# Field Validation of Attractive Senesced Banana Leaf Extract for Trapping the Banana Weevil, *Cosmopolites sordidus*, on Smallholder Banana/Plantain Farms

**Short title: Field Testing of Banana Weevil Attractants**


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**Abstract**

Palm wine alcohol extract of senesced banana leaf material, *Musa* spp., was tested for its efficacy in open field trapping of the banana weevil, *Cosmopolites sordidus* in Ghana from June to August 2014. Modified type TAL and Voltic traps were baited with either individual treatments *i.e.* palm alcohol extract, *C. sordidus* aggregation pheromone or pseudostem, or with combinations of extract plus aggregation pheromone or extract plus pseudostem. The combination of extract plus aggregation pheromone was able to lure more weevils into traps compared to the respective individual lures. There was a 2.1-fold increase in mean catch per week when the palm alcohol extract was used in combination with pheromone compared to using pheromone alone, and a corresponding 2.6-fold increase when the extract was used with pseudostem in traps. There was no statistically significant interaction between the palm alcohol extract (presence or absence) and treatment (pheromone or pseudostem), but the best combination for maximal catches of adult banana weevils was a combination of palm alcohol extract with aggregation pheromone. Management of banana weevils with attractive banana leaf extract has important practical applications in parts of the world where other management options are too expensive or commercial treatments are in short supply, but where leaf material is cheap and readily available for local use by smallholder farmers.

**Key-words:** Bananas and plantains, banana weevil, attractant leaf extract, trapping, smallholder farms

## 1. Introduction

Bananas and plantains are of great economic importance in most regions of tropical and subtropical Africa. All year-round production of bananas ensures a continuous supply of food and income to the farmer, making bananas a major food security crop in the region (Ocan et al., 2008) and an important cash and subsistence crop in most tropical and subtropical regions of the world (Ortiz & Swennen, 2014). According to estimations by the Food and Agriculture Organization (FAO), world total exports of banana accounted for 15.9 million tonnes in 2004. About 98 per cent of world banana production is in developing countries, and it is largely imported by developed countries.

Sustainable production of bananas and plantains is constrained by many biotic factors (Hallam, 1995) that significantly reduce crop yield, including insect pests and pathogens such as weevils, nematodes, black sigatoka disease, fusarium wilt and banana xanthomonas wilt disease. Most of the banana pests and pathogens are transmitted through suckers from infected parent plants and from one farm to another through the exchange of suckers, a common practice among smallholder farmers (Macharia et al., 2010). The banana weevil, *Cosmopolites sordidus*, has been cited as the most challenging constraint to banana and plantain production particularly on smallholder farms (Price, 1994; Gold et al., 2001; Foagain et al., 2002). *C. sordidus* is native to Malaysia and Indonesia but is found in nearly all banana-growing areas of the world (Gold et al., 2001; Reddy et al., 2008). The weevil has been reported as one of the foremost pests in most banana growing regions (Stover & Simmonds, 1987), attacking all types of bananas, including those destined for dessert and brewing industries, highland bananas and plantains. Management strategies for *C. sordidus* vary in efficacy and convenience, and currently include the use of synthetic pesticides (Sponagel et al., 1995); cultural control methods such as farm sanitation (Masanza et al., 2005), and use of pseudostem traps (Gold et al., 2002); biological control with entomopathogens (Treverrow et al., 1991; Nankinga and Moore, 2000) or myrmicine ants (Castineiras and Ponce, 1991); planting of host plants with resistance (Kiggundu et al., 2003); use of botanical pesticides such as neem extracts (Musabyimana et al., 2001), and mass trapping with aggregation pheromone lures (Alpizar et al., 1999; Tinzaara et al., 2005). Large scale control of *C.*

*sordidus* is currently achieved by chemical methods, while cultural controls remain highly valuable in preventing the establishment of the pest. Cultural control methods are also the main available means of management of the pest by smallholder farmers and growers, while biological control methods such as the application of arthropods and fungi in integrated pest management strategies are also being studied (Braimah & van Emden, 1999). In Asia, classical biological control of the weevil using natural enemies has so far been unsuccessful and the use of opportunistic, generalist predators have had limited efficacy. Ants have been reported to help control the weevil in Cuba, but their effects elsewhere are unknown. Effective strains of microbial agents have also been reported but their use is constrained by the need of economic mass production and delivery systems (Gold et al., 2003).

The attractiveness of pheromone-based lures for many insect species can be enhanced through combination with host plant-derived volatiles (Tewari *et al*., 2014). Combination effects between pheromones and plant odour have been reported to be a common feature for weevils (Curculionidae) and possibly more widely amongst Coleopteran species (Hugo *et al*., 1998). Adult *C. sordidus* have been shown to orient to both the male-produced aggregation pheromone and host plant volatiles (Tinzaara *et al*., 2002). In our earlier work, senesced banana leaves were found to be attractive to adult *C. sordidus*, with the active component from volatile collections being identified, via behaviour (olfactometer) assays and coupled GC-electrophysiology, as (2*R*,5*S*)-theaspirane (Braimah and Van Emden, 1999; Abagale *et al*., 2018a). Furthermore, a mixture of the theaspirane isomers was shown to enhance the activity of the aggregation pheromone (Abagale *et al*., 2018a). Additionally, palm alcohol extract of senesced leaf material was shown to be equally attractive as senesced leaf material, suggesting that the extract could be suitable for deployment in new trapping systems aimed at banana weevil management (Abagale *et al*., 2018b). Here, we report on open field trapping of banana weevils in Ghana using palm alcohol extract of dead banana leaf, the aggregation pheromone, and combinations thereof, to investigate the potential for interaction between the two treatments in the field, and assess the potential for the use of palm alcohol extract in weevil trapping systems.

## 2. Materials and Methods

**2.1** *Trap baits*. Palm alcohol extract of senesced banana leaf material required for field trapping experiments was prepared as previously described (Abagale *et al*., 2018b), by crushing banana leaf material (100 g) into palm alcohol (50 ml). The mixture was kept for 24 hours at ambient temperature, before being decanted into storage vials. Cosmolure (P160-Lure), containing the banana weevil aggregation pheromone (Beauhaire *et al*., 1995), sordinin, was purchased from ChemTica International, Costa Rica. Samples of fresh banana pseudostems (Figure 1C) were collected from growing plants in the banana fields at the site of trapping experiments.

**2.2** *Banana weevil traps.* Two types of pitfall traps were used in the field trapping; a type TAL trap (Plant Protection Institute, Budapest, Hungary) modified for use as a fully buried pitfall trap (Figure 1A), and a Voltic drinking bottle trap (Figure 1B). The type TAL trap was made from a pale pink rectangular plastic container (17 cm × 11.5 cm × 8 cm) comprising an off-white background plastic walk-way placed over the two longer edges and covered with a plain transparent plastic roof to prevent rain or dew entering the trap, while maintaining visibility inside the trap. When in use, the trap was buried in the ground such that the top edge was level with the ground and the plastic walk way lay flat, slightly above the ground. The Voltic bottle trap was made using two 1.5 L empty water bottles purchased from Kumasi Central Market, Ghana. The lower portion of one bottle was cut to provide a 10 cm high weevil collection receptacle. Two vents were cut on opposite sides of the second bottle. Each vent was made by cutting the bottle on three edges at a height of 14.5 cm from the mouth such that the resultant flap opened towards the fourth side (bottom). Each vent was approximately 36 $cm^2$. When in use, the flap was lifted up, to the outside of the trap, to serve as protection against direct entry of rain water into the trap. A narrow hole was created on the bottom of the second bottle for use in hanging the bait. To complete the trap, this second bottle was then inserted upside-down into the receptacle half made from the other bottle. In the field, the trap was buried so that the lower edge of the cut vent was at ground level, and the bait was hung from the top so that it came into level with the opening.

**2.3** *Baiting of traps.* The TAL and Voltic traps were baited with either individual treatments, *i.e.* palm alcohol extract of senesced banana leaf material, aggregation pheromone or pseudostem, or combinations of extract plus pheromone or extract plus pseudostem, giving 10 treatment combinations altogether. This formed an extract only (control lure) plus a ‘two treatments (pheromone and pseudostem) by two levels of extract (presence and absence)’ factorial set, by two types of trap (TAL and Voltic bottle). For treatment combinations involving the pheromone and pseudostem, those with palm alcohol extract were the test treatments and those without were the corresponding controls.

**2.4** *Field trapping and trapping sites.* Trapping was done on five fields located in the Ashanti region of Ghana (6º41′18″N; 1º37′27″W) between June and August 2015; two at the College of Agriculture (fields 1 & 2), one each at Kwadaso and Mwamase near Kwadaso (fields 3 & 4) and one at Mankraso (5). There were five traps of one type (Voltic or TAL) in each field, one trap for each bait treatment. Traps were arranged randomly in each field, maintaining at least 20 m between each trap and 10 m from the boundary of the field. The traps were checked weekly for 12 weeks (fields 1, 3 and 4), seven weeks (field 2) or five weeks (field 5). Hence, there were three replicates of treatments with Voltic traps (for 12, 7 and 5 weeks, fields 4, 2 and 5) and two replicates of treatments with TAL traps (for 12 weeks, fields 1 and 3) (see Table 4). Weevils captured were counted and recorded, and the total weevil capture per trap calculated. Average weevil catch per week for each treatment combination in each field was calculated, and the overall mean catch for each trap type was also calculated. All fields were part of one experiment, done at the same time. Fields were seen as sufficiently homogeneous to preclude the need for blocking but they were of insufficient size to allow all 10 treatment combinations (trap type by bait treatment) in each one. Thus, fields were seen as main plots with one type of trap in each field, and with the baits as split-plot treatments. Subsequent analysis (Table 3) accounted for this design.

*2.5 Statistical analysis*. Weighted analysis of variance (ANOVA) was applied to the average catch per week data, weighting for the number of weeks, taking account of the different fields and testing (F-tests) for the main effects and interactions between the factors of type of trap (TAL or Voltic bottle), lure treatment (pheromone or pseudostem) and extract (presence or absence), nesting out the extractonly lure from the two by two factorial set of treatment combinations. A natural logarithmic transformation was applied to the data to account for heterogeneity of variance across the treatment combinations. Checks on residuals revealed that, under the transformation, the assumptions of the analysis had been met. Given the ANOVA, appropriate tables of means were output, for comparison using the standard error of the difference (SED) between means, thus invoking the least significant difference (LSD) at the 5% level of significance. The GenStat ($17^{th}$ edition, © VSN International Ltd, Hemel Hempstead, UK) statistical package was used for this analysis. It was noted that the statistical requirement of transformation of data did not alter the fact that the effect of the treatments was shown by the means of the untransformed data, and these means were therefore presented, but with the transformed means on which statistical tests were based, given the results of ANOVA, being included in brackets and italicised.

## 3. Results

Table 1 shows the total number of adult banana weevils caught in each trap for each of the five different treatments, and the percentage of total weevil capture over treatments either with, or without, pseudostem, whilst Table 2 shows the mean weevil catch per week in each of the five fields using the five different treatments. The ANOVA of the data in Table 2 (Table 3) shows that, having accounted for the treatment using extract alone (*ExtractOnly*), there was a significant main effect of the presence of palm alcohol extract ($P = 0.002$, F-test) and a main effect of the lure (pheromone or pseudostem) treatment used ($P < 0.001$, F-test), but no interaction between the two factors ($P = 0.570$, F-test). This indicates that the two effects were independent and additive. There was also no effect of type of trap (*TrapType*) or interaction of this factor with the others. We also note that these same overall results were obtained when omitting the data from fields 2 and 5, for which trapping ran for less than 12 weeks. The means for the main effect of extract were: 4.239 (transformed data mean: 0.73) without extract and 8.862 (1.54) with extract ($n = 10$, SED = 0.204 on 12 df; LSD (5%) = 0.445). These means show that there was approximately a 2.1-fold increase in mean catch per week through using the extract. The means for the main effect of lure treatment were: 12.033 (2.39) for the pheromone and 1.068 (-0.13) for pseudostem ($n = 10$, SED = 0.204 on 12 df; LSD (5%) = 0.445). These means show that there was approximately an 11-fold increase in mean catch per week through using pheromone compared to pseudostem. Although there was no statistically significant interaction between the two factors, the best combination for maximal catch was most certainly the pheromone with the extract; this gave a mean of 16.178 (2.74), compared to 7.888 (2.05) for the pheromone without the extract (n = 5, a 2.1-fold increase). The corresponding results for pseudostem were 1.546 (0.34) with the extract and 0.59 (-0.59) without the extract (n = 5, a 2.6-fold increase). However, even though there appeared to be substantially more than an additive effect involving the treatments it was not robust enough to be statistically significant.

## 4. Discussion

It has been postulated that combinations of species-specific pheromone and host plant volatiles may interact synergistically to attract *C. sordidus* (Budenberg *et al*., 1993; Jayaraman *et al*., 1997). Preliminary studies in the laboratory have also indicated that host plant volatiles may enhance the aggregation pheromone (Tinzaara *et al*., 2003), and our recent work has demonstrated that a mixture of isomers of theaspirane, identified from senesced banana leaf material as a banana weevil attractant, improves the activity of the aggregation pheromone (Abagale *et al*., 2018a). Generally, there was large variation in the total number of weevils caught in a given type of trap with different lures from the same field (Table 1). Correspondingly, there were differences in the overall total numbers of weevils caught in all traps containing different types of lures. Thus, comparing the three non-pseudostem treatment combinations, i.e. pheromone alone, palm alcohol extract alone and pheromone with extract, 61.1 % of the total weevils captured were lured into traps containing the combination of pheromone and extract, while 8.5 % and 30.4 % of the total weevils were lured into traps containing the extract alone and pheromone alone respectively. For the treatments involving pseudostem, traps with pseudostem treated with the palm alcohol extract lured 72.1 % of the weevils captured, whilst traps with untreated pseudostem attracted 27.1 % of the pseudostem-lured weevils.

It has been reported that geographically separate populations may respond differently to on-farm conditions such as weed infestation level and the presence of other crops (Braimah & Van Emden, 2002). It was later corroborated that there could be variation in insect ecology as a result of geographical location (Zhu & Park, 2005). In addition, response of the male pine saw fly, *Neodiprion sertifer*, to sex pheromone analogues in the field has also been reported to show dependence on geographical location (Anderbrant *et al*., 2010). However, any geographic or on-farm influences in our trapping experiment were expected to contribute marginally to variation, as all experiments were conducted in the same region (6º41′18″N; 1º37′27″W) in Ghana. Despite this, Table 3 shows that the estimated underlying field-to-field variation from the ANOVA was 15.907, 7.9-fold greater than the estimated underlying within-field variation (2.006), so clearly differences between local populations could be important. The current study was carried out in fields in the same geographical location and thus enabled robust assessment of the performance of the lures. Attraction of the weevils could therefore arise mainly from the observed luring activity of the aggregation pheromone and host-derived cues without excess variation from other extraneous sources. The extent of the observed field-to-field variation can therefore be explained in terms of the different periods of time (number of weeks) over which assessment was made for two of the fields compared to the other three (12 weeks for fields 1, 3 and 4, seven weeks for field 2, five weeks for field 5) and the varying numbers of total weevils per week over weeks (Table 4).

Previous research on the synergy of attractants for the banana weevil has largely failed to produce consistent results. A study in Costa Rica reported that pseudostem traps baited with aggregation pheromone caused a 5-10-fold increase in attractiveness to weevils (Alpizar & Fallas, 1997). In another study, using olfactometry experiments, Tinzaara *et al*. (2002) observed that a greater number of weevils responded to fermented banana tissues combined with the aggregation pheromone compared to the individual treatments. Other studies also indicated that banana extract and host plant extract enhanced pheromone attractiveness to weevils when used together (Reddy *et al*., 2008; Palinichamy *et al*., 2011). However, during pheromone trap trials in South Africa, trap catches were reported to be greater for traps with lures containing the pheromone than lures containing both the pheromone and a plant kairomone (De Graaf *et al*., 2005). Also, a study in tropical Costa Rica reported that pseudostem traps and pseudostem traps baited with pheromone attracted an equal sex ratio of weevils (Jayaraman *et al*., 1997). The results of our present study suggest that palm alcohol extracts of senesced banana leaf material can enhance the attractiveness of the aggregation pheromone to adult banana weevils, and also that weevil populations can be trapped through deployment of leaf extracts alone. This suggests that either approach is suitable for use in banana weevil management, with the latter being potentially affordable for use by smallholder banana/plantain farmers, especially since leaf material and palm alcohol are both affordable and available to farmers at no, or low, cost. Further studies are planned to undertake field trapping experiments on a wider scale in Ghana and demonstrate the low-cost extraction and trapping technology to smallholder banana/plantain farmers.

In summary, palm alcohol extracts of senesced banana leaf material and the banana weevil aggregation pheromone were able to lure more weevils into modified type TAL and Voltic traps, and a combination of extract and pheromone lured a greater number of weevils into traps compared to the respective individual lures. The results showed that there was a significant main effect of the presence of extract ($P$ = 0.002, F-test) and a main effect of the lure treatment (pheromone or pseudostem) used ($P$ < 0.001, F-test), but no interaction between the two factors ($P$ = 0.570, F-test), indicating that the two effects were independent and additive. However, there was at least some synergy between the extract and either the aggregation pheromone or pseudostem, as the extract increased the attractiveness of both the aggregation pheromone and pseudostem to adult banana weevils. This study, along with our previous work (Abagale *et al*., 2018a, 2018b), provides underpinning science for use of senesced leaf extract in banana weevil management and provides a chemical marker for quality assurance and control if the envisaged management system breaks down. From an economic perspective, banana and plantain farmers could be encouraged to develop the production of leaf extracts for crop protection, thereby not only providing economic and social benefits through enhanced banana and plantain production but also by generating income from a new product.

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**Conflict of Interest**

The authors have declared no conflicts of interest

**Authors' Contributions**

All the authors have made ample contributions culminating in the manuscript. S.A.A., H.B., S.O-A., M.A.B. and J.A.P. were solely responsible for the laboratory work leading to the field work which was done with input from U.I.S., and later the data collation and analyses with manuscript preparation was done with input from S.J.P. and H.vE, Jozsef Vuts provided the TAL Traps and guidance for their use.

**Data Availability Statement**

All data and materials used in the study are either available from the corresponding author by request or have been used in this publication. Experimentally obtained raw data have also been presented in the current article.

## References

Abagale S.A., Woodcock C.M., Hooper A.M., Caulfield J.C., Chamberlain K., Acquaah, S.O., Van Emden H., Braimah H., Pickett J.A. and Birkett M.A., 2018a. (2*R*,5*S*)-Theaspirane identified as the major kairomone for the banana weevil, *Cosmopolites sordidus* from attractive senesced leaves of the host banana, Musa spp. Chemistry: A European J. 24, 1-4.

Abagale S.A, Woodcock C.M., Caulfield J.C., Chamberlain K., Acquaah S.O., Van Emden H., Braimah H., Pickett J.A. and Birkett M.A., 2018b. Attractiveness of host banana leaf materials to the banana weevil, *Cosmopolites sordidus* in Ghana for development of field management strategies. Pest Man Sci. 75, 549-555.

Alpizar D. and Fallas M., 1997. Pheromone trapping system. Ministry of Agriculture, Guapiles, Costa Rica.

Alpizar D., Fallas M., Oehlschlager A.C., Gonzalez L.M. and Jayaraman S., 1999. Pheromone-based mass trapping of the banana weevil, *Cosmopolites sordidus* (Germar) and the West Indian sugarcane weevil *Metamasius hemipterus* L. *(Coleoptera: Curculionidae)* in banana and plantain. Memorias XIII Reunion ACORBAT, 23-27 November 1998. Guayaquil. pp. 515-538.

Anderbrant, O., Löfqvist, J., Hedenström, E., Bång, J., Tai, A. and Högberg, H.-E., 2010. Field response of male pine sawflies, *Neodiprion sertifer* (Diprionidae), to Sex Pheromone Analogs in Japan and Sweden. J. Chem Ecol. 36, 969–977.

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

Braimah H. and van Emden H.F., 1999. Evidence for the presence of chemicals attractive to the banana weevil, *Cosmopolites sordidus* (Coleoptera: Curculionidae) in dead banana leaves. Bull. Ent. Res. 89, 485-491.

Braimah, H. and van Emden, H.F., 2002. Effects of soil water content and history of cultivation on the foraging behaviour of the banana weevil, *Cosmopolites sordidus* (Germar, 1824). Agric. Food Sci. J. Ghana. 1, 65-73.

Budenberg W.J., Ndiege I.O., Karago F.W. and Hansson B.S., 1993. Behavioral and electrophysiological responses of the banana weevil *Cosmopolites sordidus* to host plant volatiles. J. Chem. Ecol. 19, 267-277.

Castineiras A. and Ponce E., 1991. Efectividad de la utilizacin de *Pheidole megacephala* (Hymenoptera: Formicidae) en la lucha biolgica contra *Cosmopolites sordidus* (Coleoptera: Curculionidae). Proteccin de Plantas. 1: 15-21.

De Graaf, J., Govender, P., Schoeman, A.T.S. and Viljoen A., 2005. Efficacy of pseudostem and pheromone seasonal trapping of the banana weevil *Cosmopolites sordidus* in South Africa. *Int. J. Pest Man.* 51, 209-218.

Foagain R., Messiaen S. and Foure E., 2002. Studies on the banana borer weevil in Cameroon. Info Musa. 11(1): 12.

Gold C.S., Pena J.E. and Karamura E.B., 2003. Biology and integrated pest management for the banana weevil *Cosmopolites sordidus* (Germar) (Coleoptera Curculionidae). **In**: Control of Highland Bananas and Plantain Pests and Diseases. Integrated Pest Management Reviews. Proceedings, Research Coordination Meeting, Cotonou 12-14 November 1991. IITA, Ibadan. Kluwer Academic Publishers. Printed in the Netherlands.

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

Gold C.S., Pena J.E. and Karamura E.B., 2001. Biology and integrated pest management for the banana weevil *Cosmopolites sordidus* (Germar) (Coleoptera: Curculionidae). Integ. Pest Man. Rev. 6, 79-155.

Hallam D., 1995. The world banana economy. Pp. 509-533. **In:** S. Gowen [ed.], Bananas and plantains. Natural Resources Institute and Department of Agriculture University of Reading. Chapman and Hall, London.

Hugo C., Kenju M., Toru N. and Klaus J., 1998. A synergistic aggregation pheromone component in the banana weevil *Cosmopolites sordidus* Germar 1894 (Coleoptera: Curculionidae). Acta Cientifica Venezolana. 49, 201-203.

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

Kiggundu A., Gold C.S., Labuschagne M.T., Vuylsteke D. and Louw S., 2003. Levels of host plant resistance to banana weevil, *Cosmopolites sordidus* (Germar) (Coleoptera: Curculionidae), in Ugandan *Musa* germplasm. Euphytica 133:267-277.

Macharia I., Kagundu A.M., Kimani E.W. and Otieno W., 2010. Combating Phytosanitary Constraints to Banana (Musa spp.) Production: The Kenyan Example. Kenya Plant Health Inspectorate Service. Proc. IC on Banana & Plantain in Africa Eds.: T. Dubois et al. Acta Hort. 879.

Masanza M., Gold C.S., van Huis A., Ragama P.E., Okech S.H.O., 2005. Effect of crop sanitation on banana weevil *Cosmopolites sordidus* (Germar) (Coleoptera: Curculionidae) populations and crop damage in farmers' fields in Uganda. Crop Prot. 24, 275-283.

Masanza M., 2003. Effect of crop sanitation on banana weevil *Cosmopolites sordidus* (Germar) populations and associated damage. PhD Thesis. Wageningen University, Netherlands.

Musabyimana T., Saxena R.C., Kairu E.W., Ogol C.P.K.O. and Khan Z.R., 2001. Effects of Neem Seed Derivatives on Behavioral and Physiological Responses of the *Cosmopolites sordidus* (Coleoptera: Curculionidae). Journal of Economic Entomology. 94(2): 449-454.

Nankinga C, M., and Moore D., 2000. Reduction of banana Weevil populations using different formulations of the entomopathogenic fungus *Beauveria bassiana*. Biocontrol Science and Technology. 10: 645-657.

Ocan D., Mukasa H.H., Rubaihayo P.R., Tinzaara W. and Blomme, G., 2008. Effects of banana weevil damage on plant growth and yield of East African Musa genotypes. Journal of Applied Biosciences. 9 (2): 407 - 415.

Ortiz R. and Swennen R., 2014. From cross breeding to biotechnology- facilitated improvement of banana and plantain. Biotechnology Advances. 32: 158–169.

Ostmark, H.E., 1974. Economic insect pests of bananas. Ann Rev Entomol. 19: 161 – 176.

Palanichamy, S., Padmanaban, B., Mohamed, M.I.F. and Mustaffa, M.M., 2011. A simple and low cost semiochemical based trapping method for the management of banana pseudostem weevil, *Odoiporus longicollis* Olivier (Coleoptera: Curculionidae). *Adv. Appl. Sci. Res*. 2 (3), 69-73.

Price N.S., 1994. Alternate cropping in the management of *Radopholus similis* and *Cosmopolites sordidus*, two important pests of banana and plantain. Int. J. Pest Man. 40, 237-244.

Reddy, G.V.P., Cruz, Z. T., Naz, F. and Muniappan R., 2008. A pheromone-based trapping system for monitoring the population of *Cosmopolites sordidus* (Germar) (Coleoptera: Curculionidae). J. Plant Prot. Res. 48, 515-527.

Sponagel K.W., Diaz F.J. and Cribas A., 1995. El picudo negro del plÆtano *Cosmopolites sordidus*: un insecto-plaga importante en cultivos del gØnero Musa y su estatus de peste en Honduras. FHIA, La Lima, Honduras. Pp. 34.

Stover R.H. and Simmonds N.W., 1987. Bananas. Longman Scientific and Technical, New York.

Tewari S., Leskey T.C., Nielsen A.L., Piñero, J.C. and Rodriguez-Saona C.R., 2014. Use of Pheromones in Insect Pest Management, with special attention to weevil pheromones. Current Concepts and Ecological Perspective. Int. Pest Management. pp. 141–168.

Tinzaara W., Gold C.S., Kagezi G.H., Dicke M., Van Huis A., Nankinga C.M., Tushemereirwe W. and Ragama P.E., 2005. Effects of two pheromone trap densities against banana weevil, *Cosmopolites sordidus*, populations and their impact on plant damage in Uganda. J. of Applied Entomol., 129:265-271.

Tinzaara W., Dicke M., Van Huis A., Van Loon J.J.A. and Gold C.S., 2003. Different bioassays for investigating orientation responses of the banana weevil, *Cosmopolites sordidus*, show additive effects of host plant volatiles and a synthetic male-produced aggregation pheromone. Ent. Exp. App. 106, 169-175.

Tinzaara, W., Dicke, M., Van Huis, A. and Gold, C.S. 2002. Use of infochemicals in pest management with special reference to the banana weevil, *Cosmopolites sordidus* (Germar) (Coleoptera: Curculionidae). Insect Sci. Appl. 22, 241-261.

Treverrow N.L., Bedding R., Dettmann E.B. and Maddox C., 1991. Evaluation of entomopathogenic nematodes for the control of *Cosmopolites sordidus* Germar (Coleoptera: Curculionidae), a pest of bananas in Australia. Annals of Applied Biology 119:13945.

Zhu, J.  and Park, K-C., 2005. Methyl salicylate, a soybean aphid-induced plant volatile attractive to the predator *Coccinella septempunctata*. J. Chem Ecol. 31, 1733-1746.

**Table 1** Total numbers of adult banana weevils, *Cosmopolites sordidus*, captured at five field locations in Ashanti region, Ghana, using aggregation pheromone, senesced banana leaf palm alcohol extract, pseudostem, and combinations thereof, in type TAL and Voltic traps. Overall total and percentage of overall total capture for two groups (with/without pseudostem) of the five treatments are also shown.

| Field (Type of trap) | Duration of experiment (Weeks) | Aggregation pheromone plus banana leaf extract | Banana leaf extract | Aggregation pheromone | Pseudostem plus banana leaf extract | Pseudostem |
|---|---|---|---|---|---|---|
| 1 (TAL) | 12 | 151 | 20 | 109 | 10 | 5 |
| 2 (Voltic) | 7 | 87 | 19 | 32 | 17 | 7 |
| 3 (TAL) | 12 | 180 | 30 | 86 | 29 | 9 |
| 4 (Voltic) | 12 | 433 | 51 | 197 | 15 | 7 |
| 5 (Voltic) | 5 | 24 | 3 | 11 | 4 | 1 |
| **Total** | | **875** | **123** | **435** | **75** | **29** |
| **Overall total** | | **1433** | | | **104** | |
| **Percent weevil capture (%)** | | **61.1** | **8.5** | **30.4** | **72.1** | **27.9** |

**Table 2** Mean number of adult banana weevils, *Cosmopolites sordidus*, caught per week in field trapping experiments in Ashanti region, Ghana, using aggregation pheromone, senesced banana leaf palm alcohol extract, pseudostem, and combinations thereof, in type TAL and Voltic traps. These are the data analysed in Table 3.

| **Field (Type of trap)** | **Aggregation pheromone plus banana leaf extract** | **Banana leaf extract** | **Aggregation pheromone** | **Pseudostem plus banana leaf extract** | **Pseudostem** |
|---|---|---|---|---|---|
| 1 (TAL) | 12.58 | 2.22 | 9.08 | 0.83 | 0.42 |
| 2 (Voltic) | 12.43 | 2.71 | 4.57 | 2.43 | 1.00 |
| 3 (TAL) | 15.00 | 3.33 | 7.17 | 2.42 | 0.75 |
| 4 (Voltic) | 36.08 | 5.67 | 16.42 | 1.25 | 0.58 |
| 5 (Voltic) | 4.80 | 0.60 | 2.20 | 0.80 | 0.20 |
| **Sum of means** | **80.89** | **14.53** | **39.44** | **7.73** | **2.95** |
| **Overall mean**<br>**Standard error** | **16.2**<br>**5.3** | **2.9**<br>**0.8** | **7.9**<br>**2.4** | **1.5**<br>**0.4** | **0.6**<br>**0.1** |

**Table 3** Analysis of variance of the mean weevil catches per week data (data in Table 2 transformed to natural logarithms). The table details the sources of variation, the degrees of freedom (df), sums of squares (ss), mean squares (ms) (*i.e.* the variances), variance ratios (vr) and the *P*-values for the F-tests of the sources of variation. The ANOVA factors are denoted: *TrapType*, for Voltic *vs.* TAL type of trap; *ExtractOnly*, for the palm alcohol extract of senesced banana leaves treatment *vs.* the factorial set of four treatments involving aggregation pheromone or pseudostem; *Extract*, for the main effect of presence or absence of palm alcohol extract of senesced banana leaves; and *Treatment*, for the main effect aggregation pheromone *vs.* pseudostem. The dot indicates the interaction between factors. Significant (*P*< 0.05) ANOVA factors of interest are given in bold.

| **Source of variation** | df | ss | ms | vr | *P*-value |
|---|---|---|---|---|---|
| **Field stratum** | | | | | |
| *TrapType* | 1 | 0.054 | 0.054 | 0.00 | 0.957 |
| Residual | 3 | 47.720 | 15.907 | 7.93 | |
| **Field.Trap stratum** | | | | | |
| *ExtractOnly* | 1 | 0.432 | 0.432 | 0.22 | 0.651 |
| *ExtractOnly.**Extract*** | 1 | 31.456 | 31.456 | 15.68 | **0.002** |
| *ExtractOnly.**Treatment*** | 1 | 304.937 | 304.9371 | 51.99 | **<0.001** |
| *ExtractOnly.TrapType* | 1 | 0.007 | 0.007 | 0.00 | 0.954 |
| *ExtractOnly.Extract.Treatment* | 1 | 0.685 | 0.685 | 0.34 | 0.570 |
| *ExtractOnly.Extract.TrapType* | 1 | 0.310 | 0.310 | 0.15 | 0.701 |
| *ExtractOnly.Treatment.TrapType* | 1 | 0.130 | 0.130 | 0.06 | 0.803 |
| *ExtractOnly.Extract.Treatment.TrapType* | 1 | 0.289 | 0.289 | 0.14 | 0.711 |
| Residual | 12 | 24.075 | 2.006 | | |
| Total | 24 | 410.096 | | | |

**Table 4** Numbers of adult banana weevils, *Cosmopolites sordidus*, captured at five field locations in Ashanti region, Ghana, using aggregation pheromone, senesced banana leaf palm alcohol extract, pseudostem, and combinations thereof, in type TAL and Voltic traps.

(i) FIELD ONE (TAL trap)

| **Week** | **Aggregation pheromone plus banana leaf extract** | **Banana leaf extract** | **Aggregation pheromone** | **Pseudostem plus aggregation pheromone** | **Pseudostem** |
|---|---|---|---|---|---|
| 1 | 36 | - | 22 | 4 | 2 |
| 2 | 9 | - | 7 | 1 | 1 |
| 3 | 13 | - | 8 | 1 | 0 |
| 4 | 8 | 2 | 7 | 0 | 0 |
| 5 | 33 | 2 | 21 | 0 | 1 |
| 6 | 12 | 3 | 8 | 0 | 0 |
| 7 | 2 | 3 | 10 | 0 | 0 |
| 8 | 2 | 1 | 10 | 0 | 0 |
| 9 | 13 | 3 | 7 | 1 | 0 |
| 10 | 5 | 1 | 3 | 3 | 1 |
| 11 | 9 | 3 | 3 | 0 | 0 |
| 12 | 9 | 2 | 3 | 0 | 0 |
| **Total** | **151** | **20** | **109** | **10** | **5** |
| **Mean**<br>**Standard error** | **12.58**<br>**4.9** | **2.22**<br>**0.4** | **9.08**<br>**2.8** | **0.83**<br>**0.6** | **0.42**<br>**0.3** |

(ii) FIELD TWO (Voltic trap)

| Week | Aggregation pheromone plus banana leaf extract | Banana leaf extract | Aggregation pheromone | Pseudostem plus aggregation pheromone | Pseudostem |
|---|---|---|---|---|---|
| 1 | 18 | 2 | 7 | 0 | 0 |
| 2 | 5 | 1 | 2 | 0 | 1 |
| 3 | 5 | 1 | 3 | 5 | 1 |
| 4 | 3 | 1 | 2 | 1 | 1 |
| 5 | 12 | 1 | 4 | 6 | 2 |
| 6 | 7 | 2 | 4 | 1 | 0 |
| 7 | 37 | 11 | 10 | 4 | 2 |
| **Total** | **87** | **19** | **32** | **17** | **7** |
| **Mean**<br>**Standard error** | **12.43**<br>**5.4** | **2.71**<br>**1.6** | **4.57**<br>**1.3** | **2.43**<br>**1.1** | **1**<br>**0.4** |

(iii) FIELD THREE (TAL trap)

| **Week** | **Aggregation pheromone plus banana leaf extract** | **Banana leaf extract** | **Aggregation pheromone** | **Pseudostem plus aggregation pheromone** | **Pseudostem** |
|---|---|---|---|---|---|
| 1 | 27 | - | 21 | 0 | 0 |
| 2 | 19 | - | 6 | 4 | 1 |
| 3 | 9 | - | 7 | 4 | 0 |
| 4 | 11 | 6 | 4 | 0 | 0 |
| 5 | 12 | 4 | 7 | 2 | 0 |
| 6 | 24 | 4 | 16 | 0 | 0 |
| 7 | 4 | 1 | 1 | 1 | 0 |
| 8 | 16 | 4 | 5 | 11 | 5 |
| 9 | 10 | 1 | 2 | 2 | 0 |
| 10 | 11 | 2 | 3 | 0 | 1 |
| 11 | 24 | 5 | 9 | 3 | 1 |
| 12 | 13 | 3 | 5 | 2 | 1 |
| **Total** | **180** | **30** | **86** | **29** | **9** |
| **Mean**<br>**Standard error** | **15.00**<br>**3.2** | **3.33**<br>**0.8** | **7.17**<br>**2.6** | **2.42**<br>**1.4** | **0.75**<br>**0.6** |

(iv) FIELD FOUR (Voltic trap)

| Week | Aggregation pheromone plus banana leaf extract | Banana leaf extract | Aggregation pheromone | Pseudostem plus aggregation pheromone | Pseudostem |
|---|---|---|---|---|---|
| 1 | 53 | - | 42 | 2 | 2 |
| 2 | 48 | - | 26 | 3 | 1 |
| 3 | 19 | - | 11 | 1 | 1 |
| 4 | 26 | 5 | 3 | 1 | 0 |
| 5 | 9 | 1 | 2 | 2 | 0 |
| 6 | 74 | 12 | 23 | 1 | 0 |
| 7 | 17 | 2 | 8 | 0 | 1 |
| 8 | 36 | 4 | 17 | 0 | 0 |
| 9 | 24 | 3 | 10 | 1 | 0 |
| 10 | 17 | 2 | 4 | 1 | 0 |
| 11 | 65 | 13 | 34 | 2 | 0 |
| 12 | 45 | 9 | 17 | 1 | 2 |
| **Total** | **433** | **51** | **197** | **15** | **7** |
| **Mean**<br>**Standard error** | **36.08**<br>**9.3** | **5.67**<br>**2.0** | **16.42**<br>**5.7** | **1.25**<br>**0.4** | **0.58**<br>**0.4** |

(v) FIELD FIVE (Voltic trap)

| **Week** | **Aggregation pheromone plus banana leaf extract** | **Banana leaf extract** | **Aggregation pheromone** | **Pseudostem plus aggregation pheromone** | **Pseudostem** |
|---|---|---|---|---|---|
| 1 | 9 | 1 | 2 | 3 | 0 |
| 2 | 0 | 0 | 1 | 0 | 0 |
| 3 | 4 | 1 | 2 | 1 | 0 |
| 4 | 7 | 1 | 5 | 0 | 0 |
| 5 | 4 | 0 | 1 | 0 | 1 |
| **Total** | **24** | **3** | **11** | **4** | **1** |
| **Mean**<br>**Standard error** | **4.80**<br>**1.5** | **0.60**<br>**0.3** | **2.20**<br>**0.7** | **0.80**<br>**0.6** | **0.20**<br>**0.2** |

**Figure 1**. The type TAL modified trap (A), Voltic drinking water bottle trap (B) and pseudostem (C) used in field trapping experiments with adult banana weevils, *Cosmopolites sordidus*, in Ashanti region, Ghana.

**A**


**B**

**C**