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Identification of attractant and repellent plants to coffee berry borer, *Hypothenemus hampei*

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Abstract

Colombia is one of the world's largest producers of coffee [*Coffea arabica* L. (Rubiaceae)]. The coffee berry borer (CBB), *Hypothenemus hampei* (Ferrari) (Coleoptera: Curculionidae: Scolytinae), is the main pest of coffee. This insect is controlled through an integrated pest management program that includes cultural, biological, and chemical control strategies. Despite research seeking CBB attractants and repellents, these potential management tools have not been successfully incorporated into control programs. This work proposes the use of plant functional diversity for CBB management, for which a number of plants related to coffee and weeds were selected. CBB preference to these plants was determined by olfactometry and volatile compounds emitted by them were identified. Field trials were performed to test CBB preference under field conditions. These trials determined the olfactory preference of CBB to coffee berries accompanied by material of the plants *Crotalaria micans* Link (Fabaceae), *Lantana camara* L. (Verbenaceae), *Nicotiana tabacum* L. (Solanaceae), *Artemisia vulgaris* L., *Calendula officinalis* L., *Stevia rebaudiana* (Bertoni) Bertoni, and *Emilia sonchifolia* (L.) DC. (all four Asteraceae). Under laboratory conditions *N. tabacum*, *L. camara*, and *C. officinalis* were identified as repellents for CBB in olfactometer assays, whereas *E. sonchifolia* functioned as attractant. Controlled field trials corroborated CBB repellency of *N. tabacum* and *L. camara*; both release volatile sesquiterpenes. Selected candidate attractants included *E. sonchifolia* plants, for showing attraction in the laboratory. The potential use of these plants in agroecological management of coffee plantations is discussed.

Introduction

Colombia is one of the largest coffee [*Coffea arabica* L. (Rubiaceae)] producing countries in the world (Colombian Coffee Growers Federation, 2015). However, its participation in the growing market of organic coffees is low. Of the 725 627 ha of organic coffee produced in the world, Colombia participates with only 10 495 ha, some of which are in transition from conventional to organic production (Willer & Lernoud, 2015). One of the main reasons for this limited participation is the difficulty of pest management.

Coffee berry borer (CBB), *Hypothenemus hampei* (Ferrari) (Coleoptera: Curculionidae: Scolytinae), is currently the main pest of coffee crops worldwide, including Colombia; although CBB infestations vary with elevation and temperature, the percentage of coffee berries infested ranges from 0.5 to 7.6% (Benavides et al., 2012; Benavides et al., 2015). Controlling this insect is difficult not only because it spends almost its entire life cycle within the coffee berries but also because its population density is strongly influenced by weather conditions on coffee plantations (Constantino, 2010). The program to control CBB populations includes cultural, biological, and chemical practices to reduce economic losses (Benavides & Arévalo, 2002; Bustillo, 2008). The demand for high yields and territorial expansion of coffee crops in unshaded monoculture demands strict pest management practices increasing production costs and intense labor force. Not all coffee growers can afford the cost of these measures, presenting recurrent pest outbreaks and reducing the economic, environmental, and social sustainability of their farms

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(Nicholls, 2009; Farfán, 2014). Because this is a recurrent scenario in the Colombian coffee region, it is necessary to find sustainable pest management alternatives.

Because CBB feeds, grows, and reproduces exclusively inside the coffee fruits, previous efforts have focused on identifying volatile compounds emitted by coffee fruits (Ortiz et al., 2004). Among them, ethanol and other alcohols, emitted by ripe coffee berries appear to play a role in host localization by CBB (Borbón et al., 2000; Cardenas, 2000; Barrera et al., 2006; Dufour & Frérot, 2008; Mendesil et al., 2009; Dufour et al., 2013; Jaramillo et al., 2013). In addition to the volatiles emitted by coffee fruits, it is possible that CBB uses cues from other plant species around them. Njihia et al. (2014) identified the emission of frontalin and conophthorin in coffee fruits as key compounds in location of CBB, and mainly conifers emit these compounds. Little is known about the effect of repellency of the genus *Hypothenemus* and also the use of repellent compounds to disturb host plant localization by CBB has been little studied; two volatile compounds within the genus *Coffea*, namely cis-3-hexenyl acetate and cis-3-hexenol, were repellent to CBB when used together (Borbón et al., 2000). In addition, compounds from other plants have shown various degrees of repellency to CBB, including extracts from *Capsicum frutescens* L., *Allium sativum* L. (Benavides & Góngora, 2015), *Piper* spp. (Giraldo & Valencia, 2000; Henao, 2008; Santos et al., 2010), *Moringa oleifera* Lam. (Santoro et al., 2011), and *Tilesia baccata* (L.) Pruski (Bustamante, 2007). However, the extracts lose effectiveness under field conditions and are expensive and demanding inputs (Schmutterer, 1990; Gurr et al., 2004; Nicholls, 2009).

As an alternative, companion plants interrupt the monoculture, grow in synergy with the main crop, and potentially alter insect behavior by delivering chemical signals that distort host plant localization (Nicholls & Altieri, 2007; Parker et al., 2013). Under the hypothesis that repellent and attractant plants to CBB exist in the Colombian coffee region and assuming that these plants can accompany coffee crops as a long-term alternative for CBB management, the following objectives were addressed: (1) evaluate and characterize the repellent and attractant properties of several companion plants and their volatile compounds, and (2) evaluate the functioning of plants that repel and attract CBB under controlled field conditions. The selected plants for evaluation in this study have mostly high emission levels of volatile organic compounds and they are identified mostly as weeds of Colombian coffee plantations. CBB preference to these plants was determined by olfactometry, whereas volatile compounds emitted by them were identified and field trials were performed to test CBB preference under field conditions. This research can contribute to the understanding of ecological interactions in a coffee plantation and propose solutions with the appropriation of local resources as an alternative for pest management.

Materials and methods

Plant selection

The selection criteria for companion plants were: (1) to emit a high content of volatiles compounds, (2) to have flowers that attract potential natural enemies, (3) to have good development in the climatic conditions of the coffee plantations, (4) to be easily accessible to growers, and (5) to not compete with coffee plants or share host pests (Gómez & Rivera, 1995; Salazar & Hincapié, 2007). Based on these criteria the following seven plants were selected: *Crotalaria micans* Link (Fabaceae), *Lantana camara* L. (Verbenaceae), *Nicotiana tabacum* L. (Solanaceae), *Emilia sonchifolia* (L.) DC., *Artemisia vulgaris* L., *Calendula officinalis* L., and *Stevia rebaudiana* (Bertoni) Bertoni (all four Asteraceae) (Table 1).

Olfactometer assay

Trials were conducted at the laboratory of Entomology in Cenicafé (Manizales, Caldas, Colombia) under controlled temperature and humidity conditions, kept constant with an air conditioner and a humidifier (25 °C, 75% r.h.). A two-arm (y-tube) olfactometer was used to evaluate the preference of CBB to plant odors. For this purpose, a Y-shaped ¼-inch-diameter glass tube was connected to a Teflon hose; the airflow was adjusted by a vacuum pump and an air delivery system with six charcoal filters (ARS, Gainesville, FL, USA). The air speed was controlled by pressure regulators to provide a constant flow of 100 ml s^{-1}, as recommended by Sengonca & Kranz (2001). At the ends of both entrances, the airflow passed through two compartments (Figure 1). To test attraction and repellency of CBB, 25 ripe, recently collected coffee fruits that had developed for 200–220 days after flowering were placed in each olfactometer compartment. In addition to the coffee fruits one of the compartments contained also leaves and/or flowers (in equal weight amount) of a companion plant coming from recently collected plants. The companion plant treatments were leaves and flowers of *C. micans*, *L. camara*, *A. vulgaris*, *C. officinalis*, or *E. sonchifolia*. For *N. tabacum* and *S. rebaudiana* only leaves were used because at the time of the experiment the plants did not have flowers, unlike the others. Absolute controls consisted of both compartments with only the 25 coffee fruits. Attractant controls consisted of both compartments with 25 coffee fruits and in one of them a 25 mm diameter Whatman N1 filter paper (Whatman

Table 1 Selected plants, with the scientific name, common name in the Colombian coffee region, and characteristics taken into account for their selection

Family	Scientific name	Common name	Height (m)	Characteristics	References
Asteraceae	*Artemisia vulgaris*	Ajenjo	0.2–1.0	Weed along the edges of coffee plantations. Its extracts have repellent activity due to their high content of volatile emissions. Medicinal properties and cultural value.	Gómez & Rivera (1995); Debboun et al. (2006); Wang et al. (2006)
	Calendula officinalis	Caléndula	0.3–0.5	Used as a reservoir plant for entomophagous insects. Apiary and medical importance.	Vázquez et al. (2008); Franco (2011)
	Emilia sonchifolia	Clavel chino	0.2–1.0	Nectar-producing species found in areas cultivated with coffee, plantain, and banana. Host of natural enemies.	Gómez & Rivera (1995); Salazar & Rivera (2002); Salazar & Hincapié (2005)
	Stevia rebaudiana	Estevia	0.3–0.9	Antioxidant, anti-inflammatory, and antimicrobial properties. Important for the food industry. Incorporated in the region by Corporation for the Coffee Revenue Diversification Program	Jarma et al. (2005); Muanda et al. (2011)
Fabaceae	*Crotalaria micans*	Cascabel	0.6–3.0	South American native weed widely distributed in Colombia and associated with coffee cultivation. Nitrogen fixing. Attractive to predators and parasitoid wasps of CBB and leaf miner.	Gómez & Rivera (1995); Freire et al. (2005); Wu et al. (2005); Silveira (2007); Waller et al. (2007); Devi et al. (2013)
Solanaceae	*Nicotiana tabacum*	Tabaco	0.5–3.0	Although not related to coffee, its extract is an insecticide and repellent for a large number of insects.	Delphia et al. (2006); Isman (2006); Vázquez (2011)
Verbenaceae	*Lantana camara*	Mermelada	1.0–3.0	Distributed worldwide and weed in the Colombian coffee region. Its extract has insecticidal activity on other insects. Apiary and ornamental importance.	Gómez & Rivera (1995); Ghisalberti (2000); Raj et al. (2014); Salazar & Hincapié (2007)

International, Maidstone, UK) with 10 µl of 3:1 methanol: ethanol blend (Barrera et al., 2006). Repellent controls consisted of both compartments with 25 coffee fruits and in one of them a 25 mm diameter Whatman N1 filter paper with 10 µl of 3% extract of *Artemisia* spec. (Benavides & Góngora, 2015).

The olfactometer assays were run 200× for each treatment. Four replicates were done in different days with 50 insects per day, using one individual insect each time, for a total of 200 insects per treatment. The evaluations were conducted with adult female CBB newly emerged from coffee berries between 13:00 and 16:00 hours, which are the hours of highest insect activity.

Preference of CBB to a given treatment was determined by registering the choice of each insect in the first 3 min after its release into the Y tube. The parameter of interest was the proportion of insects arriving at each end of the Y-tube. A 95% confidence level Z test was used to determine whether the proportion of insects arriving at each end of the Y-tube differed from 50%. Proportions that were significantly higher or lower than 50% were considered evidence that the plants attracted or repelled the borers respectively.

Field tests

The field tests were conducted in a 1-ha plot of *C. arabica* var. Castillo at Naranjal Cenicafé Experimental Station, located in the municipality of Chinchiná Caldas at an elevation of 1 381 m, at 21.4 °C and 68% r.h. The coffee planting distances were 1.2 × 1.5 m in the plot, in a sun-exposed coffee monoculture production system in its third year of production. Four coffee plants in a square

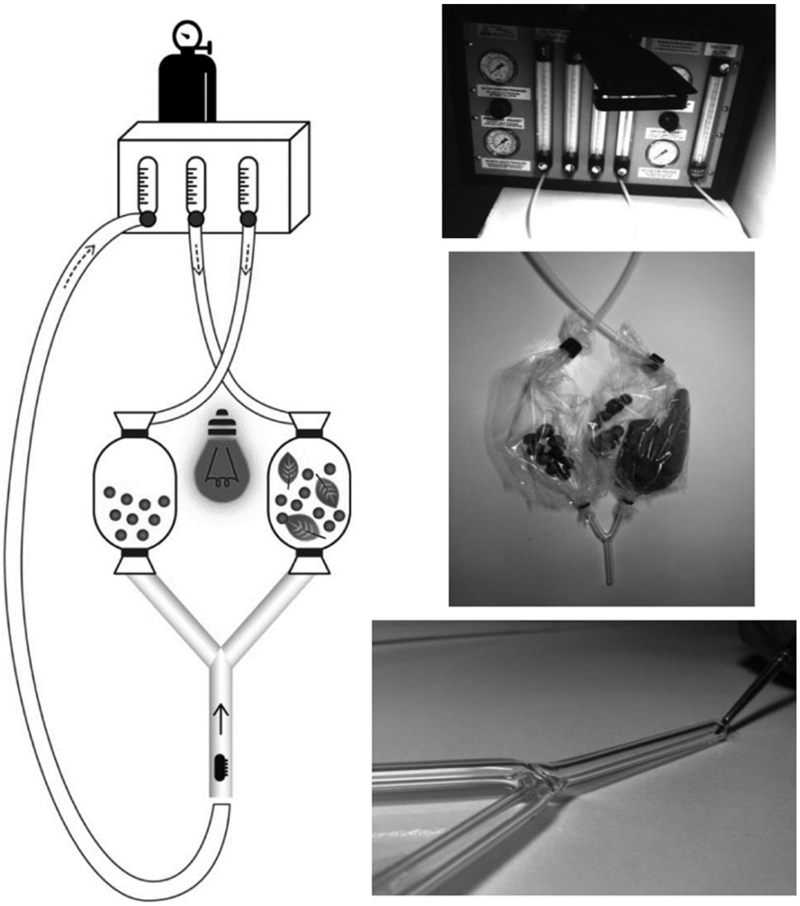

Figure 1 Y-tube olfactometer to evaluate the response of individual *Hypothenemus hampei* to volatiles of selected plants by offering them a choice between coffee berries vs. coffee berries with leaves and flowers of selected plants as odor sources.

arrangement were selected as the experimental unit, and companion plants were planted halfway between two coffee plants, the other two coffee plants served as reference inside each experimental unit (Figure 2). Six treatments were assigned randomly to 120 experimental units (20 units per treatment). The four plants were individually fenced with tulle mesh and bamboo rods (3 m wide, 3 m long, 2.5 m high). Treatment 1 corresponded to absolute control, in this case only the four coffee plants were present (without companion plants). Treatment 2 was the attractant control, in which the mixture of alcohols used in the olfactometer assays was placed between two coffee plants in the experimental unit. Based on the laboratory results, seven plants were chosen for field-testing; however, three of the species (*A. vulgaris*, *C. officinalis*, and *S. rebaudiana*) failed to establish, and only four species were used for the field study. The plants tested were *L. camara*, *N. tabacum*, *C. micans*, and *E. sonchifolia*, these were relatively tall plants that grew well among coffee plants (Figure 2). *Lantana camara* was propagated by stake whereas *N. tabacum*, *E. sonchifolia*, and *C. micans* were propagated by seeds. These plants were transplanted to the experimental plot 3–5 months after germination and they were established in the plot for a month before starting the experiment.

Prior to the CBB infestation experiment, all fruits in each experimental unit were counted. Dry coffee berries were infested with CBB adults in the laboratory. After 30 days of infestation a sample of 100 infested dry coffee berries were dissected and the progeny (eggs, larvae, and pupae) were counted – on average, 14 adult female CBB were determined inside each dry bean. With this information, the number of dry berries needed was calculated to obtain 17% of infestation according to the total number fruits for each experimental unit. The dry infested coffee berries were left on the soil in the middle of the four coffee trees of the experimental unit. For the treatment using *E. sonchifolia* as the companion plant, no infested dry coffee berries were placed on the soil; instead, adult female CBB were released, in the same proportion. For each experimental unit, the number of infested fruits on each coffee plant was evaluated 30 days after placing the dry infested coffee berries, to allow time for the development and emergence of all CBB females. The infestation (%)

was estimated for each treatment. CBB infestation in the pairs of reference coffee plants vs. pairs of coffee plants with neighboring companion plants was evaluated. Additionally, infestations of coffee plants with neighboring companion plants of different treatments were compared. One-way ANOVA for a completely randomized experimental design was performed, followed by Tukey's least significant difference (LSD) test (both $\alpha = 0.05$). Additionally, the differences in CBB infestation (%) between coffee plants with vs. without companion plants, were compared among treatments with Duncan test ($\alpha = 0.05$).

Identification of volatile compounds

The solid-phase microextraction (SPME) technique was used to identify the volatile compounds emitted by attractant and repellent CBB plants. Leaves and flowers of *N. tabacum*, *L. camara*, *C. micans*, and *E. sonchifolia* plants were individually enclosed in a 500-ml glass container and equilibrated for 45 min at room temperature. The compounds in the headspace container were trapped with carboxen-polydimethylsiloxane fiber (Supelco, Bellefonte, PA, USA) extraction for 40 min at room temperature. The detection of emitted compounds by the plants was conducted by gas chromatography coupled with mass spectrometry (GC-MS) using a 50 m × 320 µm × 1 µm, DBWAX column. The NIST 98 and Wiley 275 libraries were used for the identification of the volatile compounds.

Results

Olfactometer assay

When coffee fruits were used in both compartments as absolute control, the CBB selection to each of the compartments was 50%, indicating no orientation bias existed (Figure 3). The attractiveness of a mixture of alcohols as attractant control was confirmed, 74% of CBB chose the compartment with coffee fruits and the alcohol sample. *Artemisa* extract, as a repellent control, repelled 80% of the CBB. *Emilia sonchifolia* attracted CBB (61%; Figure 3). *Nicotiana tabacum*, *L. camara*, *C. micans*, *C. officinalis*, *A. vulgaris*, and *S. rebaudiana* showed repellency of CBB to coffee fruits accompanied by them (ranging from 61 to 77%, all significantly different from 50%, but not significantly different from one another; Figure 3).

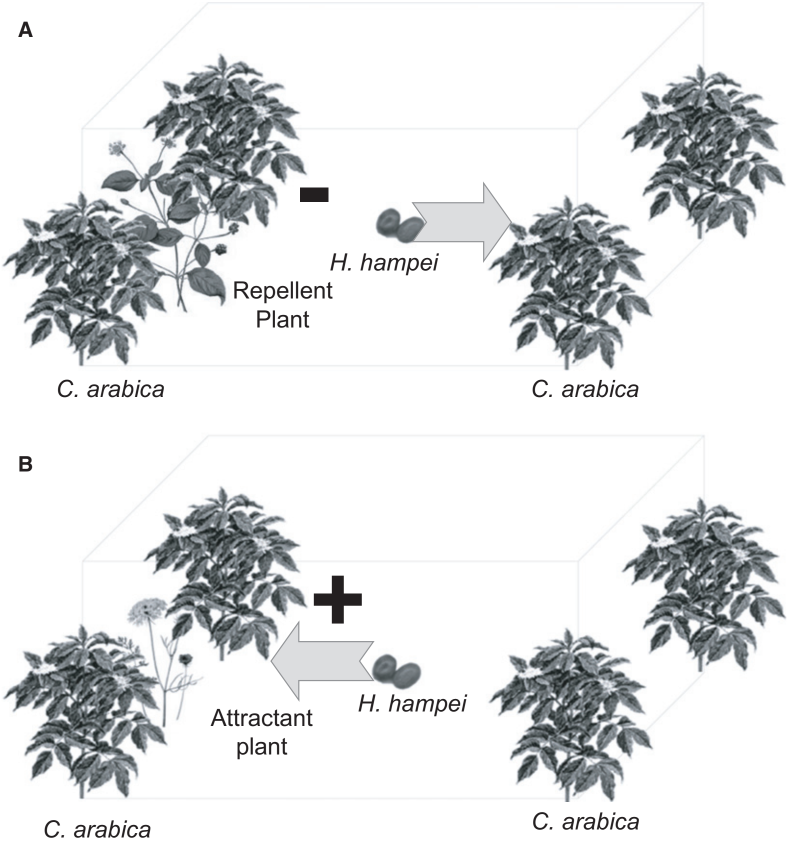

Figure 2 Sampling design for evaluating the response of *Hypothenemus hampei* to companion plants of coffee, *Coffea arabica*, in a controlled field experiment. The arrow represents the expected direction of insect movement toward (A) a repellent plant and (B) an attractive plant.

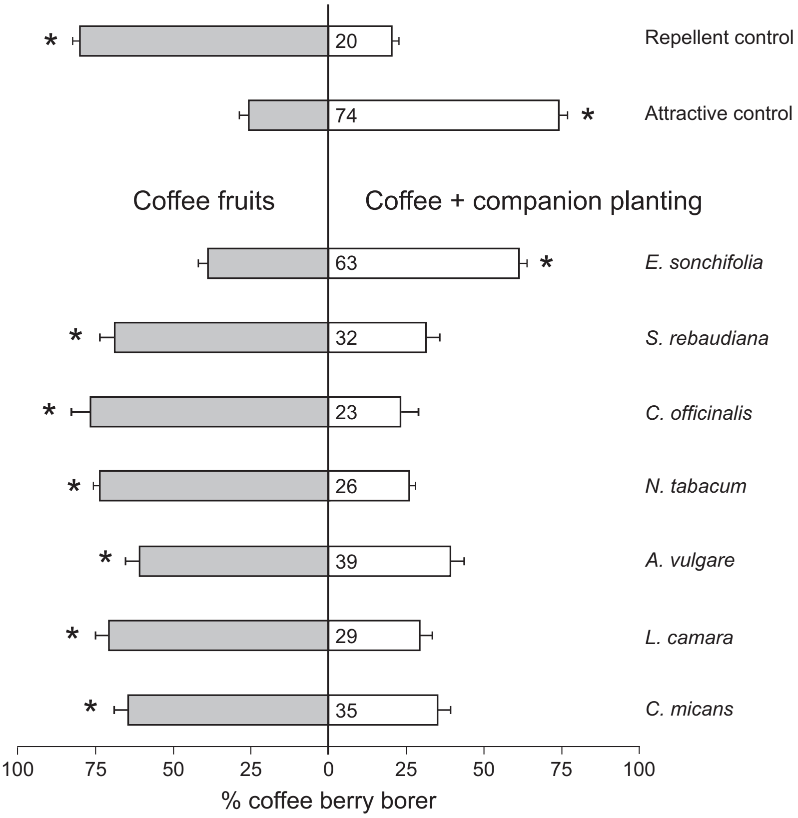

Figure 3 Mean (+ SEM; n = 200 for each plant) response (%) of *Hypothenemus hampei* when offered the choice between two odor sources in a y-tube olfactometer: coffee fruits vs. coffee + leaves and/or flowers of one of seven companion plants, a repellent control (coffee fruits + extract of *Artemisia* spec.) vs. coffee fruits, and an attractive control (coffee fruits + blend of methanol and ethanol) vs. coffee fruits. The asterisks indicate a significant difference from 50% response (95% Z test: $P<0.05$).

Field tests

The CBB infestation levels in the absolute control were 17–18% as expected (Table 2). This indicates no preference for any particular plant or location, the infestation was random in the four coffee plants that formed the experimental unit. A significant reduction was observed in the infestation on coffee plants accompanied by *N. tabacum* compared to unaccompanied coffee plants: 10.6 ± 1.8 vs. 19 ± 3.5% (Table 2). No statistical differences were found within the other treatments. *Emilia sonchifolia* displayed no attractiveness or repellency in the field tests, in contrast with the results obtained in the laboratory tests. However, note that the field infestation percentages for this treatment were very low (<5%), most likely because of the different infestation method used for this treatment compared to the others. In the other treatments, the infestation in at least one of the groups (pair of coffee trees) exceeded 14%. Differences in infestation percentage among the treatments allowed to differentiate the response to *N. tabacum* from responses to the attractant and absolute controls, indicating the repellency of tobacco plants (Figure 4).

Table 2 Mean (± SEM; n = 20) infestation (%) by *Hypothenemus hampei* in coffee fruit with and without companion plants

Treatment	With companion plants	Without companions
Attractant control[1]	29.4 ± 5.38	19.7 ± 4.03
Nicotiana tabacum	10.6 ± 1.83a	19.0 ± 3.54b
Lantana camara	13.4 ± 2.16	21.2 ± 3.25
Crotalaria micans	14.6 ± 3.89	9.4 ± 1.94
Emilia sonchifolia	4.6 ± 1.07	4.4 ± 1.00
Absolute control[2]	17.0 ± 3.47	18.8 ± 3.92

Means within a treatment followed by different letters are significantly different (LSD: $P<0.05$).

[1] 25 ml of 3:1 methanol:ethanol blend.

[2] Both options without companions.

Identification of volatile compounds

Identification of the volatile components emitted by the companion plants *N. tabacum*, *L. camara*, *C. micans*, and *E. sonchifolia* was performed by comparison of the mass spectra with literature data (NIST and WILEY) (Table 3). Few compounds were extracted from *N. tabacum*; however, the major component was 2-methyl furan (20.2% of total emitted). *Lantana camara* showed the largest amount of compounds, the major components being mono- and

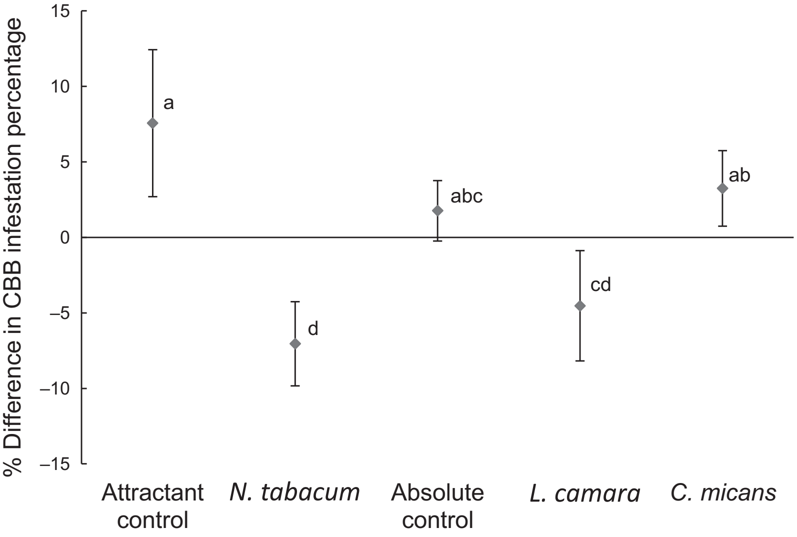

Figure 4 Mean (± SEM) differences in *Hypothenemus hampei* infestation (%) between coffee plants with vs. without companion plants. Negative values indicate repellency, positive values attraction. Means with the same letter are not significantly different (Duncan test: P<0.05).

sesquiterpenes. The major components of *C. micans* were cis-3-hexenol (50.6%), tetrahydro furan (15.5%), cis-3-hexenyl acetate (14.9%), acetic acid (6.6%), 2-methyl propanenitrile (3.8%), and dihydro 2(3H)-furanone (3.5%). The major component of *E. sonchifolia* was 1-undecene (36.0%). The only compound that was shared in the four plants was cis-3-hexenol. This compound was reported previously as repellent for CBB (Borbón et al., 2000; Dufour et al., 2013). Interestingly, the potentially attractant plant *E. sonchifolia* and *C. micans* also shared (Z)-3-hexenyl-1-ol acetate.

Discussion

This work focused on finding alternatives based on agroecological principles for Colombian coffee growers that plant dwarf rust-resistant varieties at large densities, under reduced or no shade, and that do high-input management. These production systems have low plant diversity inside the crop, but a high diversity in the surroundings. This functional diversity is used to begin designing arrangements that can reduce infestation of CBB. The selection of plants and our three experimental approaches were used to study the preference of CBB to accompanying plants. *Nicotiana tabacum* was identified as a repellent plant to CBB, in both the olfactometer and the field test. *Nicotiana tabacum* extract has historically been used as an insecticidal treatment in many crops and recently there are some reports of its use in coffee plantations (Damon, 2000; Vázquez, 2011). Recent studies (van den Boom et al., 2004; Delphia et al., 2006) have shown that *N. tabacum* emits only a few compounds, similar to our results, and no terpenes were identified contrary with previous studies (Andersen et al., 1988). Those terpenes are more related to induced defense in response to herbivory (Delphia et al., 2006). Cis-3-hexenol has also been reported as a major component of *N. tabacum*. In general, a strong indirect defense in tritrophic interactions has been shown for *N. tabacum* (van den Boom et al., 2004), which may favor this plant as a companion plants.

Lantana camara also showed repellency in the laboratory. The volatile compounds identified from this plant are consistent with those obtained previously by Abdel-Hady et al. (2005). The set of mono- and sesquiterpenes may be responsible for the repellency. Three of the compounds emitted by *L. camara* – (*E*)-β-ocimene, β-caryophyllene, and α-humulene – are reported by Khan et al. (2000). Those compounds are responsible for repellency in the push-pull strategy to manage maize pests such as the maize stem borers *Busseola fusca* Fuller and *Chilo partellus* Swinhoe (Khan et al., 2000; Khan & Pickett, 2004), consolidating the idea of using *L. camara* for a push-pull strategy in coffee. Also, this plant has red and yellow flowers that play an important role in beekeeping, being able to strengthen the system with the attraction of natural enemies for CBB (Raj et al., 2014).

This work explored the use of local plants and weeds as attractive plants for CBB in the region. Vega et al. (2012) suggested that before distancing from the center of origin some plant species, outside the *Coffea* genus, could have participated in the life cycle of *H. hampei*. Very few of these plants are known in the Colombian coffee region. *Crotalaria* spec. has been reported as a CBB temporal host by Waller et al. (2007), the present study is the first in analyzing the volatile compounds released by these plant species. The compounds emitted by *C. micans* were mostly alcohols, furans, and acetates. Alcohols and acetates are associated with the attraction responses of *H. hampei*

Table 3 Percentage of volatile organic compounds emitted by *Nicotiana tabacum*, *Lantana camara*, *Emilia sonchifolia*, and *Crotalaria micans*

RT	Compounds	*N. tabacum*	*L. camara*	*E. sonchifolia*	*C. micans*
5.60	2-Propanone	3.50	–	–	–
6.61	Tetrahydro-furan	0.96	–	–	15.45
7.49	2-Methyl furan	20.16	–	–	3.84
11.78	α-Pinene	–	–	13.37	–
12.01	α-Thujene	–	0.48	–	–
15.78	Sabinene	–	0.28	–	–
16.01	1-Undecene	–	–	35.98	–
17.92	α-Terpinene	–	1.12	–	–
18.58	L-limonene	–	0.65	8.77	–
19.99	γ-Terpinene	–	1.39	–	–
20.07	(*E*)-β-Ocimene	–	2.47	–	–
20.8	*p*-Cimene	–	1.84	–	–
21.06	α-Terpinolene	–	0.66	–	–
21.95	(Z)-3-Hexenyl-1-ol acetate	–	–	2.96	14.87
24.02	Cis-3-hexenol	1.72	0.69	17.48	50.58
24.96	(*E*,*E*)-2,4-Hexadienal	–	–	–	0.73
25.66	Acetic acid	–	–	–	6.62
25.69	α-Cubebene	–	0.57	–	–
26.64	(+)-Cicloisosativene	–	–	4.99	–
26.82	α-Copaene	–	2.68	–	–
28.97	(*E*)-Farnesene	–	1.95	–	–
29.75	Calarene	–	0.92	–	–
29.93	β-Caryophyllene	–	10.09	–	–
31.14	Trans-β-Farnesene	–	14.82	–	–
31.5	Isolongifolene	–	0.81	–	–
31.58	Alloaromadendrene	–	0.67	–	–
31.69	Dihydro 2(3H)-furanone	–	–	–	3.74
31.87	Trans-γ-bisabolene	–	1.66	–	–
31.99	α-Humulene	–	5.63	–	–
32.11	γ-Curcumene	–	5.04	–	–
32.88	Zingiberene	–	2.95	–	–
33.06	Cis-α-bisabolene	–	0.95	–	–
33.23	α3,23abolen	–	3.71	1.01	–
34.09	δ-Cadinene	–	6.68	3.03	–
34.42	ar-Curcumene	–	6.99	–	–
34.93	Cadina-1,4-diene	–	1.96	–	–
36.31	1S, *Z*-calamenene	–	3.81	3.02	–
38.62	α-Calacorene	–	1.25	–	–

RT, retention time (min).

(Mendoza Mora, 1991; Mathieu et al., 1998; Cardenas, 2000; Green et al., 2015), suggesting that *C. micans* emits the necessary compounds to attract CBB, but the emission concentration apparently was too low to affect CBB preferences in field conditions (field results were not significant). On the contrary, laboratory results suggested repellence for CBB.

The evaluation of *E. sonchifolia* volatile compounds showed the presence of α-pinene as one of the main components. α-Pinene has been reported as an attractant for CBB (Costa, 2002; Dufour et al., 2013). Cis-3-hexenyl acetate was found in *E. sonchifolia* and *C. micans*; it is an attractant for several genera and families of (beneficial) insects (James, 2003, 2005). In this work, no relationship was found between this compound and repellency by companion plants. The association between the emission of certain plant volatile compounds and the localization by an insect has been studied in many agrosystems in very specific ways, for both pest and beneficial insects (De Moraes et al., 1998). Many compounds have been evaluated as vegetable extracts or synthetic compounds for their effect on the control of CBB in coffee plantations (Mendesil et al., 2009; Dufour et al., 2013; Jaramillo et al., 2013; Njihia et al., 2014; Benavides & Góngora, 2015; Green et al., 2015). The results of these studies let us to conclude that it may be a blend of compounds that allows the localization or repulsion of the host, affecting the CBB. Rather than using individual compounds in pest control strategies, it may be more appropriate to use companion plants that emit a blend of compounds (Altieri & Nicholls, 2000). In addition, it will help to reduce the use of chemical or biological insecticides.

This is the first report of using companion plants as a source of repellency for CBB in coffee cultivation. Functional diversity could be used to manipulate CBB behavior during the colonization of coffee plantations and therefore for CBB management. Established with the appropriate design, plants within a coffee plantation may provide a long-term pest management solution. The challenge is to make a design that allows taking advantage of the ecological services of these non-host plants, not only to control the pest but also to reactivate synergistic processes such as maintenance of the biological quality of soil and an adequate microclimate in the coffee plantation.

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