traps may contribute to their effectiveness.

Olfactory stimulation was provided in this study by a methanol–ethanol mixture. MATHIEU (1995) has shown that both compounds are present in the odours emitted by ripe coffee berries. The effectiveness of this mixture in attracting CBB confirms a previous trapping study (MENDOZA MORA, 1991), as well as the results of our own olfactometric tests in the laboratory (MATHIEU, 1995). Nevertheless, different coffee varieties also emit many other substances (MATHIEU et al., 1996) whose role in host perception has not yet been determined. In contrast to methanol, ethanol is often cited in studies of forest scolytids as attracting beetles, either as a synergist (VOLZ, 1988; SCHROEDER and LINDELÖW, 1989) or when presented alone (MOECK, 1981).

With this apparatus, the olfactory and visual stimuli were tested simultaneously, in contrast to previous studies where they were examined independently (TICHELER, 1961; MENDOZA MORA, 1991; GIORDANENGO et al., 1993; MATHIEU 1995). Our set-up allowed us to examine first-order interactions between olfactory and visual stimuli. The interactions between "Dose" and "Placement" (tables 1 and 3) show that high emission rates (20 g/day) tend to reduce the impact of "Placement" on the distribution of CBB among traps (table 3). The interaction between "Dose" and "Colour" (Table 1) shows that the attractiveness of red traps in relation to white traps depends on the dose emitted by the traps. It thus appears that the phototactic and/or phototropic responses depend on the presence and intensity of the olfactory stimulus perceived by the insect. The inter-

Table 3. *Summary table of data for trapping in a mesh tent-enclosed arena*

Trap colour	Trap placement	Data	Dose 0 g/day	0.5 g/day	1.5 g/day	20 g/day	Total
White	P1	No. replicates	6	2	2	2	12
		Σ No insects captured	6	178	106	11	301
		Mean % trapped insects/trap	2.77	63.63	80.05	27.63	29.94
		Mean yield	0.26	22.25	13.25	1.38	6.28
	P2	No. replicates	6	2	2	2	12
		Σ No. insects captured	7	9	9	7	32
		Mean % trapped insects/trap	1.53	7.26	14.52	14.77	6.86
		Mean yield	0.29	1.42	1.16	0.88	0.72
	P3	No. replicates	6	2	2	2	12
		Σ No. insects captured	6	64	68	4	142
		Mean % trapped insects/trap	3.46	58.23	62.77	18.18	24.93
		Mean yield	0.25	9.29	8.50	0.50	3.17
	P4	No. replicates	6	2	2	2	12
		Σ No. insects captured	3	15	19	10	47
		Mean % trapped insects/trap	2.59	8.82	15.93	24.30	9.47
		Mean yield	0.13	1.88	2.38	1.25	0.98
No. replicates (White Trap)			24	8	8	8	48
Σ No. insects captured (White Trap)			22	266	202	32	522
Mean % trapped insects/trap (White Trap)			2.59	34.49	43.32	21.22	17.80
Mean yield (White Trap)			0.23	8.71	6.32	1.00	2.79
Red	P1	No. replicates	6	2	2	2	12
		Σ No. insects captured	27	270	63	46	406
		Mean % trapped insects/trap	12.28	93.98	82.15	63.64	46.10
		Mean yield	1.18	33.75	8.31	5.75	8.56
	P2	No. replicates	6	2	2	2	12
		Σ No. insects captured	17	47	37	13	114
		Mean % trapped insects/trap	11.42	39.98	23.45	49.15	24.47
		Mean yield	0.71	6.88	4.63	1.63	2.54
	P3	No. replicates	6	2	2	2	12
		Σ No. insects captured	11	103	75	15	204
		Mean % trapped insects/trap	4.75	78.66	71.31	61.19	37.57
		Mean yield	0.47	14.58	9.38	1.88	4.54
	P4	No. replicates	6	2	2	2	12
		Σ No. insects captured	10	62	14	22	108
		Mean % trapped insects/trap	5.42	28.07	19.93	59.71	20.66
		Mean yield	0.42	7.75	1.75	2.75	2.25
No. replicates (Red Trap)			24	8	8	8	48
Σ No. insects captured (Red Trap)			65	482	189	96	832
Mean % trapped insects/trap (Red Trap)			8.47	60.17	49.21	58.42	32.20
Mean yield (Red Trap)			0.69	15.74	6.01	3.00	4.47
Total No. replicates (Red and white Trap)			48	16	16	16	96
Total Σ No. insects captured			87	748	391	128	1354
Total Mean % trapped insects/trap			5.53	47.33	46.26	39.82	25.00
Total Mean yield			0.46	12.22	6.17	2.00	3.63

$$\text{Mean \% trapped insects/trap}_{P,j} = \frac{\text{No. insects captured}_{Pj}}{\Sigma_P \text{ No. insects captured}_{P,j}} \times 100$$

$$\text{Mean yield}_{P,j} = \frac{\text{No. insects captured}_{Pj}}{\Sigma_P \text{ No. insects captured}_{j}} \times 100$$

with P: Trap number and j: day of reading.

actions between visual and olfactory stimuli have received little attention. However, PAYNE (1986) holds that vertical forms in the presence of odour play an important role in the founding of new colonies of *Dendroctonus frontalis* (Col., Scolytidae).

So-called "semi-controlled" experimental arrange-

ments offer a large field for investigation: the flight orientation of *H. hampei* in response to simultaneous olfactory and visual stimuli. The capacity to test simultaneously the visual stimuli provided by an object (here, the trap) and by the background (here, the tree and the white walls), and the olfactory stimulus of a mix of odours will make it possible to improve our understanding of the multimodal mechanisms of host orientation. This apparatus has also enabled us to fine-tune our use of traps in field experiments (data under analysis). Traps are now used in the field as follows: Traps consist of multiple funnels with a reception box containing ground insect-rearing medium (BRUN et al., 1993). Red traps are used, and positioned at chest height, in shady locations immediately beside coffee trees. The trap dispensers are fixed for the smallest emission dose (0.5 g/day/dispensers). The development and evaluation of a trapping system will allow us to propose a useful tool in the implementation of a integrated strategy for the control of this pest.

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