Preference of Cosmopolites sordidus for fusarium wilt-diseased

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Abstract

The objective of this study was to understand the role of *Cosmopolites sordidus* in the dispersal of *Fusarium oxysporum* f. sp. *cubense* race 1 (Foc) and more specifically to determine whether *C. sordidus* is preferentially attracted to Foc-contaminated banana plant material vs. Foc-free material. The attraction of *C. sordidus* to healthy and Foc-contaminated Gros Michel banana bulbs and pseudostems, as well as to pure cultures of Foc, was compared using four-choice olfactometers. Males and females were studied separately. After storage in a dark room, weevils were placed in the central chamber of olfactometers. After 15 min, the orientation of each of the weevil was determined according to the food source located in each of the four peripheral chambers of the olfactometer. Overall, 560 olfactometer assays were carried out. Weevils were found to prefer Foc-infected plant tissues. Weevil preference was not significantly affected by weevil sex. The attraction of *C. sordidus* to Foc-contaminated plant material suggests that this insect could be important for the dissemination of Foc, especially in early stages of epidemics, when Foc-infected plants are scarce.

KEYWORDS

banana weevil, food preference, gros michel banana, musa, olfactometer, panama disease

1 | INTRODUCTION

To protect agroecological crops, an integrated pest and disease management plan should address the whole pathosystem (Deguine et al., 2017). This global approach to crop protection requires the recognition of the trade-offs between pest regulation and production (Poeydebat et al., 2016) (Poeydebat et al., 2016). Understanding the interactions between pests and diseases is thus crucial in the development of integrated management options (Allinne et al., 2016; Ratnadass et al., 2021). Like many cultivated crops, banana plants are threatened by a complex of pests and diseases that damage leaves, fruits, roots, and corms (Jones, 2009). The banana weevil, *Cosmopolites sordidus* (Germar) (Coleoptera: *Curculionidae*), is a worldwide pest of bananas (Gold et al., 2001), and its control remains challenging (Tresson et al., 2021). The main damage caused by *C. sordidus* results from the burrowing of larvae into the corms,

leading to a reduction in root growth and an overall weakening of the plants. Large weevil populations can damage and reduce sucker growth and the uptake of water and nutrients. Adults of weevils are free-living, nocturnal, and prefer humid environments, for example, the environment provided by banana plant residues (Gold et al., 2001). Although *C. sordidus* adults move freely within banana stands, their maximal dispersion is reported to be 10 m per night (Vinatier et al., 2010; Vinatier et al., 2011). Both sexes are attracted by stressed or damaged plants, residual corms, and freshly cut pseudostems (Treverrow & Bedding, 1993).

Fusarium wilt is a destructive soilborne disease of bananas caused by *Fusarium oxysporum* f. sp. *cubense* (Foc). The pathogen affects the xylem of the plants and causes wilting and progressive death. In the 1950s, an epidemic of Foc race 1 devastated banana plantations that were based on the Gros Michel (AAA) banana variety (Ploetz, 2015). Because of this epidemic, growers selected

banana varieties resistant to race Foc 1; these varieties were almost exclusively from the Cavendish group (AAA) and included the cultivars Williams, Grand Nain, and Dwarf Cavendish. Fusarium oxysporum Tropical race 4 (Foc TR4) is an emerging new race that is pathogenic on bananas from the Cavendish group. Disease caused by Foc TR4 was reported in Colombia in 2019 and in Peru in 2021 and is now widely distributed in Asia. Foc TR4 threatens the major banana export production areas in tropical America (Ploetz, 2015).

The role of C. sordidus in the epidemiology of Fusarium wilt at the plot level remains unknown. That insect pests contribute to pathogen dispersal has already been demonstrated for other pathosystems. For example, larvae of the European grapevine moth (Lobesia botrana Den. & Schiff; Lepidoptera: Tortricidae) vector the fungal pathogen Botrytis cinerea. Mondy et al. (1998) reported similar interactions occurring below the soil where Clover root borers (Hylastinus obscurus Marsham; Coleoptera: Scolytidae) showed a clear preference for fungal-infected over non-infected red clover roots (Leath & Byers, 1973). Cosmopolites sordidus helps spread Xanthomonas campestris, a bacterial pathogen of banana plants (Were et al., 2015). Guillen Sánchez et al. (2021) recently demonstrated that when feeding on banana corms infected by Foc, C. sordidus can carry infective propagules of Foc on its exoskeleton, in its digestive tract, and even in its excreta, suggesting that this insect could contribute to Fusarium wilt epidemics.

The movement of C. sordidus is driven by chemical signals (Gold et al., 2001). The males produce an aggregation pheromone (sordidin) that is attractive to both sexes (Budenberg et al., 1993) and that has been used in trapping programs in banana plantations worldwide (Rhino et al., 2010). In addition, adults are strongly attracted to banana plants and to freshly cut or decomposing banana material (Gold et al., 2001). Cosmopolites sordidus is preferentially attracted by banana corms after flowering (Cerdas et al., 1996). Very little is known about the chemical signals that attract C. sordidus to banana plants, but it is likely that volatile organic compounds are important. Although oviposition mostly occurs on corms, Sumani (1997) showed that both males and females of C. sordidus are more attracted to banana pseudostems than to banana corms. Cosmopolites sordidus can locate its host based on chemoreception of olfactory signals (Tinzaara, 2005). Fungi also produce volatile compounds through their primary and secondary metabolic pathways (Müller et al., 2013). These compounds act like semiochemicals that can affect insect behaviour (Morath et al., 2012). In the case of Foc, the production of volatile aldehydes has also been reported and used for taxonomic studies (Moore et al., 1991).

Here, we compared the attractiveness of healthy vs. Focdiseased banana plant tissue to C. sordidus. For this purpose, we used olfactometers to quantify the relative attractiveness of Foc colonies, Foc-free banana materials, and Foc-infected banana materials to C. sordidus adults. We determined whether the type of plant tissue (corm or pseudo-stem) influenced attractiveness and whether the attractiveness of these substrates differed between C. sordidus males vs. females. Finally, we discuss the implications of our findings for the management of both C. sordidus and Fusarium wilt of bananas.

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MATERIALS AND METHODS

2.1 **Experimental conditions**

To compare the attractiveness of Foc-infected and Foc-free banana plant materials to C. sordidus adults (i.e., weevils), we carried out 560 olfactometer experiments. All experiments were conducted at the Biological Control Center in the National Banana Corporation (CORBANA), La Rita, Pococí, Limón, Costa Rica. Before olfactometer experiments were conducted, weevils were stored in a dark room at 24-26°C and with a relative humidity ranging between 85 and 89%. Olfactometer experiments including observations were made under red light according to the methods proposed by (Tinzaara, 2005).

2.2 Insects

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Experiments were performed using C. sordidus collected from the San Pablo Farm located in Siguirres, Limón, Costa Rica. The insects were maintained in a chamber at 24°C and 90% relative humidity and were fed on pseudostems and corms obtained from healthy plants located at the San Pablo Farm. Before the experiments, weevil sex was determined based on the curvature of the last abdominal segment and the punctate surface of the rostrum (Longoria, 1968), and the weevils were kept in 1000 cm³ plastic containers without food for 12h to ensure that they would respond to the food sources offered in the olfactometers.

2.3 Corm and pseudostem tissues

The experiments were conducted using banana corm and pseudostem material of flowering banana plants (Musa AAA and cultivar Gros Michel) from the CORBANA experimental Station in La Rita de Pococí, Limón, Costa Rica. For Foc-infected plant material, we used pieces of plant that were collected from plants showing typical symptoms of Fusarium wilt, such as yellowish leaves, wilted older leaves, and ruptured pseudostems. We selected pieces of pseudostems that had typical dark-brown vascular bundles. The selected corms had typical discontinuous, reddish lines (between 35% and 50% of the surface) resulting from obstruction of the vascular bundles (Ploetz, 2015). Although these plant materials were Focinfected, they were not decaying. In contrast, healthy plant material (without Foc) was selected from an experimental area that was free of Foc; after the experiment, we continued monitoring the latter area and were unable to detect Foc.

Two types of corms and pseudostem were used: (i) infected with Fusarium oxysporum RT1 (Foc+) and (ii) healthy (Foc-). The material was chopped into pieces of $5 \times 5 \times 3$ cm. To confirm the presence of the fungus in Foc+tissue, pieces of vascular bundles from pseudostems and corms were placed on Komada medium. The colonies were then grown on PDA containing chloramphenicol to eliminate bacteria. When used in the olfactometers, colonies were exactly

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7 days old (after inoculation on Petri plates). Molecular identification of Foc was carried out as described by Guillen Sánchez et al. (2021).

2.4 | Olfactometer set-up

We used four-choice olfactometers (Figure 1) to simultaneously compare *C. sordidus* attraction to Foc+banana material, Foc- banana material, pure colonies of Foc, and a control (empty chamber). Each olfactometer consisted of a cylindrical central chamber (15 cm diameter and 8 cm high) made of high-resistance plastic. The central chamber was connected to four peripheral chambers (15 cm diameter and 8 cm high) via four tubes (5 cm diameter and 15 cm long). The central chamber contained an opening that was covered by a glass stopper and that enabled the placement of the insects at the beginning of the experiments. The two types of banana plant materials (corm and pseudostem) were tested separately as well as the sex of the weevils, leading to set-ups of four combinations. For each combination (type of plant material–sex of weevils), we used 20 olfactometers and carried out seven repetitions leading to a total of 560 olfactometer measurements. (Figure 2).

Between each assessment, all olfactometers were cleaned with 70% ethanol, rinsed with distilled water, and dried with sterile paper towels. The four treatments were randomly assigned to the four peripheral chambers for each experiment. To begin an assessment, three weevils (of the same sex) were deposited in the central chamber. After 15 min in complete darkness, the location of each weevil was determined in terms of movement toward a treatment or the absence of movement). Weevils were used only one time.

2.5 | Statistical analysis

To determine whether attraction of *C. sordidus* differed among substrates placed in the peripheral chambers, between sexes, or among replicates, we used multinomial logit generalized linear models. These models were implemented with the 'vglm' function in the 'VGAM' R package (Yee, 2010). In all models, the substrate selected by each *C. sordidus* individual was the qualitative response, and the sex of *C. sordidus*, the type of substrate, and the replicate were the predictor variables. We used likelihood ratio tests (LRTs) to select the



FIGURE 1 Photograph of the four-choice olfactometer used in this study

best model by removing non-significant predictors in a backwardsstepwise process. The selection procedure was done until the models included only significant predictors (Zuur et al., 2011). The significance of the intercept of each type of substrate compared to the control treatment was tested with a selected model with all significant predictors. All statistical analyses were performed with R 4.1.1 (R Core Team, 2021) and with an alpha level of 0.05.

3 | RESULTS

In total, substrate selection by 1680 C. sordidus adults was recorded. Selection of substrates was not significantly affected by C. sordidus sex or by replicate but was significantly affected by the type of plant material placed in the peripheral chambers (Table 1, Figure 3). The chambers with plant materials were more frequently selected by weevils ($25.8\pm7.9\%$ and $44.8\pm6.5\%$ for Foc- and Foc+plant materials, respectively) than chambers with the Foc in Petri plates (11.0 \pm 5.1%). A lower percentage of weevils selected the control $(6.4 \pm 3.0\%)$ than the other treatments. A low percentage of weevils did not move (12.0 \pm 4.5%). When comparing separately Foc- and Foc+, the intercept of Foc+plant material $(0.78 \pm 0.09, i.e., almost$ 80% higher) was significantly different from those of the Foc- plant material (p < 0.001). The interaction between the plant material and the selected substrate was only significant in case of the intercept of the Foc- treatment (Table 2). In this latter case, the 'pseudostem' was preferred to the 'corm' plant material. All intercepts of the different substrates selected by C. sordidus were significantly different when compared to the 'control' without any substrate (Table 2).

4 | DISCUSSION

4.1 | Diseased material is more attractive than healthy material

Our results demonstrate that corms or pseudostems are more attractive to *C. sordidus* when infected than when not infected with Foc. Raman and Suryanarayanan (2017) noted that many insects visit fungus-infected plants either for feeding on dead tissues or because they are attracted by volatiles resulting from plant-pathogen interactions. That fresh pseudostems were reported to be more attractive to *C. sordidus* than fermented pseudostems (Delattre, 1980; Hord & Flippin, 1956) suggests that the preference for diseased plant material could be linked to fungal infection and not to decaying material. Indeed, plant pathogens may induce local or systemic emissions of volatiles or non-volatile secondary metabolites that insects may exploit to locate or discriminate among host plants (Ako et al., 2003; Jallow et al., 2008; Kruess, 2002).

Our results suggest that the volatiles emitted by corms and pseudostems from Foc-infected plants positively influenced the behaviour of weevils, which is consistent with the findings of Kariyat et al. (2013), Pashalidou et al. (2015), and Conchou et al. (2019).



Control Contro



Foc

Corm

Foc

Corm

Predictors	δΑΙC	Log-likelihood	Df	<i>X</i> ²	p-value
Repetition	5.199	-2305.2	4	2.8008	0.5917
Sex	3.480	-2307.5	4	4.5199	0.3402
Plant material type	21.299	-2322.1	4	29.299	< 0.001

TABLE 1 Results from the multinomial logit generalized linear models concerning the effect of replicate, sex of weevils, and type of plant material on the selection of plant material by *C. sordidus* in olfactometer assays

Abbreviations: df, degrees of freedom; δ AIC, the variation of AIC (Akaike information criterion) explained by the predictor; X2, the value of the chi-squared test.

These authors mentioned that the complex chemical interactions between insects and plants allow many insect species to recognize and select the most appropriate time to feed or lay eggs. In addition, Holighaus and Rohlfs (2016) stated that many fungi can generate volatile allelochemical compounds that attract insects for feeding or oviposition, which likely explains the observations of the current study. Future research should investigate which of the volatiles present in Foc-infected banana plants are involved in the high attraction of weevils demonstrated in this research.

The olfactometer results of the current study were not significantly affected by the sex of *C. sordidus*. This suggests that the preferential attraction of *C. sordidus* to diseased-plant materials was linked to feeding behaviour rather than to oviposition behaviour. The current results for *C. sordidus* do not therefore provide support for the preference-performance hypotheses. This hypothesis predicts that females preferentially lay eggs in habitats that maximize the fitness of their progeny (Menacer et al., 2021). From an evolutionary point of view, it is not clear what *C. sordidus* weevils gain with this reciprocal interaction by preferentially feeding on Foc-infected tissue and by transporting Foc propagules. We hypothesize (i) that *C. sordidus* mating could be favoured by aggregating around diseased plants, especially when weevil numbers are low, and (ii) that larval fitness could be greater with diseased than with non-diseased substrates. The fungus, on the other hand, clearly gains in terms of increased dispersal and thus an increased potential to infect new hosts.

4.2 | Implications for fusarium wilt epidemiology

Given that *C. sordidus* that feed on Foc-infected tissue transport viable Foc propagules (Guillen Sánchez et al., 2021), the preference of *C. sordidus* for diseased plants increases the probability of Foc spread. This effect would be particularly important at the beginning

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FIGURE 3 Number of *C. sordidus* per replicate (mean ± SD) that selected the indicated substrate. Each replicate included 60 individuals per sex and per type of plant material. Pink and blue colours represent females and males, respectively. Plain and clear colours represent the 'corm' and the 'pseudostem' plant material types, respectively. In the legend, stars indicate the significance of the sex and plant material predictors (see Table 1 for details). Above each group of bars, black stars indicate the significance of the intercept of each selected substrate compared to the control substrate (see Table 2 for details). Stars in blue indicate significant differences between the selection of Foc + and Foc substrates (tested separately)

TABLE 2 Intercepts of the different substrates compared to the control and interaction terms because of the 'pseudostem' plant material type (compared to the 'corm')

Response levels	Estimate (mean <u>±</u> SD)	z value	p-value
Foc+plant material	1.800 ± 0.136	13.233	< 0.001
Foc- plant material	1.016 ± 0.147	6.910	< 0.001
Foc in Petri plates	0.492 ± 0.160	3.074	0.0021
No movements	0.636 ± 0.156	4.082	< 0.001
Pseudostem: Foc + plant material	0.335 ± 0.209	1.599	0.1098
Pseudostem: Foc- plant material	0.757 ± 0.219	3.447	< 0.001
Pseudostem: Foc in Petri plates	0.143 ± 0.246	0.582	0.5603
Pseudostem: No movements	-0.013 ± 0.243	-0.055	0.9559

Note: Colons (:) indicate interactions between two factors.

of an outbreak at the plot scale when only one or a few plants are infected. In this case, even a small number of *C. sordidus* could accelerate Foc dispersal, and this effect would probably be proportional to the number of weevils in the plot. This suggests that, in addition to destroying diseased banana plants, as is usually recommended, plantation managers should also control *C. sordidus* in order to limit the spread of Fusarium wilt. For example, plantation managers could help to control the disease by mass trapping via the rapid deployment of pitfall traps containing sordidin, the specific aggregation pheromone for *C. sordidus* (Beauhaire et al., 1995; Rhino et al., 2010; Vinatier et al., 2012) soon after Fusarium wilt symptoms are first detected.

5 | CONCLUSION

Our results, together with the proof that *C. sordidus* can transport propagules of Foc Race 1 (Guillen Sánchez et al., 2021), suggest that *C. sordidus* may have a key role in the spread of Fusarium wilt in banana plantations. The next step in disentangling this complex interaction will be to measure the ability of *C. sordidus* that carry Foc propagules to contaminate healthy banana plants. An additional step would be to evaluate the overall role of *C. sordidus* in spreading the disease by comparing the spread of Foc in plots with one Foc-infected plant (artificially infected) and with and without *C. sordidus*. Overall, our results illustrate the importance of integrating the management of pests and diseases in an agroecosystem.

AUTHOR CONTRIBUTIONS

CGS, LdLdB, and PT conceived research. CGS conducted experiments. CGS, LdLdB, and PT analysed data and conducted statistical analyses. CGS, LdLdB, JASF, and PT wrote the manuscript. All authors read and approved the manuscript.

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CONFLICT OF INTEREST

Authors declare that they have no conflict of interest.

DATA AVAILABILITY STATEMENT

Data are available on DataVerse: https://doi.org/10.18167/DVN1/ G9PJJJ

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REFERENCES

Ako, M., Schulthess, F., Gumedzoe, M. Y. D., & Cardwell, K. F. (2003). The effect of fusarium verticillioides on oviposition behaviour and bionomics of lepidopteran and coleopteran pests attacking the stem and cobs of maize in West Africa. *Entomologia Experimentalis et Applicata*, 106, 201–210. https://doi.org/10.1046/j.1570-7458.2003.00026.x

- Allinne, C., Savary, S., & Avelino, J. (2016). Delicate balance between pest and disease injuries, yield performance, and other ecosystem services in the complex coffee-based systems of Costa Rica. *Agriculture, Ecosystems and Environment, 222,* 1–12. https://doi. org/10.1016/j.agee.2016.02.001
- Beauhaire, J., Ducrot, P. H., Malosse, C., Rochat, D., Ndiege, I. O., & Otieno, D. O. (1995). Identification and synthesis of sordidin, a male pheromone emitted by Cosmopolites sordidus. *Tetrahedron Letters*, 36, 1043–1046. https://doi. org/10.1016/0040-4039(94)02437-G
- Budenberg, W. J., Ndiege, I. O., Karago, F. W., & Hansson, B. S. (1993). Behavioral and electrophysiological responses of the banana weevil Cosmopolites sordidus to host plant volatiles. *Journal of Chemical Ecology*, 19, 267–277. https://doi.org/10.1007/BF009 93694
- Cerdas, H., López, A., Sanoja, O., Sánchez, P., & Jaffé, K. (1996). Atracción olfativa de Cosmopolites sordidus Germar (1824) (Coleoptera: Curculionidae) estimulado por volátiles originados en musáceas de distintas edades y variedades genómicas. Agronomía Tropical, 46, 413-429.
- Conchou, L., Lucas, P., Meslin, C., Proffit, M., Staudt, M., & Renou, M. (2019). Insect odorscapes: From plant volatiles to natural olfactory scenes. Frontiers in Physiology, 10, 972. https://doi.org/10.3389/ fphys.2019.00972
- Deguine, J. P., Gloanec, C., Laurent, P., Ratnadass, A., & Aubertot, J. N. (2017). Agroecological crop protection. Springer Science ISBN: 978-94-024-1185-0.
- Delattre, P. (1980). Recherche d'une méthode d'estimation des populations du charançon du bananier, *Cosmopolites sordidus* Germar (Col., *Curculionidae*). Acta Oecologica, 1, 83–92.
- Gold, C. S., Pena, J. E., & Karamura, E. B. (2001). Biology and integrated pest management for the banana weevil Cosmopolites sordidus (Germar) (coleoptera: Curculionidae). Integrated Pest Management Reviews, 6, 79–155. https://doi.org/10.1023/A:1023330900707
- Guillen Sánchez, C., Tixier, P., Tapia Fernández, A., Conejo Barboza, A.M., Sandoval Fernández, J.A., & de Lapeyre de Bellaire, L. (2021). Can the banana weevil Cosmopolites sordidus be a vector of fusarium oxysporum f.sp. cubense race 1? Unravelling the internal and external acquisition of effective inoculum. Pest Management Science, 77, 3002–3012. https://doi.org/10.1002/ ps.6339
- Holighaus, G., & Rohlfs, M. (2016). Fungal allelochemicals in insect pest management. Applied Microbiology and Biotechnology, 100, 5681– 5689. https://doi.org/10.1007/s00253-016-7573-x
- Hord, H. H. V., & Flippin, R. S. (1956). Studies of banana weevils in Honduras. *Journal of Economic Entomology*, 49, 296–300.
- Jallow, M. F. A., Dugassa-Gobena, D., & Vidal, S. (2008). Influence of an endophytic fungus on host plant selection by a polyphagous moth via volatile spectrum changes. *Arthropod-Plant Interactions*, *2*, 53– 62. https://doi.org/10.1007/s11829-008-9033-8
- Jones, D. R. (2009). Disease and pest constraints to banana production. Acta Horticulturae, 828, 21–36. https://doi.org/10.17660/ActaH ortic.2009.828.1
- Kariyat, R. R., Mauck, K. E., Balogh, C. M., Stephenson, A. G., Mescher, M. C., & De Moraes, C. M. (2013). Inbreeding in horsenettle (*solanum carolinense*) alters night-time volatile emissions that guide oviposition by *manduca sexta* moths. *Proceedings of the Royal Society* B: Biological Sciences, 280, 20130020. https://doi.org/10.1098/ rspb.2013.0020
- Kruess, A. (2002). Indirect interaction between a fungal plant pathogen and a herbivorous beetle of the weed *Cirsium arvense*. *Oecologia*, 130, 563–569. https://doi.org/10.1007/s00442-001-0829-9
- Leath, K. T., & Byers, R. (1973). Attractiveness of diseased red clover roots to the clover root borer. *Phytopathology*, *63*, 428–431.

- Longoria, A. G. G. (1968). Diferencias Sexuales en la Morfologia externa de Cosmopolites sordidus Germar (coleoptera, Curculionidae). Ciencias Biologicas, La Habana, 1, 1–11.
- Menacer, K., Cortesero, A. M., & Hervé, M. R. (2021). Challenging the preference-performance hypothesis in an above-belowground insect. Oecologia, 197, 179–187. https://doi.org/10.1007/s00442-021-05007-5
- Mondy, N., Charrier, B., Fermaud, M., Pracros, P., & Corio-Costet, M. F. (1998). Mutualism between a phytopathogenic fungus (Botrytis cinerea) and a vineyard pest (Lobesia botrana). Positive effects on insect development and oviposition behaviour. Comptes Rendus de l'Academie des Sciences - Serie III, 321, 665-671. https://doi. org/10.1016/S0764-4469(98)80006-1
- Moore, N. Y., Hargreaves, P. A., Pegg, K. G., & Irwin, J. A. G. (1991). Characterisation of strains of *fusarium oxysporum* f.sp. cubense by production of volatiles. Australian Journal of Botany, 39, 161–166. https://doi.org/10.1071/BT9910161
- Morath, S. U., Hung, R., & Bennett, J. W. (2012). Fungal volatile organic compounds: A review with emphasis on their biotechnological potential. *Fungal Biology Reviews*, 26, 73–83. https://doi.org/10.1016/j. fbr.2012.07.001
- Müller, A., Faubert, P., Hagen, M., Zu Castell, W., Polle, A., Schnitzler, J. P., & Rosenkranz, M. (2013). Volatile profiles of fungi - Chemotyping of species and ecological functions. *Fungal Genetics and Biology*, 54, 25–33. https://doi.org/10.1016/j.fgb.2013.02.005
- Pashalidou, F. G., Gols, R., Berkhout, B. W., Weldegergis, B. T., van Loon, J. J. A., Dicke, M., & Fatouros, N. E. (2015). To be in time: Egg deposition enhances plant-mediated detection of young caterpillars by parasitoids. *Oecologia*, 177, 477–486. https://doi.org/10.1007/ s00442-014-3098-0
- Ploetz, R. C. (2015). Fusarium wilt of banana. *Phytopathology*, 105, 1512– 1521. https://doi.org/10.1094/PHYTO-04-15-0101-RVW
- Poeydebat, C., Carval, D., de Lapeyre de Bellaire, L., & Tixier, P. (2016). Balancing competition for resources with multiple pest regulation in diversified agroecosystems: A process-based approach to reconcile diversification and productivity. *Ecology and Evolution*, *6*, 8607– 8616. https://doi.org/10.1002/ece3.2453
- R Core Team. (2021). R: A language and environment for statistical computing. R Foundation for Statistical Computing. https://www.R-proje ct.org/
- Raman, A., & Suryanarayanan, T. S. (2017). Fungus-plant interaction influences plant-feeding insects. *Fungal Ecology*, 29, 123–132. https:// doi.org/10.1016/j.funeco.2017.06.004
- Ratnadass, A., Avelino, J., Fernandes, P., Letourmy, P., Babin, R., Deberdt, P., Deguine, J. P., Grechi, I., Naudin, K., Rhino, B., DeClerck, F., Kadi Kadi, H. A., Mahob, R., Rabary, B., Rafarasoa, L. S., Lescourret, F., & Van Den Berg, J. (2021). Synergies and tradeoffs in natural regulation of crop pests and diseases under plant species diversification. *Crop Protection*, 146, 105658. https://doi.org/10.1016/j. cropro.2021.105658
- Rhino, B., Dorel, M., Tixier, P., & Risède, J. M. (2010). Effect of fallows on population dynamics of *Cosmopolites sordidus*: Toward integrated management of banana fields with pheromone mass trapping. Agricultural and Forest Entomology, 12, 195–202. https://doi. org/10.1111/j.1461-9563.2009.00468.x

- Sumani, A. J. (1997). Patterns of relationship between banana (Musa spp.) types and the banana weevil, Cosmopolites sordidus Germar (coleoptera: Curculionidae). Ph.D. thesis, University of Zambia. http://34.250.91.188:8080/xmlui/handle/123456789/208
- Tinzaara, W. (2005). Chemical ecology and integrated management of the banana weevil Cosmopolites sordidus in Uganda. Ph.D Thesis Wageningen University ISBN: 90-8504-176-7.
- Tresson, P., Tixier, P., Puech, W., & Carval, D. (2021). The challenge of biological control of *Cosmopolites sordidus* Germar (Col. Curculionidae): A review. *Journal of Applied Entomology*, 145, 171–181. https://doi. org/10.1111/jen.12868
- Treverrow, L. N., & Bedding, R. (1993). Development of a system for the control of the banana weevil borer, *Cosmopolites sordidus* with entomopathogenic nematodes. In R. R. A. Bedding & H. K. Kaya (Eds.), *Nematodes and the biological control of pest* (pp. 41–47). Melbourne Australia ISBN: 978-0-643-10521-8.
- Vinatier, F., Chailleux, A., Duyck, P. F., Salmon, F., Lescourret, F., & Tixier, P. (2010). Radiotelemetry unravels movements of a walking insect species in heterogeneous environments. *Animal Behaviour*, 80, 221– 229. https://doi.org/10.1016/j.anbehav.2010.04.022
- Vinatier, F., Lescourret, F., Duyck, P. F., Martin, O., Senoussi, R., & Tixier, P. (2011). Should i stay or should i go? A habitat-dependent dispersal kernel improves prediction of movement. *PLoS One*, *6*, e21115. https://doi.org/10.1371/journal.pone.0021115
- Vinatier, F., Lescourret, F., Duyck, P. F., & Tixier, P. (2012). From IBM to IPM: Using individual-based models to design the spatial arrangement of traps and crops in integrated pest management strategies. *Agriculture, Ecosystems and Environment, 146, 52–59.* https://doi. org/10.1016/j.agee.2011.10.005
- Were, E., Nakato, G. V., Ocimati, W., Ramathani, I., Olal, S., & Beed, F. (2015). The banana weevil, *Cosmopolites sordidus* (Germar), is a potential vector of *Xanthomonas campestris* pv. *Musacearum* in bananas. *Canadian Journal of Plant Pathology*, 37, 427–434. https://doi. org/10.1080/07060661.2015.1113444
- Yee, T. W. (2010). The VGAM package for categorical data analysis. Journal of Statistical Software, 32, 1–34. https://doi.org/10.18637/ jss.v032.i10
- Zuur, A. F., Ieno, E. N., & Walker, N. J. (2011). *Mixed effects models and extensions in ecology with R. Springer-Verlag ISBN:* 9780387875163 0387875166.

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