

Field validation of senesced banana leaf extracts for trapping banana weevils on smallholder banana/plantain farms

Article

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1 **Abstract**

2 Palm wine alcohol extract of senesced banana leaf material, *Musa* spp., was tested for its
3 efficacy in open field trapping of the banana weevil, *Cosmopolites sordidus* in Ghana from
4 June to August 2015. Modified pitfall and bottle traps were baited with either individual
5 treatments, *i.e.* palm alcohol extract, *C. sordidus* aggregation pheromone or pseudostem, or
6 with combinations of extract plus aggregation pheromone or extract plus pseudostem. The
7 combination of extract plus aggregation pheromone was able to lure more weevils into traps
8 compared to the respective individual lures. There was a 2.1-fold increase in mean catch per
9 week when the palm alcohol extract was used in combination with pheromone compared to
10 using pheromone alone, and a corresponding 2.6-fold increase when the extract was used with
11 pseudostem in traps. There was no statistically significant interaction between the palm alcohol
12 extract (presence or absence) and treatment (pheromone or pseudostem), but the best
13 combination for maximal catches of adult banana weevils was a combination of palm alcohol
14 extract with aggregation pheromone. Management of banana weevils with attractive banana
15 leaf extract has important practical applications in parts of the world where other management
16 options are too expensive or commercial treatments are in short supply, but where leaf material
17 is cheap and readily available for local use by smallholder farmers.

18

19 **Keywords:** *Musa* spp, *Cosmopolites sordidus*, Ghana, lure, TAL trap, Voltic trap

20 **1. Introduction**

21 Bananas and plantains are of great economic importance in most regions of tropical and
22 subtropical Africa. All year round production of bananas ensures a continuous supply of food
23 and income to the farmer, making bananas a major food security crop in the region (Ocan,
24 Mukasa, Rubaihayo, Tinzaara & Blomme, 2008) and an important cash and subsistence crop
25 in most tropical and subtropical regions of the world (Ortiz & Swennen, 2014). According to
26 estimations by the Food and Agriculture Organization (FAO), world total exports of banana
27 accounted for 15.9 million tonnes in 2004 (Kumar, Jain, Meena & Sen, 2015) In 2018, global
28 exports of bananas, excluding plantain, reached a record high of 19.2 to 23.3 million tonnes
29 (FAO, 2019; Mordor Intelligence, 2019) but in Africa there was an estimated drop of 9 percent
30 below the level of 2017 exports (FAO, 2019). Banana export from Ghana has grown from about
31 3,000 tonnes per year in 2007 to over 70,000 tonnes in 2017, positioning the commodity as
32 second to cocoa and oil palm (Ghanaweb reports, 2018). The largest export portion (43%) of
33 banana from Ghana in 2015 was to The United Kingdom, followed by Belgium in second place
34 (Ghana Export Promotion Authority, 2017). Currently, Ghana is one of the Africa Caribbean
35 Pacific (ACP) countries that have concluded negotiations on an Economic Partnership
36 Agreement (EPA) for **supply of bananas to countries in the European Union** (FAO, 2019).

37 Approximately 98% of world banana production is in developing countries, with
38 bananas mainly being imported by developed countries (Kumakech, 2008). The estimated
39 worldwide average total increase of banana exports was 43.3% in 2019, over a five-year period
40 from 2015. Latin America excluding Mexico plus the Caribbean had the greatest monetary
41 value of banana exports in 2019 (\$8.3 billion, 56.7%), followed by Europe (17.5%), Asia
42 (15.6%), Africa (5.2%), North America (4.9%) and Oceania (0.004%) (Workman, 2020).

43 Sustainable production of bananas and plantains is constrained by many biotic factors
44 (Hallam, 1995) that significantly reduce crop yield, including insect pests and pathogens such

45 as weevils, nematodes, black sigatoka disease, fusarium wilt and banana xanthomonas wilt
46 disease. Most of the banana pests and pathogens are transmitted through suckers from infected
47 parent plants and from one farm to another through the exchange of suckers, a common practice
48 among smallholder farmers (Macharia, Kagundu, Kimani & Otieno, 2010). The banana weevil,
49 *Cosmopolites sordidus* Germar (Coleoptera: Curculionidae) has been cited as one of the most
50 challenging constraints to banana and plantain production, particularly on smallholder farms
51 (Price, 1994; Gold, Pena & Karamura, 2001; Foagain, Messiaen & Foure, 2002; Twesigye et
52 al. 2018). *C. sordidus* is native to Malaysia and Indonesia but is found in nearly all banana-
53 growing areas of the world (Gold et al. 2001; Reddy, Cruz, Naz & Muniappan, 2008). The
54 weevil has been reported as one of the foremost pests in most bananas growing regions (Stover
55 & Simmonds, 1987), attacking all types of bananas, including those destined for dessert and
56 brewing industries, highland bananas and plantains. Management strategies for *C. sordidus*
57 vary in efficacy and convenience, and currently include the use of synthetic pesticides
58 (Sponagel, Diaz & Cribas, 1995); cultural control methods such as farm sanitation (Masanza,
59 Gold, van Huis & Ragama, 2005), and use of pseudostem traps (Gold, Okech & Nokoe, 2002);
60 biological control with entomopathogens (Treverrow, Bedding, Dettmann & Maddox, 1991;
61 Nankinga & Moore, 2000) or myrmicine ants (Castineiras & Ponce, 1991); planting of host
62 plants with resistance (Kiggundu, Gold, Labuschagne, Vuylsteke & Louw, 2003); use of
63 botanical pesticides such as neem extracts (Musabyimana, Saxena, Kairu, Ogol & Khan, 2001),
64 and mass trapping with aggregation pheromone lures (Alpizar, Fallas, Oehlschlager, Gonzalez
65 & Jayaraman, 1999; Tinzaara et al. 2005). Large-scale control of *C. sordidus* is currently
66 achieved by chemical methods, while cultural controls remain highly valuable in preventing
67 the establishment of the pest. Cultural control methods are also the main available means of
68 management of the pest by smallholder farmers and growers, while biological control methods
69 such as the application of arthropods and fungi in integrated pest management strategies are
70 also being developed (Braumah & van Emden, 1999). In Asia, classical biological control of

71 the weevil using natural enemies has so far been unsuccessful and the use of opportunistic,
72 generalist predators have had limited efficacy (Waterhouse and Norris, 1987; Koppenhofer et
73 al., 1992). Ants have been reported to help control the weevil in Cuba, but their effects
74 elsewhere are unknown (Castineiras and Ponce, 1991). Effective strains of microbial agents
75 have also been reported, but their use is constrained by the need of economic mass production
76 and delivery systems (Gold, Pena & Karamura, 2003).

77 The attractiveness of pheromone-based lures for many insect species can be enhanced
78 through combination with host plant-derived volatiles (Tewari, Leskey, Nielsen, Piñero &
79 Rodriguez-Saona, 2014). Combination effects between pheromones and plant odour have been
80 reported to be a common feature for weevils (Curculionidae) and possibly more widely
81 amongst Coleopteran species (Hugo, Kenju, Toru & Klaus, 1998; Wertheim, van Baalen, Dicke
82 & Vet, 2005; Vidal, Moreira, Coracini & Zarbin, 2019). Adult *C. sordidus* have been shown to
83 orient to both the male-produced aggregation pheromone and host plant volatiles (Tinzaara,
84 Dicke, Van Huis & Gold, 2002). In our earlier work, senesced banana leaves were found to be
85 attractive to adult *C. sordidus*, with the active component from volatile collections being
86 identified, via behaviour (olfactometer) assays and coupled GC-electrophysiology, as (2*R*,5*S*)-
87 theaspirane (Braithwaite & Van Emden, 1999; Abagale et al. 2018a). Furthermore, a mixture of
88 the theaspirane isomers was shown to enhance the activity of the aggregation pheromone
89 (Abagale et al. 2018a). Additionally, palm alcohol extract of senesced leaf material was shown
90 to be equally attractive as senesced leaf material, suggesting that the extract could be suitable
91 for deployment in new trapping systems aimed at banana weevil management (Abagale et al.
92 2018b). Here, we report on open field trapping of banana weevils in Ghana using palm alcohol
93 extract of dead banana leaf, the aggregation pheromone, pseudostem, and combinations
94 thereof, to investigate the potential for interaction between the treatments in the field, and

95 assess the additive/synergistic potential for the use of palm alcohol extract in weevil trapping
96 systems using two trap designs.

97

98 **2. Materials and Methods**

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

108

109 *2.2 Banana weevil traps.* Two types of traps were used in the field trapping; a CSALOMON®
110 pitfall trap codenamed TAL (Plant Protection Institute, Budapest, Hungary) (Figure 1A) and a
111 Voltic drinking bottle trap (Figure 1B). The TAL trap is a modified pitfall trap with a cover
112 that protects it from rainwater collection. To set up the trap, it is usually placed on the soil
113 surface without digging into the soil and also without adding a killing liquid. It has consistent
114 sensitivity with a very high holding capacity of weevil catch (Tóth et al., 2002). The catch
115 container of the TAL trap is a pale pink plastic tray (7 × 17.5 × 11.5 cm) that, for this study,
116 was sunk into a shallow hole in the soil. A roof made of a folded transparent plastic sheet is
117 placed above the container, and two vertical off-white side sheets on the ground are attached
118 at soil level, thus providing a smooth surface for weevils entering the trap and leading them
119 into the container. The Voltic bottle trap (Abagale et al., 2017) was made using two 1.5 L

120 empty water bottles purchased from Kumasi Central Market, Ghana. The lower portion of one
121 bottle was cut to provide a 10 cm high weevil collection receptacle. Two vents were made on
122 opposite sides of the second bottle, each by cutting the bottle on three edges at a height of 14.5
123 cm from the mouth such that the resultant flap opened towards the fourth side (bottom). Each
124 vent was approximately 36 cm². When in use, the flap was lifted up towards the outside of the
125 trap to serve as protection against direct entry of rainwater into the trap. A narrow hole was
126 created on the bottom of the second bottle for use in hanging the bait. To complete the trap,
127 this second bottle was then inserted upside-down into the receptacle half made from the other
128 bottle. In the field, the trap was buried so that the lower edge of the cut vent was at ground
129 level, and the bait was hung from the top so that it came into level with the opening.

130

131 *2.3 Baiting of traps.* The TAL and Voltic traps (figure1) were baited with either individual
132 treatments, *i.e.* palm alcohol extract of senesced banana leaves, or the use of aggregation
133 pheromone or pseudostem, or combinations of extract plus pheromone or extract plus
134 pseudostem, giving 10 treatment combinations altogether. This formed an extract only (control
135 lure) plus a ‘two treatments (pheromone and pseudostem) by two levels of extract (presence
136 and absence)’ factorial set, by two types of traps (TAL and Voltic bottle). For treatment
137 combinations involving the pheromone and pseudostem, those with palm alcohol extract were
138 the test treatments and those without were the corresponding controls. The traps were baited
139 by applying palm alcohol extract (ca 1 ml) of senesced banana leaves using a syringe and
140 needle. The extract (lure) was applied at trap set and re-applied every two weeks over the period
141 of trapping. Controls were baited using only the solvent of extraction.

142 For the Cosmolure, the dispenser was hung from the roof of the traps using the flexible copper
143 wire. For the palm alcohol extract, flexible copper wire was also used to suspend a 0.50 g piece
144 of polyurethane based synthetic latex foam (made in Ghana) as dispenser. The dispensers were

145 hanged from the top of TAL and Voltic traps (Abagale et al., 2017). The palm alcohol extract
146 of banana bait was applied on the surface of the foam. In the use of Cosmolure, the bait
147 dispenser was fastened to the copper wire. The baits were suspended to fall in line with
148 openings in each trap to facilitate diffusion of the bait odours to the outside to attract weevils
149 into the trap. It was also ensured that the dispensers did not touch walls of the trap.

150 The traps with pseudostem were made of fresh material. Ca. 25 cm lengths of pseudostem made
151 from fresh plantain/banana were cut and split in half. Each half was enough for a trap.
152 Smallholder farmers already use pseudostem for trapping the weevils as indicated in previous
153 studies (Jayaraman et al., 1997; Gold et al., 2002).

154

155 *2.4 Field trapping and trapping sites.* Trapping was done on five fields located in the Ashanti
156 region of Ghana (6°41'18"N; 1°37'27"W) between June and August 2015; two at the College
157 of Agriculture (fields 1 & 2), one each at Kwadaso and Mwamase near Kwadaso (fields 3 &
158 4) and one at Mankraso (field 5). Experimental sites were within few a km from each other,
159 and no more than 10 km apart. There were five traps of one type (Voltic or TAL) in each field,
160 one trap for each bait treatment. Each field contained one replicate of each treatment associated
161 with one type of trap. There was no blocking. Each field was a main-plot in a split-plot design,
162 the main plots providing the overall replication of the trap by lure treatment
163 combinations. There was a single experiment, and underlying variation from the single
164 experiment was used to make assessment of differences between treatments overall. There were
165 no blocks, only main-plots with the trapping positions as split-plots. Traps were randomly
166 allocated to fields as it was obviously not possible to start off with the same numbers of weevils
167 per field for comparing trap by lure combinations. Geographically separate populations may
168 respond differently to on-farm conditions or insect ecology (Braumah and van Emden, 2002;

169 Zhu and Park, 2005). Thus, a priori, one population of weevils was assumed over all the fields
170 seeing that they were in the same geographic location.

171 Traps were arranged randomly in each field, maintaining at least 20 m between each trap and
172 10 m from the boundary of the field. The traps were checked weekly for 12 weeks (fields 1, 3
173 and 4), seven weeks (field 2) or five weeks (field 5). Hence, there were three replicates of
174 treatments with Voltic traps (for 12, 7 and 5 weeks, fields 4, 2 and 5) and two replicates of
175 treatments with TAL traps (for 12 weeks, fields 1 and 3) (see Table 4). Replication was applied
176 over separate fields. The experimental fields were not large enough to accommodate more than
177 5 traps per field. Thus it was experimentally necessary to apply different treatment factors to
178 the different sized experimental areas. Trap type was therefore assigned to fields and lure
179 treatments to within fields using the split-plot design (Jones and Nachtsheim, 2009; Arnouts,
180 2018). There were unequal numbers of weeks per field, but to account for this situation the
181 average catch per week is analysed, and weighted for the number of weeks (12, 7, 5; or 9 for
182 the palm alcohol extract of banana leaf treatment in fields 1, 3 and 4).

183 Weevils captured were counted and recorded, and the total weevil capture per trap calculated.
184 Average weevil catch per week for each treatment combination in each field was calculated,
185 and the overall mean catch for each trap type was also calculated. All fields were part of one
186 experiment, done at the same time. The weevil does not fly but moves mainly by crawling
187 (Gold et al., 2001; Gold et al., 1999). Movement up to maximum rates of 60m in five months
188 (Delattre, 1980), 35m in three days (Gold and Bagabe, 1997), and 15m in one night have been
189 reported. Therefore, fields were seen as sufficiently homogeneous to preclude the need for
190 blocking, but they were of insufficient size to allow all 10 treatment combinations (trap type
191 by bait treatment) in each one. Thus, fields were seen as main plots with one type of trap in
192 each field, and with the baits as split-plot treatments. Subsequent analysis (Table 3) accounted
193 for this design.

194

195 *2.5 Statistical analysis.* Weighted analysis of variance (ANOVA) was applied to the average
196 catch per week data, weighting for the number of weeks, taking account of the different fields
197 and testing (F-tests) for the main effects and interactions between the factors of type of trap
198 (TAL or Voltic bottle), lure treatment (pheromone or pseudostem) and extract (presence or
199 absence), nesting out the extract-only lure from the two by two factorial set of treatment
200 combinations. A natural logarithmic transformation was applied to the data to account for
201 heterogeneity of variance across the treatment combinations. Checks on residuals (see Figure
202 2) revealed that, under the transformation, the assumptions of the analysis had been met. Given
203 the ANOVA, appropriate tables of means were output, for comparison using the standard error
204 of the difference (SED) between means, thus invoking the least significant difference (LSD) at
205 the 5% level of significance. The GenStat (17th edition, © VSN International Ltd, Hemel
206 Hempstead, UK) statistical package was used for this analysis. It was noted that the statistical
207 requirement of transformation of data did not alter the fact that the effect of the treatments was
208 shown by the means of the untransformed data, and these means were therefore presented, but
209 with the transformed means on which statistical tests were based, given the results of ANOVA,
210 being included in brackets and italicised.

211

212 **3. Results**

213 Table 1 shows the total number of adult banana weevils caught in each trap for each of
214 the five different treatments, and the percentage of total weevil capture over treatments either
215 with or without pseudostem, whilst Table 2 shows the mean weevil catch per week in each of
216 the five fields using the five different treatments. **Figure 3 shows the average weekly catch for**
217 **the ten combinations of trap type by treatment. Table 3 expresses the ANOVA of the data in**
218 **Table 2. The ANOVA shows that there was a significant ($P = 0.002$, F-test) main effect of the**

219 presence of palm alcohol extract and that of the lure (pheromone or pseudostem) treatment
220 used ($P < 0.001$, F-test), but no interaction ($P = 0.570$, F-test) between the two factors. This
221 indicates the two effects (palm alcohol and lure (pheromone or pseudostem)) were independent
222 and additive. There was also no effect of type of trap (*TrapType*) or interaction of this factor
223 with the others. We also note that these same overall results were obtained when omitting the
224 data from fields 2 and 5, for which trapping ran for less than 12 weeks. The means for the main
225 effect of extract were: 4.239 (transformed data mean: 0.73) without extract and 8.862 (1.54)
226 with extract ($n = 10$, $SED = 0.204$ on 12 df; $LSD (5\%) = 0.445$). These means show that there
227 was approximately a 2.1-fold increase in mean catch per week through using the extract. The
228 means for the main effect of lure treatment were also calculated for the pheromone and for
229 pseudostem lures. These means show that there was approximately an 11-fold increase in mean
230 catch per week through using pheromone compared to pseudostem. Although there was no
231 statistically significant interaction between the two factors, the best combination for maximal
232 catch was most certainly the pheromone with the extract; this gave a mean of 16.178 (2.74),
233 compared to 7.888 (2.05) for the pheromone without the extract ($n = 5$, a 2.1-fold increase).
234 The corresponding results for pseudostem were 1.546 (0.34) with the extract and 0.59 (-0.59)
235 without the extract ($n = 5$, a 2.6-fold increase). However, even though there appeared to be
236 substantially more than an additive effect involving the treatments, it was not robust enough to
237 be statistically significant.

238

239 4. Discussion

240 It has been postulated that combinations of species-specific pheromone and host plant
241 volatiles may interact synergistically to attract *C. sordidus* (Budenberg, Ndiege, Karago &
242 Hansson, 1993; Jayaraman et al. 1997). Preliminary studies in the laboratory have also

243 indicated that host plant volatiles may enhance the aggregation pheromone (Tinzaara, Dicke,
244 Van Huis, Van Loon & Gold, 2003), and our recent work has demonstrated that a mixture of
245 isomers of theaspirane, identified from senesced banana leaf material as a banana weevil
246 attractant, improves the activity of the aggregation pheromone (Abagale et al. 2018a).
247 Generally, there was large variation in the total number of weevils caught in a given type of
248 trap with different lures from the same field (Table 1). Correspondingly, there were differences
249 in the overall total numbers of weevils caught in all traps containing different types of lures.
250 Thus, comparing the three non-pseudostem treatment combinations, i.e. pheromone alone,
251 palm alcohol extract alone and pheromone with extract, 61.1 % of the total weevils captured
252 were lured into traps containing the combination of pheromone and extract, while 8.5 % and
253 30.4 % of the total weevils were lured into traps containing the extract alone and pheromone
254 alone respectively. For the treatments involving pseudostem, traps with pseudostem treated
255 with the palm alcohol extract lured 72.1 % of the weevils captured, whilst traps with untreated
256 pseudostem attracted 27.9 % of the pseudostem-lured weevils.

257 **Studies on the banana weevil show that various human and natural factors influence**
258 **weevil capture in traps (Braumah and van Emden, 2002; Gold et al., 2001, 2002; Tinzaara et**
259 **al., 2002; Zhu and Park, 2005; Dahlquist et al., 2007). Adult banana weevils have also been**
260 **shown to orient to both host plant volatiles and their aggregation pheromone (Tinzaara et al.,**
261 **2003), though the distance over which the weevils can be influenced is unknown (Gold et al.,**
262 **1999). Weevils could therefore move within and between fields (Dahlquist et al., 2007).**
263 **Therefore, even though geographical influences are real, field trapping has previously been**
264 **deployed to study how trap designs, and bait material could influence the capture of weevils**
265 **(Zhu and Park, 2005). Also in another study, cropping systems in different geographical**
266 **locations were reported to be similar (Somarriba and Harvey, 2003), but the rate of weevils**
267 **captured in trapping at the two places had some variation. In addition, Anderbrant et al. (2010)**

268 reported a dependence on geographical location from a field study using pheromones.
269 Therefore, any geographic or on-farm influences in our trapping experiment were off set and
270 expected to contribute marginally to variation, as all experiments were conducted in the same
271 region (6°41'18"N; 1°37'27"W). The relative location of fields could not limit weevil migration
272 into and out of the fields so that influence by the lure could manifest. Despite this, Table 3
273 shows that the estimated underlying field-to-field variation from the ANOVA was 15.907, 7.9-
274 fold greater than the estimated underlying within-field variation (2.006), so clearly differences
275 between local populations could be important. The current study was carried out in fields in
276 the same geographical location and thus enabled robust assessment of the performance of the
277 lures. Attraction of the weevils could therefore arise mainly from the observed luring activity
278 of the aggregation pheromone and host-derived cues without excess variation from other
279 extraneous sources. The extent of the observed field-to-field variation can therefore be
280 explained in terms of the different periods of time (number of weeks) over which assessment
281 was made for two of the fields compared to the other three (12 weeks for fields 1, 3 and 4,
282 seven weeks for field 2, five weeks for field 5) and the varying numbers of total weevils per
283 week over weeks (Table 4). That notwithstanding, the comparative outcome of the ANOVA of
284 within-field, and field-to-field variation (Table 3) indicated that the former is less pronounced.

285 Previous research on the synergy of attractants for the banana weevil has largely failed
286 to produce consistent results. A study in Costa Rica reported that pseudostem traps baited with
287 aggregation pheromone caused a 5-10-fold increase in attractiveness to weevils (Alpizar &
288 Fallas, 1997). In another study, using olfactometry experiments, Tinzaara et al. (2002) observed
289 that a greater number of weevils responded to fermented banana tissues combined with the
290 aggregation pheromone compared to the individual treatments. Other studies also indicated that
291 banana extract and host plant extract enhanced pheromone attractiveness to weevils when used
292 together (Reddy et al. 2008; Palanichamy, Padmanaban, Mohamed & Mustaffa, 2011).

293 However, during pheromone trap trials in South Africa, trap catches were reported to be greater
294 for traps with lures containing the pheromone than lures containing both the pheromone and a
295 plant kairomone (De Graaf, Govender, Schoeman & Viljoen, 2005). Also, a study in tropical
296 Costa Rica reported that pseudostem traps and pseudostem traps baited with pheromone
297 attracted an equal sex ratio of weevils (Jayaraman *et al.*, 1997). The results of our present study
298 suggest that palm alcohol extracts of senesced banana leaf material can enhance the
299 attractiveness of the aggregation pheromone to adult banana weevils, and that weevil
300 populations can be trapped through deployment of leaf extracts alone. This suggests that either
301 approach is suitable for use in banana weevil management, with the latter being potentially
302 affordable for use by smallholder banana/plantain farmers, especially since leaf material and
303 palm alcohol are both affordable and available at no, or low cost. Further studies are planned
304 to undertake field trapping experiments on a wider scale in Ghana and demonstrate the low-
305 cost extraction and trapping technology to smallholder banana/plantain farmers.

306 In summary, palm alcohol extracts of senesced banana leaf material and the banana
307 weevil aggregation pheromone were able to lure more weevils into modified type TAL and
308 Voltic traps, and a combination of extract and pheromone lured a greater number of weevils
309 into traps compared to the respective individual lures. The results showed that there was a
310 significant main effect of the presence of extract and a main effect of the lure treatment
311 (pheromone or pseudostem) used, but no interaction between the two factors, indicating that
312 the two effects were independent and additive. However, there was at least some synergy
313 between the extract and either the aggregation pheromone or pseudostem, as the extract
314 increased the attractiveness of both the aggregation pheromone and pseudostem to adult banana
315 weevils. Interaction of the bait materials were independent of the differences in trapping
316 durations since the number of weevils caught in each case was averaged to give per-week
317 values for analysis. In Table 4, for each field (sub-table), the overall mean per week (over n=5

318 or 4 traps) and standard error (SE) as well as the overall mean and SE of these weekly means
319 has been calculated and transformed into trap type by treatment means (Figure 3). The
320 significant differences in the catch of weevils per week in TAL and Voltic traps indicate the
321 variation of effectiveness of the different baits and their combinations. The significant additive
322 effect in both TAL and Voltic traps is clear (Figure 3).

323 This study, along with our previous work (Abagale et al. 2018a, 2018b), provides
324 underpinning science for use of senesced leaf extract in banana weevil management and
325 provides a chemical marker for quality assurance and control if the envisaged management
326 system breaks down. From an economic perspective, banana and plantain farmers could be
327 encouraged to develop the production of leaf extracts for crop protection, thereby not only
328 providing economic and social benefits through enhanced banana and plantain production, but
329 also by generating income from a new product.

330 However, differences in climatic conditions and variegation of banana weevil species
331 may not necessarily permit success of the technology in other geographic locations. The study
332 area has a tropical climate, with much rainier summers than winters with temperature averages
333 of 26.3 °C | 79.3 °F and annual rainfall of 1448 mm | 57.0 inches. A repeat of this study in other
334 banana/plantain growing areas such as Central America and Asia is therefore required.

335 **Conflict of Interest Statement**

336 The authors have declared no conflicts of interest

337

338 **Author Contributions**

- 339 • SAA, HB, SOA, MB and JAP conceived research.
- 340 • SAA, HB and UIS conducted experiments.
- 341 • JV contributed TAL traps.

- 342 • SAA, SJP and HvE analysed data and conducted statistical analyses.
- 343 • SAA and MB wrote the manuscript.
- 344 • HB, MB and JAP secured funding.
- 345 • All authors read and approved the manuscript.

346

347 **Data Availability Statement**

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

351

352 **References**

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354 Integrated Management of the Banana Weevil, *Cosmopolites sordidus*, (GERMA, 1824)
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567 **Figure legends**

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

571

572 Figure 2. Residual plots from ANOVA of logged trap catches per week data.

573

574 Figure 3. Overall mean (\pm SE) catch of banana weevils per week using different baits in TAL
575 and Voltic bottle traps.

576