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Citation for final published version:

Abagale, Samson A., Braimah, Haruna, Osafo-Acquaah, Samuel, Powers, Stephen J., Emden, Helmut, Birkett, Michael A., Pickett, John A. ORCID: <https://orcid.org/0000-0002-1008-6595>, Sanda, Umar I. and Vuts, József 2021. Field validation of senesced banana leaf extracts for trapping banana weevils on smallholder banana/plantain farms. *Journal of Applied Entomology* 145 (1-2) , pp. 26-35. 10.1111/jen.12838 file

Publishers page: <http://dx.doi.org/10.1111/jen.12838>  
<<http://dx.doi.org/10.1111/jen.12838>>

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

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

4  
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23 **Abstract**

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

39

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

## 41 **1. Introduction**

42 Bananas and plantains are of great economic importance in most regions of tropical and subtropical  
43 Africa. All year-round production of bananas ensures a continuous supply of food and income to the  
44 farmer, making bananas a major food security crop in the region (Ocan et al., 2008) and an important  
45 cash and subsistence crop in most tropical and subtropical regions of the world (Ortiz & Swennen,  
46 2014). According to estimations by the Food and Agriculture Organization (FAO), world total exports  
47 of banana accounted for 15.9 million tonnes in 2004. About 98 per cent of world banana production is  
48 in developing countries, and it is largely imported by developed countries.

49

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

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

77

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

94

95 **2. Materials and Methods**

96 **2.1 Trap baits.** Palm alcohol extract of senesced banana leaf material required for field trapping  
97 experiments was prepared as previously described (Abagale *et al.*, 2018b), by crushing banana leaf  
98 material (100 g) into palm alcohol (50 ml). The mixture was kept for 24 hours at ambient temperature,  
99 before being decanted into storage vials. Cosmolure (P160-Lure), containing the banana weevil  
100 aggregation pheromone (Beauhaire *et al.*, 1995), sordinin, was purchased from ChemTica  
101 International, Costa Rica. Samples of fresh banana pseudostems (Figure 1C) were collected from  
102 growing plants in the banana fields at the site of trapping experiments.

103

104 **2.2 Banana weevil traps.** Two types of pitfall traps were used in the field trapping; a type TAL trap  
105 (Plant Protection Institute, Budapest, Hungary) modified for use as a fully buried pitfall trap (Figure  
106 1A), and a Voltic drinking bottle trap (Figure 1B). The type TAL trap was made from a pale pink  
107 rectangular plastic container (17 cm × 11.5 cm × 8 cm) comprising an off-white background plastic  
108 walk-way placed over the two longer edges and covered with a plain transparent plastic roof to  
109 prevent rain or dew entering the trap, while maintaining visibility inside the trap. When in use, the  
110 trap was buried in the ground such that the top edge was level with the ground and the plastic walk  
111 way lay flat, slightly above the ground. The Voltic bottle trap was made using two 1.5 L empty water  
112 bottles purchased from Kumasi Central Market, Ghana. The lower portion of one bottle was cut to  
113 provide a 10 cm high weevil collection receptacle. Two vents were cut on opposite sides of the second  
114 bottle. Each vent was made by cutting the bottle on three edges at a height of 14.5 cm from the mouth  
115 such that the resultant flap opened towards the fourth side (bottom). Each vent was approximately 36  
116 cm<sup>2</sup>. When in use, the flap was lifted up, to the outside of the trap, to serve as protection against direct  
117 entry of rain water into the trap. A narrow hole was created on the bottom of the second bottle for use  
118 in hanging the bait. To complete the trap, this second bottle was then inserted upside-down into the  
119 receptacle half made from the other bottle. In the field, the trap was buried so that the lower edge of  
120 the cut vent was at ground level, and the bait was hung from the top so that it came into level with the  
121 opening.

122

123 **2.3 Baiting of traps.** The TAL and Voltic traps were baited with either individual treatments, *i.e.* palm  
124 alcohol extract of senesced banana leaf material, aggregation pheromone or pseudostem, or  
125 combinations of extract plus pheromone or extract plus pseudostem, giving 10 treatment combinations  
126 altogether. This formed an extract only (control lure) plus a ‘two treatments (pheromone and  
127 pseudostem) by two levels of extract (presence and absence)’ factorial set, by two types of trap (TAL  
128 and Voltic bottle). For treatment combinations involving the pheromone and pseudostem, those with  
129 palm alcohol extract were the test treatments and those without were the corresponding controls.

130

131 **2.4 Field trapping and trapping sites.** Trapping was done on five fields located in the Ashanti region  
132 of Ghana ( $6^{\circ}41'18''N$ ;  $1^{\circ}37'27''W$ ) between June and August 2015; two at the College of Agriculture  
133 (fields 1 & 2), one each at Kwadaso and Mwamase near Kwadaso (fields 3 & 4) and one at Mankraso  
134 (5). There were five traps of one type (Voltic or TAL) in each field, one trap for each bait treatment.  
135 Traps were arranged randomly in each field, maintaining at least 20 m between each trap and 10 m  
136 from the boundary of the field. The traps were checked weekly for 12 weeks (fields 1, 3 and 4), seven  
137 weeks (field 2) or five weeks (field 5). Hence, there were three replicates of treatments with Voltic  
138 traps (for 12, 7 and 5 weeks, fields 4, 2 and 5) and two replicates of treatments with TAL traps (for 12  
139 weeks, fields 1 and 3) (see Table 4). Weevils captured were counted and recorded, and the total  
140 weevil capture per trap calculated. Average weevil catch per week for each treatment combination in  
141 each field was calculated, and the overall mean catch for each trap type was also calculated. All fields  
142 were part of one experiment, done at the same time. Fields were seen as sufficiently homogeneous to  
143 preclude the need for blocking but they were of insufficient size to allow all 10 treatment  
144 combinations (trap type by bait treatment) in each one. Thus, fields were seen as main plots with one  
145 type of trap in each field, and with the baits as split-plot treatments. Subsequent analysis (Table 3)  
146 accounted for this design.

147 **2.5 Statistical analysis.** Weighted analysis of variance (ANOVA) was applied to the average catch per  
148 week data, weighting for the number of weeks, taking account of the different fields and testing (F-  
149 tests) for the main effects and interactions between the factors of type of trap (TAL or Voltic bottle),  
150 lure treatment (pheromone or pseudostem) and extract (presence or absence), nesting out the extract-

151 only lure from the two by two factorial set of treatment combinations. A natural logarithmic  
152 transformation was applied to the data to account for heterogeneity of variance across the treatment  
153 combinations. Checks on residuals revealed that, under the transformation, the assumptions of the  
154 analysis had been met. Given the ANOVA, appropriate tables of means were output, for comparison  
155 using the standard error of the difference (SED) between means, thus invoking the least significant  
156 difference (LSD) at the 5% level of significance. The GenStat (17<sup>th</sup> edition, © VSN International Ltd,  
157 Hemel Hempstead, UK) statistical package was used for this analysis. It was noted that the statistical  
158 requirement of transformation of data did not alter the fact that the effect of the treatments was shown  
159 by the means of the untransformed data, and these means were therefore presented, but with the  
160 transformed means on which statistical tests were based, given the results of ANOVA, being included  
161 in brackets and italicised.

162

### 163 **3. Results**

164 Table 1 shows the total number of adult banana weevils caught in each trap for each of the five  
165 different treatments, and the percentage of total weevil capture over treatments either with, or without,  
166 pseudostem, whilst Table 2 shows the mean weevil catch per week in each of the five fields using the  
167 five different treatments. The ANOVA of the data in Table 2 (Table 3) shows that, having accounted  
168 for the treatment using extract alone (*ExtractOnly*), there was a significant main effect of the presence  
169 of palm alcohol extract ( $P = 0.002$ , F-test) and a main effect of the lure (pheromone or pseudostem)  
170 treatment used ( $P < 0.001$ , F-test), but no interaction between the two factors ( $P = 0.570$ , F-test). This  
171 indicates that the two effects were independent and additive. There was also no effect of type of trap  
172 (*TrapType*) or interaction of this factor with the others. We also note that these same overall results  
173 were obtained when omitting the data from fields 2 and 5, for which trapping ran for less than 12  
174 weeks. The means for the main effect of extract were: 4.239 (transformed data mean: 0.73) without  
175 extract and 8.862 (1.54) with extract ( $n = 10$ ,  $SED = 0.204$  on 12 df;  $LSD (5\%) = 0.445$ ). These means  
176 show that there was approximately a 2.1-fold increase in mean catch per week through using the  
177 extract. The means for the main effect of lure treatment were: 12.033 (2.39) for the pheromone and  
178 1.068 (-0.13) for pseudostem ( $n = 10$ ,  $SED = 0.204$  on 12 df;  $LSD (5\%) = 0.445$ ). These means show



179 that there was approximately an 11-fold increase in mean catch per week through using pheromone  
180 compared to pseudostem. Although there was no statistically significant interaction between the two  
181 factors, the best combination for maximal catch was most certainly the pheromone with the extract;  
182 this gave a mean of 16.178 (2.74), compared to 7.888 (2.05) for the pheromone without the extract (n  
183 = 5, a 2.1-fold increase). The corresponding results for pseudostem were 1.546 (0.34) with the extract  
184 and 0.59 (-0.59) without the extract (n = 5, a 2.6-fold increase). However, even though there appeared  
185 to be substantially more than an additive effect involving the treatments it was not robust enough to be  
186 statistically significant.

187

#### 188 **4. Discussion**

189 It has been postulated that combinations of species-specific pheromone and host plant  
190 volatiles may interact synergistically to attract *C. sordidus* (Budenberg *et al.*, 1993; Jayaraman *et al.*,  
191 1997). Preliminary studies in the laboratory have also indicated that host plant volatiles may enhance  
192 the aggregation pheromone (Tinzaara *et al.*, 2003), and our recent work has demonstrated that a  
193 mixture of isomers of theaspirane, identified from senesced banana leaf material as a banana weevil  
194 attractant, improves the activity of the aggregation pheromone (Abagale *et al.*, 2018a). Generally,  
195 there was large variation in the total number of weevils caught in a given type of trap with different  
196 lures from the same field (Table 1). Correspondingly, there were differences in the overall total  
197 numbers of weevils caught in all traps containing different types of lures. Thus, comparing the three  
198 non-pseudostem treatment combinations, i.e. pheromone alone, palm alcohol extract alone and  
199 pheromone with extract, 61.1 % of the total weevils captured were lured into traps containing the  
200 combination of pheromone and extract, while 8.5 % and 30.4 % of the total weevils were lured into  
201 traps containing the extract alone and pheromone alone respectively. For the treatments involving  
202 pseudostem, traps with pseudostem treated with the palm alcohol extract lured 72.1 % of the weevils  
203 captured, whilst traps with untreated pseudostem attracted 27.1 % of the pseudostem-lured weevils.

204 It has been reported that geographically separate populations may respond differently to on-  
205 farm conditions such as weed infestation level and the presence of other crops (Braithwaite & Van  
206 Emden, 2002). It was later corroborated that there could be variation in insect ecology as a result of  
207 geographical location (Zhu & Park, 2005). In addition, response of the male pine saw fly, *Neodiprion*  
208 *sertifer*, to sex pheromone analogues in the field has also been reported to show dependence on  
209 geographical location (Anderbrant *et al.*, 2010). However, any geographic or on-farm influences in  
210 our trapping experiment were expected to contribute marginally to variation, as all experiments were  
211 conducted in the same region (6°41'18"N; 1°37'27"W) in Ghana. Despite this, Table 3 shows that the  
212 estimated underlying field-to-field variation from the ANOVA was 15.907, 7.9-fold greater than the  
213 estimated underlying within-field variation (2.006), so clearly differences between local populations  
214 could be important. The current study was carried out in fields in the same geographical location and  
215 thus enabled robust assessment of the performance of the lures. Attraction of the weevils could  
216 therefore arise mainly from the observed luring activity of the aggregation pheromone and host-  
217 derived cues without excess variation from other extraneous sources. The extent of the observed field-  
218 to-field variation can therefore be explained in terms of the different periods of time (number of  
219 weeks) over which assessment was made for two of the fields compared to the other three (12 weeks  
220 for fields 1, 3 and 4, seven weeks for field 2, five weeks for field 5) and the varying numbers of total  
221 weevils per week over weeks (Table 4).

222

223 Previous research on the synergy of attractants for the banana weevil has largely failed to produce  
224 consistent results. A study in Costa Rica reported that pseudostem traps baited with aggregation  
225 pheromone caused a 5-10-fold increase in attractiveness to weevils (Alpizar & Fallas, 1997). In  
226 another study, using olfactometry experiments, Tinzaara *et al.* (2002) observed that a greater number  
227 of weevils responded to fermented banana tissues combined with the aggregation pheromone  
228 compared to the individual treatments. Other studies also indicated that banana extract and host plant  
229 extract enhanced pheromone attractiveness to weevils when used together (Reddy *et al.*, 2008;  
230 Palinichamy *et al.*, 2011). However, during pheromone trap trials in South Africa, trap catches were

231 reported to be greater for traps with lures containing the pheromone than lures containing both the  
232 pheromone and a plant kairomone (De Graaf *et al.*, 2005). Also, a study in tropical Costa Rica  
233 reported that pseudostem traps and pseudostem traps baited with pheromone attracted an equal sex  
234 ratio of weevils (Jayaraman *et al.*, 1997). The results of our present study suggest that palm alcohol  
235 extracts of senesced banana leaf material can enhance the attractiveness of the aggregation pheromone  
236 to adult banana weevils, and also that weevil populations can be trapped through deployment of leaf  
237 extracts alone. This suggests that either approach is suitable for use in banana weevil management,  
238 with the latter being potentially affordable for use by smallholder banana/plantain farmers, especially  
239 since leaf material and palm alcohol are both affordable and available to farmers at no, or low, cost.  
240 Further studies are planned to undertake field trapping experiments on a wider scale in Ghana and  
241 demonstrate the low-cost extraction and trapping technology to smallholder banana/plantain farmers.

242

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

258 **Acknowledgements**

259 Funding for this work was provided by a Royal Society/ Leverhulme Trust Africa Award (2012-  
260 2016), UK. Rothamsted Research receives grant-aided support from the UK Biotechnology and  
261 Biological Sciences Research Council (BBSRC) of the United Kingdom. Other forms of support were  
262 provided by the Crops Research Institute of the Council for Scientific and Industrial Research (CRI-  
263 CSIR), Kumasi, Ghana, the Chemistry Department of Kwame Nkrumah University of Science and  
264 Technology (KNUST), Kumasi, Ghana, and the University for Development Studies, Tamale, Ghana.  
265 Field staff of the CRI-CSIR, Kumasi, Ghana also offered some support during the field work.

266

267 **Conflict of Interest**

268 The authors have declared no conflicts of interest

269

270 **Authors' Contributions**

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

276

277 **Data Availability Statement**

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

281

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

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| Field<br>(Type of trap)               | Duration of<br>experiment<br>(Weeks) | Aggregation<br>pheromone plus<br>banana leaf extract | Banana leaf<br>extract | Aggregation<br>pheromone | Pseudostem plus<br>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           |
| <b>Total</b>                          |                                      | <b>875</b>   | <b>123</b>             | <b>435</b>               | <b>75</b>                              | <b>29</b>   |
| <b>Overall total</b>                  |                                      | <b>1433</b>  |                        |                          | <b>104</b>                             |             |
| <b>Percent weevil<br/>capture (%)</b> |                                      | <b>61.1</b>  | <b>8.5</b>             | <b>30.4</b>              | <b>72.1</b>                            | <b>27.9</b> |

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

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| Field<br>(Type of trap) | Aggregation pheromone<br>plus banana leaf extract | Banana leaf<br>extract | Aggregation pheromone | Pseudostem plus<br>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        |
| <b>Sum of means</b>     | <b>80.89</b>                                      | <b>14.53</b>           | <b>39.44</b>          | <b>7.73</b>                            | <b>2.95</b> |
| <b>Overall mean</b>     | <b>16.2</b>                                       | <b>2.9</b>             | <b>7.9</b>            | <b>1.5</b>                             | <b>0.6</b>  |
| <b>Standard error</b>   | <b>5.3</b>  | <b>0.8</b>             | <b>2.4</b>            | <b>0.4</b>                             | <b>0.1</b>  |

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455 **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  
 456 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  
 457 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  
 458 leaves treatment vs. the factorial set of four treatments involving aggregation pheromone or pseudostem; *Extract*, for the main effect of presence or absence of  
 459 palm alcohol extract of senesced banana leaves; and *Treatment*, for the main effect aggregation pheromone vs. pseudostem. The dot indicates the interaction  
 460 between factors. Significant ( $P < 0.05$ ) ANOVA factors of interest are given in bold.

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| 462 Source of variation                           | df | ss      | ms       | vr    | <i>P</i> -value  |
|---|----|---------|----------|-------|------------------|
| 463 <b>Field stratum</b>                          |    |         |          |       |                  |
| 464 <i>TrapType</i>                               | 1  | 0.054   | 0.054    | 0.00  | 0.957            |
| 465 Residual                                      | 3  | 47.720  | 15.907   | 7.93  |                  |
| 466 <b>Field.Trap stratum</b>                     |    |         |          |       |                  |
| 467 <i>ExtractOnly</i>                            | 1  | 0.432   | 0.432    | 0.22  | 0.651            |
| 468 <i>ExtractOnly.Extract</i>                    | 1  | 31.456  | 31.456   | 15.68 | <b>0.002</b>     |
| 469 <i>ExtractOnly.Treatment</i>                  | 1  | 304.937 | 304.9371 | 51.99 | <b>&lt;0.001</b> |
| 470 <i>ExtractOnly.TrapType</i>                   | 1  | 0.007   | 0.007    | 0.00  | 0.954            |
| 471 <i>ExtractOnly.Extract.Treatment</i>          | 1  | 0.685   | 0.685    | 0.34  | 0.570            |
| 472 <i>ExtractOnly.Extract.TrapType</i>           | 1  | 0.310   | 0.310    | 0.15  | 0.701            |
| 473 <i>ExtractOnly.Treatment.TrapType</i>         | 1  | 0.130   | 0.130    | 0.06  | 0.803            |
| 474 <i>ExtractOnly.Extract.Treatment.TrapType</i> | 1  | 0.289   | 0.289    | 0.14  | 0.711            |
| 475   |    |         |          |       |                  |
| 476 Residual                                      | 12 | 24.075  | 2.006    |       |                  |
| 477 Total   | 24 | 410.096 |          |       |                  |

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482 **Table 4** Numbers of adult banana weevils, *Cosmopolites sordidus*, captured at five field locations in Ashanti region, Ghana, using aggregation pheromone,  
 483 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           |
| <b>Total</b>          | <b>151</b>                                     | <b>20</b>           | <b>109</b>            | <b>10</b>                             | <b>5</b>    |
| <b>Mean</b>           | <b>12.58</b>                                   | <b>2.22</b>         | <b>9.08</b>           | <b>0.83</b>                           | <b>0.42</b> |
| <b>Standard error</b> | <b>4.9</b>                                     | <b>0.4</b>          | <b>2.8</b>            | <b>0.6</b>                            | <b>0.3</b>  |

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(ii) FIELD TWO (Voltic trap)

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| 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          |
| <b>Total</b>          | <b>87</b>                                      | <b>19</b>           | <b>32</b>             | <b>17</b>                             | <b>7</b>   |
| <b>Mean</b>           | <b>12.43</b>                                   | <b>2.71</b>         | <b>4.57</b>           | <b>2.43</b>                           | <b>1</b>   |
| <b>Standard error</b> | <b>5.4</b>                                     | <b>1.6</b>          | <b>1.3</b>            | <b>1.1</b>                            | <b>0.4</b> |

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(iii) FIELD THREE (TAL trap)

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| Week                  | Aggregation pheromone plus banana leaf extract | Banana leaf extract | Aggregation pheromone | Pseudostem plus aggregation pheromone | 508 Pseudostem 509 |
|-----------------------|--|---------------------|-----------------------|---------------------------------------|--------------------|
| 1                     | 27   | -                   | 21                    | 0                                     | 0 510              |
| 2                     | 19   | -                   | 6                     | 4                                     | 1                  |
| 3                     | 9  | -                   | 7                     | 4                                     | 0 511              |
| 4                     | 11   | 6                   | 4                     | 0                                     | 0                  |
| 5                     | 12   | 4                   | 7                     | 2                                     | 0 512              |
| 6                     | 24   | 4                   | 16                    | 0                                     | 0                  |
| 7                     | 4  | 1                   | 1                     | 1                                     | 0 513              |
| 8                     | 16   | 4                   | 5                     | 11                                    | 5                  |
| 9                     | 10   | 1                   | 2                     | 2                                     | 0 514              |
| 10                    | 11   | 2                   | 3                     | 0                                     | 1                  |
| 11                    | 24   | 5                   | 9                     | 3                                     | 1 515              |
| 12                    | 13   | 3                   | 5                     | 2                                     | 1 516              |
| <b>Total</b>          | <b>180</b>                                     | <b>30</b>           | <b>86</b>             | <b>29</b>                             | <b>9</b>           |
| <b>Mean</b>           | <b>15.00</b>                                   | <b>3.33</b>         | <b>7.17</b>           | <b>2.42</b>                           | <b>0.75</b>        |
| <b>Standard error</b> | <b>3.2</b>                                     | <b>0.8</b>          | <b>2.6</b>            | <b>1.4</b>                            | <b>0.6</b> 517     |

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(iv) FIELD FOUR (Votlic trap)

| <b>Week</b>           | <b>Aggregation pheromone plus banana leaf extract</b> | <b>Banana leaf extract</b> | <b>Aggregation pheromone</b> | <b>Pseudostem plus aggregation pheromone</b> | <b>Pseudostem</b> |
|-----------------------|---|----------------------------|------------------------------|--|-------------------|
| 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                 |
| <b>Total</b>          | <b>433</b>  | <b>51</b>                  | <b>197</b>                   | <b>15</b>                                    | <b>7</b>          |
| <b>Mean</b>           | <b>36.08</b>  | <b>5.67</b>                | <b>16.42</b>                 | <b>1.25</b>                                  | <b>0.58</b>       |
| <b>Standard error</b> | <b>9.3</b>  | <b>2.0</b>                 | <b>5.7</b>                   | <b>0.4</b>                                   | <b>0.4</b>        |

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(v) FIELD FIVE (Votlic trap)

| <b>Week</b>           | <b>Aggregation pheromone plus banana leaf extract</b> | <b>Banana leaf extract</b> | <b>Aggregation pheromone</b> | <b>Pseudostem plus aggregation pheromone</b> | <b>Pseudostem</b> |
|-----------------------|---|----------------------------|------------------------------|--|-------------------|
| 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                 |
| <b>Total</b>          | <b>24</b>   | <b>3</b>                   | <b>11</b>                    | <b>4</b>                                     | <b>1</b>          |
| <b>Mean</b>           | <b>4.80</b>   | <b>0.60</b>                | <b>2.20</b>                  | <b>0.80</b>                                  | <b>0.20</b>       |
| <b>Standard error</b> | <b>1.5</b>  | <b>0.3</b>                 | <b>0.7</b>                   | <b>0.6</b>                                   | <b>0.2</b>        |

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535 **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  
536 weevils, *Cosmopolites sordidus*, in Ashanti region, Ghana.

537 **A**



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**B**



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545 **C**



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