Optimization of coffee berry borer, *Hypothenemus hampei* Ferrari (Col., Scolytidae), mass trapping with an attractant mixture

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Keywords
attractant, capture, coffee berry borer, integrated CBB management, kairomone, mass trapping

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Received: October 11, 2007; accepted: February 26, 2008.

doi: 10.1111/j.1439-0418.2008.01291.x

Abstract

Mass trapping is a technique currently being considered to control the coffee berry borer (CBB), *Hypothenemus hampei* Ferrari (Col., Scolytidae), as part of the integrated management of its populations. However, the research undertaken in this field has variable and sometimes contradictory results. The purpose of this study carried out with a single type of trap (experimental model '1B') was to evaluate the technique and define parameters for its efficient use. The first result obtained was detection of the excellent attractant properties of the ethanol–methanol mixture, and its efficiency related to the proportion of the two alcohols. Coffee borers were not attracted to traps with caffeine, green coffee powder, freshly pulped and hulled coffee berries and ground CBB. It was shown that the ethanol–methanol mixture (1 : 1) release rate varied without affecting the capture rate, and that the red colour of the trap substantially increased CBB attraction. In terms of trap set-up, it was found that capture rates were three times better with a trap height at 1.2 m, than that for a position near ground level. In addition, the best density of traps for achieving efficient mass trapping was 22 units per hectare. These results show the importance of developing an attractant using pure compounds, and of improving the trap and the trapping technique in line with CBB behaviour.

Introduction

The coffee berry borer (CBB), *Hypothenemus hampei* Ferrari (Col., Scolytidae) is the main pest of coffee plants worldwide (Bustillo 2006). This pest affects species of great economic importance, such as *Coffea arabica* L. and *Coffea canephora* Pierre. Only fruits are attacked. Damage is caused by galleries mined in the seeds by the CBB to feed and reproduce (Decazy 1990). Chemical control of CBB began as soon as it was introduced into South and Central American coffee-producing countries. However chemical control is increasingly being abandoned because of its negative impact on human health and the environment, leaving the way for cultural, biological and ethological control. Mass trapping is one of the most promising alternatives to CBB control. This strategy is based on understanding the behaviour of colonizing females, especially during the post-harvest period, when they leave residual fruits to search for new host fruits suitable for the development of a new generation (Mathieu et al. 1997a).

Several authors highlighted the attractive properties of the coffee berries for the CBB. Giordanengo et al. (1993) showed that volatile compounds (kairomones) released by berries attracted CBB females, thus facilitating the colonization mechanism. Corbett (1933) suspected the attraction of CBB females to coffee berries in a variety of susceptibility studies. Ticheler (1961) found olfaction-related responses in CBB females placed in contact with berries, but minimum attention was paid to that activity in favour of

visual attraction. More recently, using the dynamic headspace collection technique, Mathieu et al. (1996, 1998) identified 45 volatile compounds emitted by fresh *C. arabica* and *Coffea canephora* var. Robusta berries at different degrees of ripeness and demonstrated that the chemical composition of berry effluvia changed during berry ripening. Mathieu et al. (2001) demonstrated that the process leading to host location relies on chemical and visual cues released by ripe berries, acting only on colonizing females characterized as mated females, leaving the berries where they were born.

Various studies of CBB attraction and capture have previously been carried out to investigate the efficacy of chemical attractants, coffee berry extracts, and different shapes and size of traps. A mixture of ethanol and methanol was found to be attractive in field trapping (Mendoza Mora 1991; Mathieu et al. 1997b), and high proportions of those alcohols were identified in berry effluvia (Mathieu 1995). Ethanol and methanol are currently the best known attractants for trapping CBB, yet berry extracts may attract CBB better than the two alcohols (Velasco Pascual et al. 1997). There may also be synergistic effects because of the presence of other components in berry extracts. In addition, Gutiérrez-Martínez and Ondarza (1996) reported an increase in CBB attraction to ripe coffee berry extracts and to caffeine dissolved in ethanol, whereas Borbón-Martínez et al. (2000) and Cardenas (2000) failed to confirm the attractiveness of coffee berry extracts and caffeine to CBB respectively. All these studies with contradictory results justified new experiments designed to develop trapping techniques to control CBB populations. The idea of using CBB olfaction to develop mass trapping strategies has been considered by several authors. For instance, Gutiérrez-Martínez et al. (1995b) succeeded in catching large quantities of CBB, and reducing damage, using home-made traps baited with a mixture of coffee berry extracts, ethanol and methylene chloride, distributed systematically in CBB-infested coffee plantations. However, the system was not subsequently improved upon. More recently, Mathieu et al. (1997b) and Borbón-Martínez et al. (2000) obtained capture results with different multiple funnel traps based on the design described by Lindgren (1983), but these models were not found to be practical for use in coffee plantations because of their design.

Mass trapping is a technique aimed at eliminating the different waves of colonizing females surviving and developing in dry berries left in the field (Dufour et al. 2000). Such residual berries serve as veritable CBB reservoirs (Corbett 1933; Decazy 1990) and are difficult to eliminate as they require very careful, labour-intensive picking over a long period. When surviving colonizing females leave the dry berries, very few suitable berries are present in the field. Thus, with a good attractant, efficient traps and an adequate technique, it can be expected that the waves of colonizing females can be drastically reduced, especially in the absence of natural attractive berries that might compete with synthetic attractants. To achieve that objective, several parameters that might increase capture numbers were studied. The first research question was to assess different attractant mixtures composed of ethanol and methanol, along with products tested by Gutiérrez-Martínez et al. (1995a,b): caffeine, green coffee powder, mashed fresh coffee berry filtrate and a ground CBB extract, in order to select the best combination. The second research question was to find the best diffusion rate for the selected mixture and see if the colour of the dispensers and traps might have a decisive effect on CBB attraction. Finally, it was important to specify the role of trap height and the number of traps per unit area, in order to make the trapping technique more effective.

Materials and Methods

Experimental site

The trials were carried out in the central region of El Salvador, in a 200-ha private coffee plantation generating relatively moderate yields of around 800 kg of green coffee per hectare. Similar to most of the plantations in that country, it was planted with *C. arabica*, var. Bourbon, grown with shade canopies (40–60% canopy cover), largely dominated by trees of the genus *Inga*. Annual agricultural upkeep was ensured with moderate management, characterized by moderate coffee tree pruning, shade regulation, one or two rounds of manual weeding and a single round of fertilization. CBB control was virtually the only control activity undertaken in the plantation. It was limited to simple sanitation harvesting of residual fruits. The experimental site was located at an elevation of 900 m above sea level, and displaying suitable ecological conditions for CBB development. The trial period began in February, in the middle of the dry season, a month after the end of the coffee harvesting season. At that time, the future colonizing CBB females survived in residual fruits.

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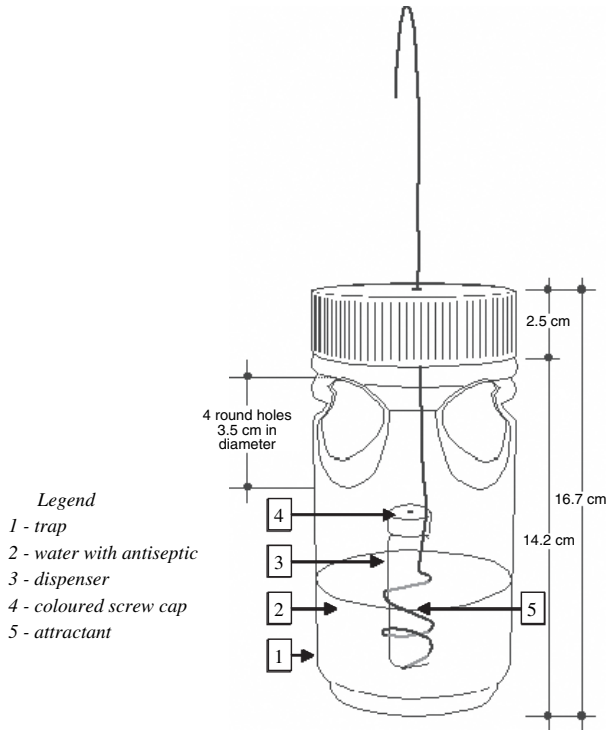

Fig. 1 Model '1B' CBB trap.

The trap

We used one type of trap in our work ('1B' model, precursor of Brocap® trap; PROCAFE, Santa Tecla, El Salvador, and CIRAD, Montpellier, France). It was a cylindrical container made of transparent plastic, with a capacity of 750 ml, fitted with a white lid. The upper third of the container was pierced with four circular holes 3.5 cm in diameter that allowed the attractant mixture to diffuse from the trap and the insects to enter the trap (fig. 1).

The trap contained 200–250 ml of water and three drops of wetting agent (Teepol HB7; Sigma, St Louis, MO, USA). CBB entering the trap automatically fell into the water where they drowned. In order to slow down insect decomposition, four drops of sodium hypochlorite solution (2.6% of active chlorine) was added to the capture liquid. Under normal conditions of use, each trap was hung from a coffee tree branch so that the holes were located around 1.20 m from the ground. In one trial, another trap height was used: 0.40 m.

The dispenser

The dispensers used were 8 ml transparent glass vials closed by a screw cap pierced with a hole, the size of which modified the release rate. Three hole diameters were used: 2, 4 and 6 mm. The diffusion rates corresponded to the mean values of the weights of attractant lost per dispenser and per treatment, measured by the difference between the beginning and the end of each trial, and considered in 'day' units (Montgomery and Wargo 1983; Schroeder 1988).

The attractants

We tested five attractive or presumably attractive mixtures. The reference mixture used in all the trials consisted of 95% ethanol and commercial methanol (100%). In accordance with the methodology proposed by Mathieu et al. (1997b), the two alcohols were used undiluted. The volume of the mixture was 7 ml, in a ratio of 1 : 1. Pure caffeine powder was purchased from Sigma. The dilution was 50 mg in 7 ml of the reference mixture, which corresponded to a higher concentration than that tested by Gutiérrez-Martínez et al. (1995b) (0.04 mg in 7 ml of ethanol).

The green coffee powder was obtained by grinding fresh Robusta coffee beans and 1 g of the powder was added to 7 ml of reference mixture. The berry extract was obtained by crushing 500 g of fresh ripe Robusta berry residues (epicarp and mesocarp), obtained after pulping, in 200 ml of 95% ethanol, using an electric laboratory mill for 10 min. In each dispenser, 1 ml of the extract was added to 6 ml of reference mixture. In this case the mixture obtained contained a little more ethanol than methanol (approx. 51 : 43) compared with the reference mixture, with a proportion of water coming from the pulp. In order to reveal any volatile attractants produced by CBB (Giordanengo 1992), 1 ml of ground CBB extract was added to 6 ml of the reference mixture. The extract was obtained by crushing 2 g of female CBB that had recently emerged from their residual berries, in 10 ml of 95% ethanol, followed by filtration. Likewise, the proportion of ethanol and methanol in the mixture with extract (approx. 57 : 43) was different from that of the reference mixture.

Colour tests

In the dispenser colour test, the upper surface of the dispenser (screw cap) was painted white, red or black and the trap was transparent. In the trap colour test, the trap was painted white, red, yellow or black and the upper surface of the dispenser was black. The colour reference was given by the

Pantone colour formula guide 1000, a component of Pantone Matching System® (Pantone Inc., Carlstadt, NJ, USA), for three colours: 186 C for red, 109 C for yellow and 2C 2X for black.

Trap set-up and statistics

Trials focusing on attractants, diffusion, trap colour and height were set up in single plots of 60×120 m, 60×180 m and 60×240 m, for two, three and four treatments, respectively, with 16 traps per treatment. The traps were installed in a regular grid perfectly centred in relation to the plots boundaries. The plots were divided into a 15×15 m squares, of which the four corners were each occupied by a trap. In that way, the effect of each trap was approximately the same everywhere. On the other hand, the treatments were randomly distributed in the plots. The statistical unit was therefore the trap. The capture results were analysed by Kruskall–Wallis or Mann–Whitney non-parametric tests.

The trial for determining the best trap density was conducted in four blocks of 240×60 m comprising four identical plots of 60×60 m, each for a different treatment. The treatments were 4, 8, 12 and 16 traps per plot. The traps were installed in accordance with the same grid system as mentioned previously, but in which the size of grid squares differed. The plots were divided up into 30×30, 21.2×21.2, 17.3×17.3 and 15×15 m squares respectively. The statistical unit was the plot. The results were assessed by a Friedman non-parametric test.

Results

Relative attractiveness of alcohol and other compounds

The capture results obtained in the field slightly before the high migration period indicated that the ethanol–methanol mixture was much more attractive than methanol alone (table 1). The second trapping results obtained in the high migration period, using ethanol and methanol, separately or in a mixture (table 2), showed that ethanol alone was not attractive, with only 0.36% of total captures, i.e. 0.30% more than the control with water as bait. Methanol used alone gave a better capture level, with 6% of total captures. The ethanol–methanol mixture (1 : 1) had higher efficiency, with more than 93% of total captures. A comparison of the three mixtures containing different proportions of ethanol and methanol in trials conducted at the end of the high migration period showed that the capture level did not significantly differ between the three proportions tested (table 3). All of them remained significantly higher ($P < 0.05$) than methanol used alone.

Table 1 Comparison of capture rates with methanol only

Duration: 5 days. Attractants: T1 = 7 ml ethanol–methanol (1 : 1), T2 = 7 ml methanol. Replicates = 12

	T1	T2
Average captures per trap and per day	30.07	11.13
Standard deviation	19.91	4.86
Sum of ranks	215.5	84.5
U-test	6.5	137.5
Mann–Whitney test: $P < 0.01$, thresholds 5% and 1%	107	117

Table 2 Comparison of capture rates with ethanol, methanol and a mixture of the two

Duration: 11 days. Attractants: T1 = 7 ml ethanol–methanol (1 : 1), T2 = 7 ml ethanol, T3 = 7 ml methanol, T4 = 7 ml water (absolute control). Replicates = 16

	T1	T2	T3	T4
Average captures per trap and per day	370.50	1.44	24.13	0.25
Standard deviation	395.98	1.21	21.35	0.17
Sums of ranks	645	138	393	–
Kruskall–Wallis test:* $H = 41.00$, $P < 0.001$, d.f. = 2	A	C	B	

*Kruskall–Wallis test with T1, T2 and T3 only.
†The same letter indicates that there was no significant difference, with a probability of 5%.

Table 3 Comparison of the capture rates with different ethanol–methanol mixtures

Duration: 4 days. Attractants: T1 = 7 ml ethanol–methanol (1 : 1), T2 = 7 ml ethanol–methanol (3 : 1), T3 = 7 ml ethanol–methanol (1 : 3), T4 = 7 ml methanol only. Replicates = 16

	T1	T2	T3	T4
Average captures per trap and per day	110.92	92.16	100.83	33.44
Standard deviation	101.65	75.29	167.46	20.19
Sum of ranks	646.5	589.5	553	291
Kruskall–Wallis test: $H = 13.41$, $P < 0.01$, d.f. = 3*	A	A	AB	B

*The same letter indicates that there were no significant differences, with a probability of 5%.

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Table 4 Comparison of capture rates with the ethanol–methanol mixture in the presence of caffeine and green coffee powder

Duration: 7 days. Attractants: T1 = 7 ml ethanol–methanol (1 : 1), T2 = 7 ml ethanol–methanol (1 : 1) + 0.05 g of caffeine, T3 = 6 ml ethanol–methanol (1 : 1) + 1 g of green coffee powder. Replicates = 16

	T1	T2	T3
Average captures per trap and per day	20.67	19.77	20.01
Standard deviation	12.51	11.14	9.79
Sum of ranks	384	390	402
Kruskall–Wallis test: H = 0.05, NS, d.f. = 2*	A	A	A

*The same letter indicates that there was no significant difference, with a probability of 5%.

Table 5 Comparison of capture rates with the ethanol–methanol mixture in the presence of freshly pulped and hulled coffee berry extract and ground CBB alcohol suspension

Duration: 11 days. Attractants: T1 = 7 ml ethanol–methanol (1 : 1), diffusion rate = 0.16 g/dispenser/day; T2 = 6 ml ethanol–methanol (1 : 1) + 1 ml pulped coffee berry extract, diffusion rate = 0.12 g/dispenser/day; T3 = 6 ml ethanol–methanol (1 : 1) + 1 ml ground CBB alcohol suspension, diffusion rate = 0.14 g/dispenser/day. Replicate = 12

	T1	T2	T3
Average captures per trap and per day	18.80	10.79	12.52
Standard deviation	9.08	7.00	8.91
Sum of ranks	297	173	196
Kruskall–Wallis test: H = 6.35, P < 0.05, d.f. = 2*	A	B	AB

*The same letter indicates that there was no significant difference, at a probability of 5%.

The trapping results obtained with the ethanol–methanol mixture (1 : 1) alone and the mixture containing caffeine or fresh green coffee powder are shown in table 4. The analysis showed that adding pure caffeine or green coffee powder did not increase the level of catches. The alcohol extract of freshly pulped and hulled coffee berries and the crushed CBB females did not increase capture levels either (table 5).

Diffusion

The question addressed in these experiments was relative to the release rate of the ethanol–methanol mixture (1 : 1) and the capture rate. The capture results shown in table 6 refer to three diffusion rates for the ethanol–methanol mixture (1 : 1): 0.174, 0.366 and 0.476 g per dispenser per day, corresponding to hole sizes of 2, 4 and 6 mm in diameter respectively. The increase in release rate did not significantly affect the capture rate (table 6).

Table 6 Influence of 1 : 1 ethanol–methanol mixture diffusion rates on CBB captures

Duration: 7 days. Attractants: 7 ml ethanol–methanol (1 : 1), Diffusion rate: T1 = 0.174 g/dispenser/day, T2 = 0.366 g/dispenser/day, T3 = 0.476 g/dispenser/day, Replicate = 16

	T1	T2	T3
Average captures per trap and per day	7.60	7.44	9.80
Standard deviation	7.42	8.12	8.04
Sum of ranks	374.5	355.5	446
Kruskall–Wallis test: H = 1.45, NS, d.f. = 2*	A	A	A

*The same letter indicates that there was no significant difference, with a probability of 5%.

Colour responses

The dispenser colour tested alone under natural conditions did not have a significantly effect on capture levels (table 7). However, a change in trap colour gave completely different results. For instance, red was significantly more attractive than the other three colours: black, yellow and white.

Influence of trap height

The results of the trials comparing two trap heights, 0.40 and 1.20 m, showed that the CBBs were caught in much greater numbers in traps placed higher up (table 8).

Mass trapping efficiency depending on the number of traps per unit area

The average numbers of CBB caught with different trap densities could be classed into two distinct groups and one intermediate group, based on the results of the Friedman test (table 9). With densities of 8 and 16 traps per 3600 m^2, the trapping level was not significantly different. With 4 traps per 3600 m^2 the capture level fell by half. Under our experimental conditions, the best density tested was therefore 8 per 3600 m^2, or around 22/ha.

Table 7 Influence of colour on CBB captures

	Dispenser colour			Trap colour			
	Duration: 5 days Attractant = 7 ml ethanol–methanol (1 : 1) Transparent trap T1 = white dispenser T2 = red dispenser T3 = black dispenser Replicates/treatment = 16			Duration: 13 days Attractant = 7 ml ethanol–methanol (1 : 1) Dispenser with a black upper surface T′1 = white trap T′2 = red trap T′3 = yellow trap T′4 = black trap Replicates/treatment = 16			
	T1	T2	T3	T′1	T′2	T′3	T′4
Average captures/trap/day	385.13	342.73	216.88	49.78	290.14	102.83	96.42
Standard deviation	531.90	426.50	124.55	41.52	208.45	72.82	87.63
Sum of ranks	429	390	357	288	820	508	464
Kruskall–Wallis test*	A	A	A	B	A	B	B
	H = 0.83, NS, d.f. = 2			H = 26.52, P < 0.001, d.f. = 3			

*The same letter indicates that there was no significant difference, with a probability of 5%.

Table 8 Effect of trap height on CBB captures

Duration = 10 days. Attractant: 7 ml ethanol–methanol (1 : 1). Position: T1 = lower position (0.40 m)*, T2 = upper position (1.20 m).* Replicates = 16

	T1	T2
Average captures per trap and per day	5.20	18.61
Standard deviation	2.52	8.09
Sum of ranks	136	392
U-test	256	0
Mann–Whitney test: P < 0.01; thresholds 5% and 1%	181	196

*Distance between ground level and trap orifices.

Diffusion results

For a given attractant, diffusion measurement usually differed little on a treatment scale or even a trial scale. In most cases, the coefficient of variation fluctuated between 1.95% and 14.84% (table 10), not exceeding the 15% upper limit generally accepted for trial validation (Snedecor and Cochran 1971). Some extreme conditions, such as exposure to strong sunlight, or intense shade, could lead to an increase in that coefficient, without any consequences for captures. It needs to be pointed out that for the same kind of dispenser, the daily diffusion rate for the ethanol–methanol mixture varied substantially from one trial to another: from 0.138 g/day for the lowest to 0.209 g/day for the highest.

Table 9 CBB capture in 3600 m^2 depending on the number of traps

Duration: 7 days. Attractants = 7 ml ethanol–methanol (1 : 1). Quantity of traps: T1 = 4 per 3600 m^2, T2 = 8 per 3600 m^2, T3 = 12 per 3600 m^2, T4 = 16 per 3600 m^2

	Replicates	T1	T2	T3	T4
Captures per plot (3600 m^2), per replicate and per day	1	833.14	2025.71	1461.71	1997.14
	2	536.00	1083.57	875.57	2515.00
	3	835.57	1676.43	1573.86	1736.43
	4	1127.86	2697.14	2440.29	2455.14
Average captures per plot (3600 m^2) and per day		833.14	1870.71	1587.86	2175.93
Standard deviation		169.14	472.06	451.86	261.31
Sum of ranks		4	14	8	14
Friedman test:* χ^2 = 10.8, P < 0.05, d.f. = 3		B	A	AB	A

*The same letter indicates that there was no significant difference, with a probability of 5%.

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Table 10 Diffusion results for all the trials

Trial	Treatment*	Diffusion rate (g/dispenser/day)	Standard deviation (g/dispenser/day)	Coefficient of variation (%)
Comparison of capture rates with methanol only	T1	0.162	0.021	13.01
	T2	0.191	0.028	14.84
Comparison of capture rates with ethanol, methanol and a mixture of the two	T1	0.068	0.012	18.23
	T2	0.138	0.021	15.61
	T3	0.204	0.026	12.95
	T4	Not measured		
Comparison of capture rates with different ethanol–methanol mixtures	T1, T2, T3, T4	Not measured		
Comparison of capture rates with the ethanol–methanol mixture combined with caffeine and green coffee powder	T1	0.182	0.004	1.95
	T2	0.182	0.004	2.02
	T3	0.182	0.005	2.72
Comparison of capture rates with the ethanol–methanol mixture combined with pulped coffee berry extract and ground CBB	T1	0.159	0.019	11.99
	T2	0.118	0.008	6.95
	T3	0.142	0.031	21.49
Influence of 1 : 1 ethanol–methanol mixture diffusion rate on CBB captures	T1	0.174	0.010	5.51
	T2	0.366	0.028	7.65
	T3	0.476	0.028	5.83
Influence of colour on CBB captures	T1	0.199	0.029	14.58
	T'1 + T'2 + T'3 + T'4	0.209	0.014	6.51
Effect of height on CBB captures	T1	0.208	0.014	6.94
	T2	0.184	0.016	8.59
CBB capture efficiency per unit area depending on the number of traps	T1 + T2 + T3 + T4 (replicate 1)	0.167	0.011	6.35

*All the treatments correspond to the treatments already described in the other tables.

Discussion and Conclusion

This project was designed to develop a trapping technique useful for controlling CBB. More specifically, the project aim was to identify the best attractant, make improvements to the trap and to fine-tune the technique in order to improve capture efficiency for a true control method. Field testing was carried out throughout the migration period as CBB abandoned the fruits left behind from the final harvest, which explained the abundance of captures and, consequently, the short duration of most of the tests.

The higher capture rates obtained with the ethanol–methanol mixture compared with that obtained when methanol was tested separately indicates a true synergistic effect and confirms previous observations by Mendoza Mora (1991), Mathieu (1995) and da Silva et al. (2006). Similarly, the synergistic attractant effect of methanol and (−)α-pinene mixture was previously reported for *Tomicus piniperda* (L.) (Curculionidae: Scolytinae) by Schroeder and Lindelöw (1989), Vité et al. (1986) and Zumr (1989).

In contrast to reports by Mendoza Mora (1991), CBB response to ethanol alone was minimal (table 2). It is possible that the difference in response depended on the degree of purity of ethanol. The reinforcement of the activity of the ethanol–methanol attractant with coffee berry extracts was one aspect of trapping investigated by Gutiérrez-Martínez et al. (1995a,b), using impregnated pieces of cork as the diffusion system. In our trials, adding either caffeine or green coffee powder to the ethanol–methanol mixture did not have a synergistic effect. Caffeine is a secondary metabolite with low volatility, which has not been identified in coffee berry effluvia (Mathieu et al. 1998). With the extracts of fresh pulped berries and crushed CBB females added to the ethanol–methanol mixture, no synergistic effect was induced. Although the proportions of methanol in those mixtures were slightly lower than in the control mixture, they did not explain the reduction in the capture levels, as we saw previously

that changes in proportions of ethanol and methanol only slightly modified capture levels, if at all. This investigation into the attractants resulted in the ethanol–methanol mixture (1 : 1) being identified as the most efficient. It was therefore used for the other tests.

The study of ethanol–methanol mixture diffusion showed that variations in the diffusion rate had very little effect on captures. According to Mendoza Mora (1991), trapping yield increased for decreasing rates of 0.12–0.06 g/day, and for a ethanol–methanol mixture of the type 1 : 3. According to Mathieu et al. (1997b), catches decreased for release rates ranging from 1.5 to 20 g/day. A similar response was obtained with *T. piniperda* for higher ethanol and α-pinene diffusion rates than those found in the field (Schroeder 1988). In that context, CBB olfaction might be affected by a saturation effect of the antenna receptors, which could be accentuated by an increase in emissions caused by the rise in temperature as has been shown for *T. piniperda* (Czokajlo and Teale 1999). On the whole, variations in the mixture composition were found to affect capture rates more than variations in the quantities diffused, suggesting that CBB was sensitive to a very precise mixture composition. In coffee plantations, CBBs apparently attack all the coffee trees regardless of the quantity of berries on the tree. Thus, they do not appear to be particularly sensitive to variations in the quantities of attractive effluvia emitted by berries in a plantation. In practice, a low diffusion rate is an advantage for large-scale trapping because less attractant is used.

The results obtained with the dispensers corroborated Mathieu's (1995) observations showing that CBBs can only distinguish between colours at very short distances of around 1 cm. CBBs did not detect the colour of the dispensers before entering the trap because the distance between the dispenser and the trap entrance was at least 3 cm. When the colour was applied to the outside of the traps, CBB detected it before entering the traps. Consequently, the colour provided an additional stimulation to that initially provided by the effluvia of the ethanol–methanol mixture and facilitated capture. In our experiment with trap colours, CBB reacted more to red than to the other colours. A similar trial carried out with red and white traps (Mathieu et al. 1997b) showed the same trend. Borbón-Martínez et al. (2000) showed that white was more attractive than black, yellow, red, blue and green. On the other hand, the results obtained with coloured beads simulating coffee berries (Ticheler 1961; Mendoza Mora 1991; Mathieu 1995) showed that black was more attractive or as attractive as red and that yellow and white were significantly less attractive than red and black. This result could be explained by a visual capacity of the insect in which red is assimilated as black (Mathieu 1995).

For the first time, the foundations of a mass trapping system have been laid, by specifying the height of traps and their layout in plots. In migration periods, colonizing female populations leave residual fruits in vast numbers and take flight. The instability and precariousness of their flight (Baker 1984) would suggest that the best captures would be achieved with traps placed in low positions. It was shown that traps placed 1.2 m from the ground appeared to capture much more CBB than traps placed at 0.4 m. The best trap density that we observed amounted to 8/3600 m^2, for model '1B' since with that density the quantity of CBB was twice as high as with 4 traps per 3600 m^2. The reduction in insect capture observed with 12 traps per 3600 m^2 can only be explained by a putative disruption of orientation of flying females. The diffusion rate of the ethanol–methanol mixture showed some variations which did not affect captures. Environmental factors, such as temperature,

Table 11 Summary showing the absolute highest captures rates

Factor	Product	Average captures per trap and per day				
Alcohol mixtures and other compounds	Ethanol–methanol (1 : 1)	30.07	370.50	110.92	20.67	18.80
Diffusion rate	Ethanol–methanol (1 : 1) 0.476 g/dispenser/day	9.80				
Trap colour	Ethanol–methanol (1 : 1) red trap	290.14				
Trap height	Ethanol–methanol (1 : 1) upper position	18.61				
		Average captures per replicate and per day				
Number of traps	Ethanol–methanol (1 : 1) 16 traps/3600 m^2	2175.93				

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relative humidity and wind, were undoubtedly the main factors responsible for those variations.

The absolute highest capture rates achieved during this study (table 11) show that, for the best possible trapping results, red traps should be used at a height of 1.2 m, distributed within the plantation at a density of 16 traps per 3600 m^2 or 44/ha, functioning with an attractant consisting of ethanol and methanol (1 : 1), diffusing 0.476 g of mixture/dispenser/day. However, to optimize trapping the diffusion rate should be reduced to 0.175 g/dispenser/day and the number of traps to 22/ha. All these results led to the development of a new type of trap which was subsequently patented and registered under the trademark 'Brocap' and also for mass trapping, as part of integrated CBB management programmes (Dufour et al. 2002, 2004).

Acknowledgements

The authors are pleased to thank the technical staff at PROCAFE (Fundación Salvadoreña de Investigaciones del Café, Santa Tecla, El Salvador) for their contribution to this work, along with the Management of that institute for providing the material resources required for implementing the different trials. This research was undertaken as part of the IICA/PROMECAFE (Inter-American Institute for Cooperation on Agriculture/Regional Cooperation Programme for the Technological Development and Modernization of the Coffee industry in Central America, Jamaica, the Dominican Republic and Panama).

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