

Activity rhythm of the banana weevil, *Cosmopolites sordidus* Germar (Coleoptera: Curculionidae)

Abstract

Laboratory and field investigations in Kenya, East Africa, on the activity rhythm of the banana weevil, *Cosmopolites sordidus* Germar indicated a nocturnal lifestyle for this pest. This **behaviourbehavior** persisted even under constant dark (DD) condition during free-running trials. This proved an endogenously controlled, true circadian rhythm for the pest. Activity generally commenced sharply with the start of scotophase (6 pm) reaching peak at about 9 pm and maintaining that level till about 4 am, and gradually declined with the start of photophase (6 am). Light was a major deterrent to the pest, as constant light (LL) condition completely suppressed activity. Temperature and light intensity correlated negatively with weevil activity ($r=-0.726$, $P<0.01$; $r=-0.690$, $P<0.01$ respectively), but correlated positively with relative humidity ($r=0.821$, $P<0.001$). These findings provide baseline information on the **behaviourbehavior** of the pest, and will help to guide timing of future laboratory and field experiments on the pest.

Keywords: Activity rhythm, diel **behaviourbehavior**, light regime, scotophase, endogenous, free-running rhythm

Introduction

The banana weevil, *Cosmopolites sordidus* Germar (Coleoptera: Curculionidae) is recognized globally as the major insect pest of bananas (*Musa* sp) and plantains (*M. paradisiaca*). It causes considerable production losses yearly all over the world (Ostmark, 1974; Tinzaara *et al.*, 2011). The pest attacks all species of *Musa* and no cultivar has total resistance to it. Certain cultivars are however, more susceptible to the borer than others (Viswanath, 1981; Mesquita *et al.*, 1984; Gold *et al.*, 2001).

Currently, no single control strategy guarantees effective control (Gold *et al.*, 2001). As a result, integrated approaches comprising farm hygiene, careful varietal selections, pseudostem and pheromone trappings, properly selected insecticides are often adopted in controlling this pest.

Knowledge of various facets of pest biology, ecology and behaviour is absolutely essential for development of novel control (Bottrell, 1979; Kumar, 1984). Activity rhythm profiling or chronological studies on pests can greatly enhance our knowledge of pest life, biology and temporal

Comment [M1]: Delete
Please no repeat words indicated in title

Comment [M2]: sp or spp no italic form

Formatted: Font: Not Italic

organizations (Lazzari and Insausti, 2008). This can ultimately aid in their control, especially when appropriate measures are adopted at critical moments in pest diel or seasonal cycles. Periods of ecdysis for instance would be times of high susceptibility for pests, since body cuticle is most permeable and thus, most vulnerable at such moments (Lazzari and Insausti, 2008).

The laboratory studies on the activity rhythm of the banana weevil have clearly revealed that this insect restrict its activities to certain times of the diel cycle. Activity generally commenced soon after the onset of scotophase and continued uniformly throughout the dark period, but virtually come to a standstill during the photophase.

Comment [M3]: please consider this paragraph here. Please rewrite in a good form

Understanding the peak times of activity of a pest can also adequately instruct researchers on the need for correct timing of studies (especially laboratory-based semio-chemical studies); and can also guide the timing of field interventions for effective pests control. This study was therefore undertaken with a view to unraveling the diel **behaviourbehavior** of the banana weevil, and to possibly help open-up the opportunity for better control options against this pest.

Materials and methods

(a) Preliminary laboratory studies on activity rhythm

A preliminary study on the activity of the banana weevil was performed in the laboratory over 13 days, with a view to gaining a rough idea about the **behaviourbehavior** of the insect in 24-hrs. Into each of two wooden cages (each measuring 80 x 80 x 50cm) were introduced 200 weevils (100 males and 100 females). The base of each cage was filled with soil to a depth of 10 cm and two pairs of sliced banana pseudostems (each piece approximately 20 cm long and 8cm high) were placed on the soil to act as food and shelter for the weevils. The split was placed approximately 20 cm away from the **centrecenter** of the cage and directly opposite the other.

The soil in each cage was kept moist with water on the first day of the experiment and the weevils introduced into the cage were allowed the entire day to settle down before commencement of data collection. Records on weevil activity namely, movement, feeding and mating were made for 10 minutes at hourly intervals (over a 24-hr period), beginning from the second day till the end of the experiment (i.e. 12 days later); **this a**. Activity **here** was defined as any visible actions of the pest occurring within the cage, but not underneath the split pseudostems. The experiments were conducted under 12L:12D light regime in the laboratory; with temperature and relative humidity ranging between $25 \pm 2^{\circ}\text{C}$ and $80 \pm 5\%$ respectively.

67 Torch-lights covered with red-light filters (Kodak Wratten No 70) and transmitting only wavelengths
68 greater than 640nm were used during observation periods at night. Such dim light made
69 observations in the dark possible, with no obvious disturbance to the insects (adapted from
70 Budenberg *et al.*, 1993; Uzakah *et al.*, 2015).

71 **(b) Free-running rhythm in the laboratory**

72 After gaining some insights into the daily activity of the insect under a 12L:12D condition (as stated
73 above), a closer look at the diel **behaviourbehavior** of the pest was undertaken over a shorter time-
74 frame of 12 hrs (i.e. 6L:6D) daily, using nine smaller cages of size 38cm³ each (Plate 1). This was done
75 because the preliminary study revealed a somewhat 'mirror-image' of the activity of the weevil
76 during periods "12 noon–12 midnight" and "12 midnight–12 noon". For this stage of experiment, a
77 shorter daily observation period (12 noon – 12 midnight) was chosen, to allow for more painstaking
78 observations. Also, for ease of monitoring the activity of this pest, the experiment was carried out in
79 a laboratory room with altered light regimes, with the scotophase (dark phase) starting at 2 pm. 12
80 pm and 12 midnight thus corresponded to 8 am and 8 pm respectively in the room. Weevils used in
81 this study were left in this light regime for a week to acclimatize before they were used.

82 Hourly records on weevil activity were recorded as the experiment progressed. For the first two days
83 of the experiment, all the nine cages were kept in 12 hrs of light and 12 hrs of dark (LD condition) in
84 the room. On the third day of the experiment, three cages were transferred to a room with constant
85 light (LL condition), and another three to a room with constant darkness (DD condition); while the
86 last three remained in the LD condition. All transfers were done at exactly 5.30 pm (i.e. the usual
87 "lights-off" time). All rooms were identical and maintained at same conditions of 25 ± 2°C and 80 ±
88 5% relative humidity. The experiment lasted for six days. The results or observations made under the
89 different conditions (LL, DD and LD) were then compared at the end of the experiments.



97
98
99
100
101
102
103
104
105
106
107
108
109

110
111
112
113
114
115

116

117
118
119
120

121
122
123
124
125

Plate 1: The wooden cages used in the free-running rhythm studies of the banana weevil in the laboratory

(c) Field investigations at Mbita Point Station, South Kenya

Field investigation on the activity rhythm of the banana weevil was undertaken on a 3-acre plot at Mbita Point Field Station, South Nyanza, Kenya. The field is located along the shores of Lake Victoria on latitudes 0°25' and 0°30' S, longitudes 34°11' and 34°20' E, altitude 1200_m, annual temperature ranged 24-31°C, relative humidity 40-60% and yearly average rainfall of 900_mm during 2 rainy seasons (March-July and September-December, respectively). The vegetation is a savannah/semi-arid type, with clay-cotton, black and moderately basic soil type.

Fifty (50) banana traps were randomly set across the farm. At regular intervals of 2 hrs in 24 hrs cycle (for 9 days) traps were inspected for weevil activities (i.e. for number of weevils trapped, number found feeding, mating or moving on/around the traps). Trap catches were not released back into the field, but were taken to the laboratory for other studies. Records of daily weather parameters (temperature, relative humidity and rainfall) were also recorded for correlation between environmental parameters and weevil activity.

Results

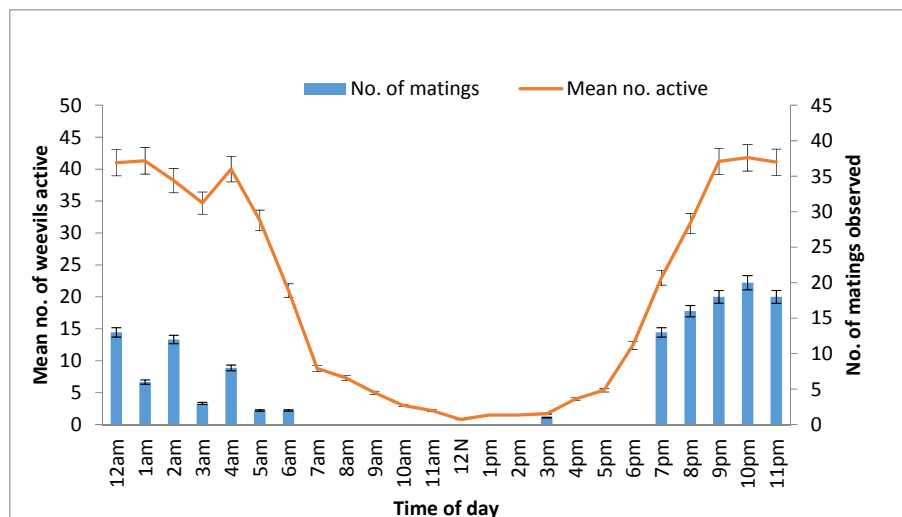
(a): Preliminary laboratory investigations on the activity rhythm

The preliminary laboratory studies conducted on the activity rhythm showed that there was a mirror-image of activity for the periods of 12 noon to 12 midnight and 12 midnight to 12 noon (Fig. 1).

The weevils were most active from 6 pm to 6 am every day. Activity rose sharply from 6 pm reaching the peak at about 9 pm and remained at that level till 4am when it starts to fall gradually. It decreased sharply after 6 am with sunrise, reaching its lowest level at 12 noon. Photophase in the lab, which occurred between 7 am–5 pm, seemed to inhibit weevil activity, while scotophase (6 pm–dawn) was associated with high weevil activity.

126 Mating frequency also followed the same pattern as shown in Fig.1. The process was rarely observed
 127 during photophase, but restricted to scotophase period alone. The result showed only 0.8% records
 128 of mating was made during photophase (7 am–5 pm) compared with 99.2% during scotophase (6
 129 pm–6 am) (n=132).

130



131

132 **Fig. 1: The diel activity of the banana weevil *C. sordidus* under laboratory conditions**
 133 **as influenced by time of day**

134

135 **(b): Free-running rhythm in the laboratory**

136 The result in Fig.2 shows the activity trend of the weevil during the free-running rhythm (FRR) trial in
 137 a 12-hrs cycle. The weevils displayed a nocturnal habit, as they generally commenced activity at or
 138 soon after dark or lights-off at 5.30 pm. Fig. 2A shows the trend for the first 2 days under 12L:12D
 139 condition (i.e. preparatory to the free-running trials); while Fig. 2B-E reveals the trend during FRR.

140 Day 3 of the experiment (which is actually Day 1 of FRR) (Fig. 2B) showed that weevil activity
 141 followed same pattern as the previous (Fig. 2A); rising soon after 5.30 pm, except for the LL
 142 condition where activity was clearly suppressed. The trend was exactly the same on day 2 of FRR (i.e.
 143 the day 4 of the experiment) as more insects became active soon after 5.30 pm (Fig. 2C). This
 144 observation is also true for even the cages that were in constant darkness (DD). Activity did not
 145 continue indefinitely, but was restricted to the usual times only (similar to those in LD condition).
 146 Activity in LL however, was again completely suppressed. [However,](#)

147 However, on day 3 of FRR, activity under DD condition shifted slightly, commencing after 6 pm but
 148 not under LD conditions, as activity continued starting soon after 5.30 pm (Fig. 2D). Activity under LL
 149 condition was virtually non-existent on this day having been completely suppressed by the constant
 150 light. It remained like this for the entire duration of the study. Mating observed in this study was
 151 restricted to the periods of high activity only (i.e. with the onset of scotophase); it was virtually
 152 absent in the photophase. A total of 65 matings were recorded, only 1.5% occurred under light
 153 condition and the rest (98.5%) occurred in DD.

154 The natural periodicity (τ) of this rhythm could not be calculated, because observations were made
 155 for only 12 hrs each day and not for 24 hrs.

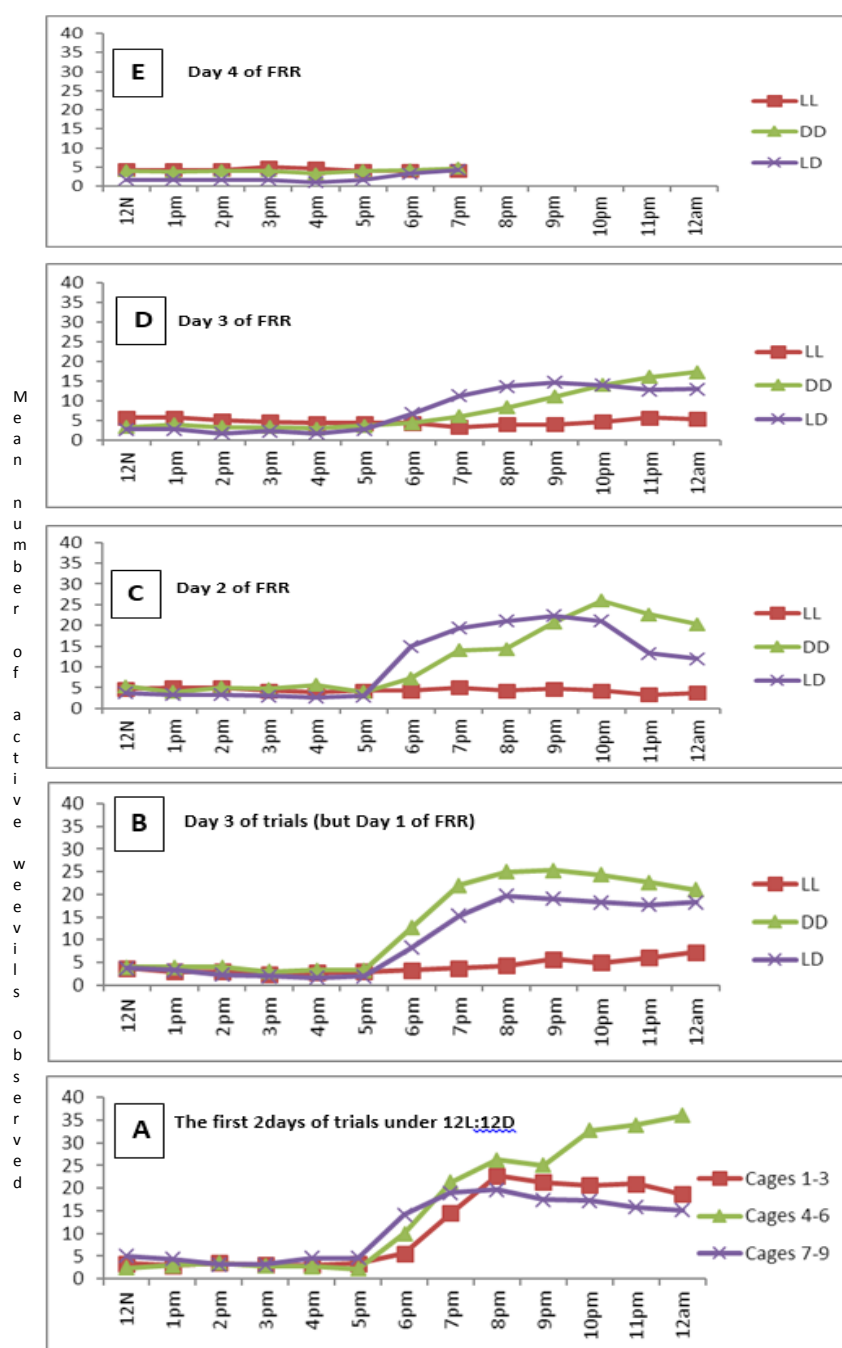


Fig. 2: The free-running rhythm of the banana weevil, *C. sordidus* in the laboratory
(After the first 2days, cages 1-3 were transferred to LL; cages 4-6 to DD, while cages 7-9 remained in LD)

(c): Field Investigations at Mbita Point Station, South Kenya

The field investigations revealed highly significant weevil activity during the night (6 pm-6 am) than during the day (6 am-6 pm) ($P < 0.0001$) and thus confirmed the nocturnal nature of this pest (Table 1 and Fig. 3). All three weather parameter means (temperature, relative humidity (RH) and light intensity) had significant effects on weevil activity. The result furthermore showed that RH was positively correlated with the number of weevils caught ($r = 0.821$, $P < 0.001$), temperature and light intensity correlated negatively with weevil activity ($r = -0.726$, $P < 0.01$; and $r = -0.690$, $P < 0.01$, respectively). The result is presented in Table 2 and Fig. 3.

Table 1: Comparison of weevil populations caught at Day and Night times at Mbita Point Field Station, South Kenya

Time	No. of observation	No. caught	Mean	Variance
Day	42	49	1.167 ^b	2.045
Night	42	279	6.643 ^a	21.650

Means with same letters are not significantly different at 5% level, Student's t-test

Table 2: Correlation matrix between environmental parameters and weevil activity

		Mean No. Active	Temp (°C)	Rel Hum. (%)	Light Intensity (X100 lux)
Mean No. Active	Pearson Correlation	1	-.726**	.821**	-.690**
	Sig. (2-tailed)		.008	.001	.013
	N	12	12	12	12
Temp (°C)	Pearson Correlation	-.726**	1	-.962**	.916**
	Sig. (2-tailed)	.008		.000	.000
	N	12	12	12	12

Formatted Table

Comment [M4]: lines of this table please considering lines of table 1

Re	Hum (%)	Pearson Correlation	.821**	-.962**	1	-.888**
		Sig. (2-tailed)	.001	.000		.000
		N	12	12	12	12
Light Intensity (X100 lux)		Pearson Correlation	-.690*	.916**	-.888**	1
		Sig. (2-tailed)	.013	.000	.000	
		N	12	12	12	12

** Correlation is significant at the 0.01 level (2-tailed).

* Correlation is significant at the 0.05 level (2-tailed).

Fig.3: Fluctuations in no. of banana weevils, *C. sordidus* caught at different times of the day in relation to environmental conditions at Mbita Point Field Station, South Kenya

Comment [M5]: completely words

Discussions

The laboratory studies on the activity rhythm of the banana weevil have clearly revealed that this insect restrict its activities to certain times of the diel cycle. Activity generally commenced soon after the onset of scotophase and continued uniformly throughout the dark period, but virtually come to a standstill during the photophase.

The endogenous nature of this behaviour behavior was clearly revealed when the weevils were transferred from LD cycle to DD, as the rhythm persisted under these “free-running” trials. According to Aschoff (1960), when an organism is transferred from LD to DD or LL under constant conditions of temperature and other possible influences, an endogenous oscillation controlling the rhythmic activity free-runs reveals its natural periodicity (r). In such a state, r often deviated slightly from 24 h, so that onset or peak activity appeared either earlier or later by a few minutes each day. However, the persistence of the rhythm in the DD and the slight shift from the usual time for onset of activity on day 2 of FRR, is a clear evidence of the endogenous nature of this rhythm in *C. sordidus*. This assertion is supported by Beck (1980), who noted that if an insect became active each day beginning about an hour after sunset and remained active for several hours before finally becoming relatively quiescent until the same time the next day, and this daily pattern of activity and quiescence continued even under experimental conditions, then, amongst other conclusions that could be drawn, is the fact that the activity is not simply evoked by the light-off stimulus of sunset. It is rather a manifestation of an endogenous circadian rhythm which can be entrained by environmental photoperiod. The observations made in this study, clearly show that the activity rhythm of *C. sordidus* is in nature, maintained in synchrony with photoperiod, by means of small daily adjustments in response to sunrise or sunset. This is very true because when the photoperiod stimuli which usually entrained the rhythm was artificially removed under laboratory conditions of

214 DD, the rhythm free-run exhibited a gradual shift from the normal time for onset of activity.
215 Constantinou's (1979), work also revealed that locomotory activity in three adult triatomid bugs
216 (*Rhodnius prolixus*, *Triatoma infestans* and *Panstrongylus megistus*) followed a strictly nocturnal
217 trend, with pronounced peaks at onset of darkness; same author. He showed that in constant dark
218 (DD) and constant light (LL) conditions, the activity rhythm of these bugs, free-ran to reveal their
219 true circadian nature.

220 The findings obtained in this study on the diel activity of *C. sordidus* is in agreement with those of
221 Cuille (1950), who also observed a marked diel rhythm for the pest that persisted in continuous
222 darkness (DD) between 18 hrs and 0600 hrs, followed by a virtually motionless period of about 12
223 hrs (i.e. 6 am – 6 pm) was also confirmed in this study. However, some minimal activity was
224 observed during the day (i.e. between 6 am – 6 pm) in this study. This finding disagreed with
225 Delattre's (1980), who claimed that no regular activity existed under DD for the banana weevil. This
226 study clearly showed that the diel rhythm of the pest persisted even under DD. Continuous light (LL)
227 completely suppressed activity.

228 The results from the diel activity and from the free-running studies of *C. sordidus* show that
229 laboratory trials with these insects (e.g. pheromonal bioassays and mating) could be conducted
230 approximately 2 hrs after scotophase and 2 – 3 hrs before photophase. This period generally
231 ensured fairly high and virtually uniform activity amongst the weevil populations.

232 The field observations on the pest were similar to the laboratory findings as the pest still clearly
233 exhibited a well marked nocturnal rhythm. Significantly high activity was recorded during the night
234 than during the day. Light, as already observed in the laboratory studies was a major factor
235 associated with the diel behaviourbehavior of this pest under field conditions. Similar observation
236 was made by Poinar and Gyrisco (1960), on the alfalfa weevil. The minimal activity which was
237 observed during the day in the field particularly under banana traps and plant debris, had also been
238 reported by Delattre (1980).

239 The peak period of activity in the field occurred between 10 pm and midnight, though some fairly
240 high and reasonably significant activity was also recorded at 8 pm, and between 2 – 4 am. The
241 results from this study suggest that for accurate estimates of weevil populations (or level of
242 infestation) of *C. sordidus* in fields, surveys should be embarked upon in the evenings or at night.
243 This was also similar to the recommendation made by Poinar and Gyrisco (1960) for the alfalfa
244 weevils. Samplings at 12 midnight might not be feasible but the period between 7 and 10 pm, which
245 also guarantees significant numbers (catches), would be less problematic.

Comment [M6]: requote this section. Is to long

Comment [M7]: check in reference please

246 This study has provided important baseline information to guide future experiments. it should also
247 equally eliminate time wastage on fresh activity rhythm profiling for the weevils. The findings
248 obtained in this study will most importantly help in the correct timing of sensitive experiments e.g.
249 pheromonal and mating related investigations. It will also have possible implications for timing of
250 interventions (control options/strategies) in the field.

251

252 **Conclusion:**

253 The studies on the activity rhythm of *C. sordidus* have revealed an endogenously controlled, true
254 circadian (nocturnal) rhythm for the pest. This nocturnal cycle generally peaked at about 9 pm and
255 persisted till about 4 am, when it gradually declined with the onset of photophase. The pest's
256 activity also generally correlated negatively with relative humidity but negatively with temperature
257 and light intensity. The findings recorded provide baseline information on the pest's ecology and
258 population dynamics; and will help to guide timing of future laboratory and field experiments. Most
259 importantly, it shall guide timing of interventions or control options against the pest.

260

261 **References**

262 | Aschoff, J. (1960). Exogenous and endogenous components in circadian rhythms. *Cold Spring Harb.*
263 *Symp. Quant. Biol.* 5, 11-28.

264 Beck, S.D. (1980). *Insect photoperiodism*. Second edition. Academic Press, New York. 387 pp.

265 Bottrell, D.G. (1979). *Integrated Pest Management Council on Environmental Quality*. US
266 Government Printing Office, Washington D.C., 120 pp.

267 | Budenberg, W.J., Ndiege, I.O, & Karago, F. (1993). Evidence for a male produced aggregation
268 pheromone in the banana weevil, *Cosmopolites sordidus*. *J. Chem. Ecol.* 19, 1905-1916.

269 Bottrell, D.G. (1979). *Integrated Pest Management Council on Environmental Quality*. US
270 Government Printing Office, Washington D.C., 120 pp.

271 Constantinou, C. (1979). *Circadian rhythms in insects*. *Doctoral Thesis*, University of London. Doctoral
272 ETHOS ID:uk.bl.ethos.452050.

273 Cuille, J. (1950). Recherches sur le charancon du bananier (*Cosmopolites sordidus* Germar). *Institutde*
274 *Fruits et Agrumes Coloniaux Technique* (4). 225 pp.

275 Delattre, P. (1980). Recherche d'une method d'estimation des populations du charancon du
 276 bananier, *Cosmopolites sordidus* Germar (Coleoptera: Curculionidae). *Acta Oecologica: Oecologia*
 277 *Applicata* 1:83-92.

278 Gold, C.S., Pena, J.E. &Karamura, E.B. (2001). Biology and Integrated Pest Management for the
 279 banana weevil, *Cosmopolites sordidus* (Germar) Coleoptera: Curculionidae. *Integrated Pest*
 280 *Management Reviews*, 6, 79-155.

281 Kumar, R. (1984). *Insect Pest Control with special reference to African Agriculture*. Edward Arnold
 282 Publishers Ltd., London. 298 pp.

283 Lazzari, C.R. &Insausti, T.C. (2008). Circadian rhythms in insects. In: M.L. Fajul-Moles & R. Aguilar-
 284 Roblero (eds.). *Comparative aspects of circadian rhythms*. ISBN: 978-81-7895-329-8). Transworld
 285 Research Network, Kerala, India.pp 2-18.

286 Mesquita, A.L.M., Alves, E.J. & Caldas, R.C. (1984). Resistance of banana cultivars to *Cosmopolites*
 287 *sordidus* (Germar, 1824). *Fruits*,39 (4), 254-257.

288 Ostmark, H.E. (1974). Economic Insect Pests of Banana. *Annual Review of Entomology*, 19,161-176.

289 Poinar, G.O. &Gyriscio, G.G. (1960). Effects of light, temperature and relative humidity on the diel
 290 behavior of alfalfa weevil, *Hypera postica*. *J. Econ. Entomol.*, 53 (4), 675-677.

291 Tinzaara, W., Gold, C.S., Dicke, M., Van Huis, A.,&Ragama, P.E. (2011). Effect of age, female mating
 292 status and weevil density on banana weevil response to aggregation pheromone. *African Crop*
 293 *Science J.*, 19(2), 105-116.

294 Uzakah, R.P., Odebiyi J.A., Chaudhury, M.F.B. & Hassanali, A. (2015). Evidence for the presence of a
 295 female-produced sex pheromone in the banana weevil, *Cosmopolites sordidus* Germar (Coleoptera:
 296 Curculionidae). *Scientific Research and Essays*, 10(15), 471-481.

297 Viswanath, B.N. (1981). Development of *Cosmopolites sordidus* (Coleoptera: Curculionidae) on
 298 banana varieties in South India. *Colemania*1 (1), 57-58.

Comment [M8]: check it in text please.

Comment [M9]: Please check one by one in references and check editorial rules

Please consider 3 or 4 refernces from JEA!