International Journal of Tropical Insect Science (2019) 39:35–43
https://doi.org/10.1007/s42690-019-00009-6

ORIGINAL RESEARCH ARTICLE

Evaluation of different trapping systems for the banana weevils *Cosmopolites sordidus* and *Odoiporus longicollis*

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Accepted: 17 January 2019 / Published online: 6 March 2019

Abstract

Banana weevils *Cosmopolites sordidus* Germar and *Odoiporus longicollis* Olivier are worldwide pests of banana plants. The present study evaluated different trapping systems for *C. sordidus* and *O. longicollis*. Various types of pseudostem traps and pheromone (sordidin) traps were designed. Several factors that can influence the trapping efficacy, such as plant species, placement, height, colour, shading, watering and covering, were evaluated. Pseudostem traps constructed of *Musa acuminata* Colla stems appeared to be more effective in trapping both *C. sordidus* and *O. longicollis than* traps constructed of *Musa formasana* Warburg ex Schumann. The results also revealed that horizontal- and vertical-pseudostem traps were suitable for catching *C. sordidus and O. longicollis*, respectively. Vertical-pseudostem traps with cut sections above the ground from 60 to 100 cm high caught more *O. longicollis* individuals than those of other heights. Moreover, pseudostem traps with rip-cutting were superior to the other tested cut types, and watering or covering the pseudostem traps enhanced the *capture efficacy for both C. sordidus and O. longicollis*. For pheromone traps, the brown, black and grey ramp traps attracted higher numbers of *C. sordidus* than other colours. An increase in capture efficacy was observed when pheromone traps were covered with banana leaves or placed in the shade. Finally, either pheromone-baited pseudostem traps or the addition of pseudostem to pheromone ramp traps enhanced the catch of *C. sordidus*. These findings expand the understanding of the use of trapping systems as a useful strategy for the integrated pest management (IPM) of *C. sordidus* and *O. longicollis*.

Keywords Banana · Weevils · Pseudostem · Pheromone · Trap types · Integrated pest management (IPM)

Introduction

Banana weevils *Cosmopolites sordidus* Germar and *Odoiporus longicollis* Olivier are worldwide pests of banana plants (Gold et al. 2001; Alpizar et al. 2012). These two weevils are known to attack all species of banana crops wherever they are cultivated (Koppenhoffer et al. 1994; Reddy et al. 2009). These weevils cause damage to banana plants mainly by their larvae burrowing into the vascular tissue of the corm and stem, which finally results in physical weakening and decreased yield (Collins et al. 1991; Chavarria-Carvajal and Irizarry 1997; Gold et al. 1998; Gold et al. 2001; Masanza et al. 2005, 2009). At present, damage caused by *C. sordidus* and *O. longicollis* have increased in numerous banana plantations in southern China, leading to large annual economic losses through yield reductions and management costs (Lin et al. 2008).

Chemical treatment has been the primary strategy for the control of *C. sordidus* and *O. longicollis*. However, insecticide sprays do not appear to be effective against these weevils, mainly because of their concealing behaviour to hide deep in the stem of the banana plants (Collins et al. 1991; Musabyimana et al. 2000). Moreover, the application of synthetic insecticides can induce environmental pollution, the development of resistance, and harm their natural enemies (Collins et al. 1991). Biological control using predatory ants, entomopathogenic nematodes and fungi have also been ineffective and impractical (Musabyimana et al. 2000, 2001; Nankinga and Moore 2000; Abera-kalibata et al. 2007, 2008; Tinzaara et al. 2007). Cultural control measures, such

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as deep planting, or inter or cover cropping, provide effective weevil control, but they are labour intensive and reduce yield (Seshu-reddy et al. 1995; Duyck et al. 2001; Degraaf et al. 2008).

From 1980, traps constructed of banana pseudostem have been commonly used to monitor *C. sordidus* populations (Koppenhoffer et al. 1994). Pseudostem traps used for the control of *C. sordidus* are made from two pieces of stems cut from a plant stem base, with one of them placed on top of the other, with a small stone or stick to hold the two pieces apart on one side. The cut surfaces of the trap are generally sprayed with insecticides in order to kill the arriving insects. (Koppenhoffer et al. 1994; Masanza 1995). Field studies have shown that trapping using pseudostem traps in Honduras, Kenya, Uganda and Tanzania resulted in a reduction of *C. sordidus* capture rates and increased banana yields (Seshu-reddy et al. 1995; Ngode 1999; Gold et al. 2002). However, to date, not much is known about the capture efficacy of pseudostem traps for *O. longicollis*, and trapping of banana weevils has never been conducted in China.

Sordidin, a male produced specific aggregation pheromone for *C. sordidus*, was identified in 1995 (Beauhaire et al. 1995) and formulated by ChemTica Internacional in Costa Rica in 1996 (Jayaraman et al. 1997a, 1997b). Since then, different types of pheromone traps, differing in colour, location, size, shading and the addition of pseudostems, have been studied extensively. These studies have been conducted to enhance the capture efficacy of *C. sordidus* (Gailce et al. 2008; Palanichamy et al. 2011; Alpizar et al. 2012). Previous studies demonstrated that successful control of *C. sordidus* is achieved when sordidin-baited traps were placed in the banana plantations (Alpizar et al. 1999; Degraaf et al. 2005; Tinzaara et al. 2005; Reddy et al. 2009; Reddy and Raman 2011). Nevertheless, several studies have reported that sordidin-baited traps used in mass trapping programmes were not effective in the control of *C. sordidus* (Gold et al. 2001; Tinzaara et al. 2005). Thus, in this context, taking in account factors such as trap colour, trap placement, watering or covering, further bioassays are important to optimize this control method for *C. sordidus*.

Therefore, the present study was directed towards developing different trapping systems for capturing both *C. sordidus* and *O. longicollis* in commercial banana plantations in China. More importantly, this was the first study in which trapping of the two weevils that are important to banana production in South East Asia has been studied simultaneously. The main objectives of this study were to (1) determine the efficacy of different types of pseudostem traps for capturing both *C. sordidus* and *O. longicollis*, and (2) examine the performance of different types of pheromone-based traps for capturing *C. sordidus*, considering the following factors that can influence trapping efficacy: colour, placement, covering, watering and the addition of pseudostem. This study has increased our knowledge of the trapping systems used for banana weevils in order to improve these tools for the control of *C. sordidus* and *O. longicollis*.

Materials and methods

Study sites

All experiments were carried out in commercial banana plantations in Chengmai (19.23° N, 110.15° E) and Danzhou (19.11° N, 108.°56 E) in Hainan Province, China. The total planting area was approximately 30 ha. Plant density was ~2100 trees per hectare. The banana species, *Musa acuminata* Colla, was cultivated in the study sites. Fertilizer application and other agronomic practices were carried out regularly as needed.

General protocol of field experiments

Field experiments were conducted from May to June in 2015, from April to June in 2016 and from April to June in 2017, when banana plants were in the fruiting to harvesting season. Each experiment used a randomized block design, and a total of 20 traps with 4 replicates for each treatment were tested. All traps used in each experiment were initially placed in a line 12 m from a border and 20 m apart. The captured *C. sordidus* and *O. longicollis* individuals were counted and removed weekly.

Pseudostem traps

Pseudostem traps were made from the stem of the harvested banana plants and cut in different trap types. Figure 1 shows the types of pseudostem traps used in this study. The horizontal trap (Fig. 1a) was constructed from two pieces of approximately 60 cm long banana plant stems cut from a stem base, with one of the piece placed on top of the other with a small stone or stick to hold the two pieces apart at one side. The vertical trap was a pseudostem trap with the cut sections on the upper side in a vertical placement (Fig. 1b). Pseudostem traps were treated with chlorpyrifos (480 $g \cdot L^{-1}$ EC, DOW AgroSciences) at the dose of 1.25 $g \cdot L^{-1}$ to kill captured weevils.

Effect of trap height

Vertical traps (Fig. 1b) was used in this experiment. Vertical traps with cut sections oriented towards the ground that were 20, 60 and 100 cm in height were used to determine the capturing efficacy on *C. sordidus* and *O. longicollis*. This experiment was conducted in Chengmai from the 10th to the 24th of May 2015.

Fig. 1 Types of pseudostem trap and pheromone trap used in the experiments on the banana weevils. **a**, **b**, and **c** represent the horizontal-pseudostem trap, vertical-pseudostem trap and pheromone ramp trap, respectively

Effect of trap placement

To determine the effect of trap placement on capturing both *C. sordidus* and *O. longicollis*, pseudostem traps in horizontal and vertical placement were measured. The horizontal traps (Fig. 1a) were placed with cut sections towards the ground, while the vertical traps (Fig. 1b) with cut sections towards the ground of 60 cm in height. The experiment was conducted in Chengmai from 20th May to 3rd June 2015.

Effect of cut style

In this experiment, pseudostem traps with rip-cutting and 'v'-shaped cutting were tested to determine their capture efficacy for *C. sordidus* and *O. longicollis* compared to the uncut traps. The experiment was conducted in Chengmai from 10th to 24th of June 2015.

Effect of pseudostem (plant species)

Stems of two banana varieties, *M. acuminata* and *M. formasana* were used to determine the capturing efficacy of *C. sordidus* and *O. longicollis*, respectively. For the trapping of *C. sordidus*, horizontal traps with the cut section placed on the ground were used, while vertical traps with a cut section of 60 cm in height were used for trapping *O. longicollis*. The experiment was carried out in Danzhou from 7th to 21st of April 2016.

Effect of watering and covering

On the basis of our previous experiments, in this experiment, we used horizontal traps (Fig. 1a) to catch *C. sordidus* and vertical traps to catch *O. longicollis*. To test the effect of watering, each pseudostem trap was sprinkled with a bottle of 500 ml water every 3 days. To test the effect of covering, every week each pseudostem trap was covered with several pieces of banana leaves. Traps without watering and covering were used as controls. This experiment was carried out in Danzhou from 30th April to 14th May 2016.

Pheromone lures

Cosmolure™ (ChemTica Internacional, Costa Rica), which is a mixture of sordidin isomers, was used for *C. sordidus*. Lures, each containing 90 mg of pheromone with a release rate of 3 mg/day (Tinzaara et al. 2005), were stored at 4 °C until use.

Pheromone traps

Ramp traps, supplied by ChemTica Internacional (San José, Costa Rica), with pheromone lures were used to trap *C. sordidus* (Fig. 1c). The polyethylene traps consisted of two box-shaped components, 26 cm long by 4 cm high (inside dimensions) and 14 cm wide. Four sloping ramps led from the four sides of the lower open box. Each ramp was 14 cm wide and 26 cm long and slid into a slot in the floor of the box component. The other box had four corner ridges (4 cm high) that extended downward into the bottom box. The bottom box was partially filled with soapy water to retain the attracted weevils. The pheromone lures were suspended near the centre from wires 2–3 cm above the trap bottom.

Effect of trap colour

To determine the effect of the colours of the pheromone traps on capturing *C. sordidus*, blue, green, white, red, pink, purple, yellow, grey, black or brown coloured vinyl tapes were adhered to all sides of the ramp traps. The experiment was carried out in Chengmai from 4th to 18th April 2017.

Effect of trap covering

Pheromone ramp traps covered with several pieces of banana leaves were placed on the ground to determine their *C. sordidus* capture efficacy. Ramp traps without covering

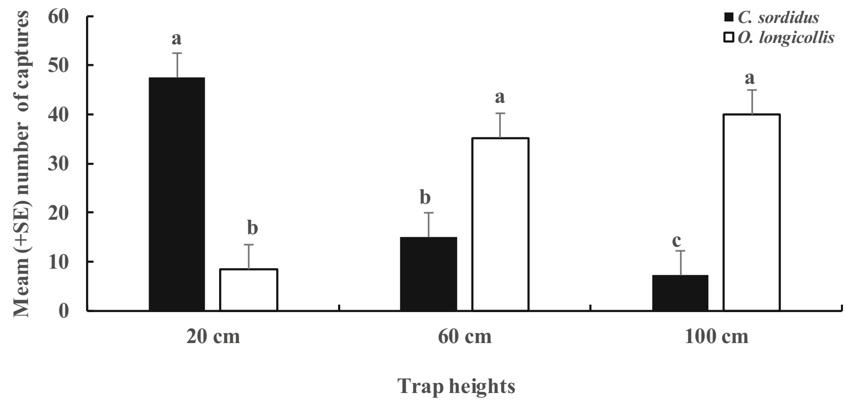

Fig. 2 Mean (+SE) number of captured *C. sordidus* and *O. longicollis* individuals using pseudostem traps with cut sections of 20, 60 and 100 cm height. All the pseudostem traps were in vertical placement. Different lower-case letters indicate significant differences between treatments (one-way ANOVA using Poisson analysis, least-square means, $P < 0.05$)

served as the control group. The experiment was carried out in Chengmai from 20th April to 4th of May 2017.

Effect of trap shading

To determine the effect of trap shading on capture efficacy, the ramp traps were placed in the shade of the banana plants. Additionally, a group of the ramp traps was placed in the open space in a sunlit area of the banana plantation. The experiment was conducted in Chengmai from the 6th to 20th of May in 2017.

Evaluation of pheromone-based traps

To expand the understanding of pheromone-based traps for capturing of *C. sordidus*, two types of pheromone-baited traps were constructed. For baited trap type I, one piece of pseudostem was placed on top of another with a stone to hold the two pieces apart on one side. Then a pheromone lure was positioned within the gap between the two pieces of the pseudostems. For baited trap type II, the pheromone ramp trap was first placed in the trial site, then pieces of fresh banana stem were added into the bottom box of the ramp trap every 3 days. The experiment was carried out in Chengmai from the 24th of May to the 7th of June in 2017.

Statistical analysis

Because of all the responses measured in the experiments are variables, a one-way Poisson analysis of variance model was fitted using the GLIMMIX Procedure SAS Version 9.13 (SAS Institute, www.sas.com). A least-square means test was used to make multiple comparisons for significant differences between treatments.

Results

Effect of trap height The number of captured *C. sordidus* individuals decreased with increasing height of the pseudostem trap. Traps with cut sections at 20 cm height captured significantly more *C. sordidus* individuals than those with cut section at 60 and 100 cm ($F = 52.05$, $df = 19$, $P < 0.05$, Fig. 2). In contrast, the capture of *O. longicollis* in the 60 and 100 cm traps were significantly more than those in the 20 cm traps ($F = 54.38$, $df = 19$, $P < 0.05$, Fig. 2).

Effect of trap placement Pseudostem traps in a horizontal placement captured significantly more *C. sordidus* individuals than did those in a vertical placement, while the vertical traps caught more *O. longicollis* than did the horizontal traps ($F = 16.23$, $df = 19$, $P < 0.05$, Fig. 3).

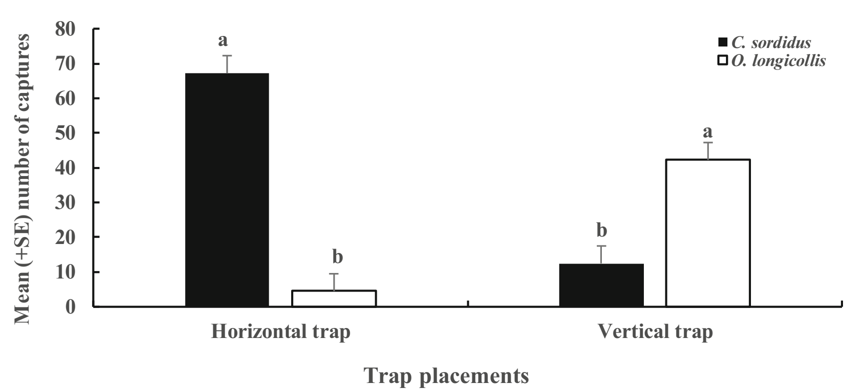

Fig. 3 Mean (+SE) number of captured *C. sordidus* and *O. longicollis* individuals by using horizontal-pseudostem traps and vertical-pseudostem traps. Different lower-case letters indicate significant differences between treatments (one-way ANOVA using Poisson analysis, least-square means, $P < 0.05$)

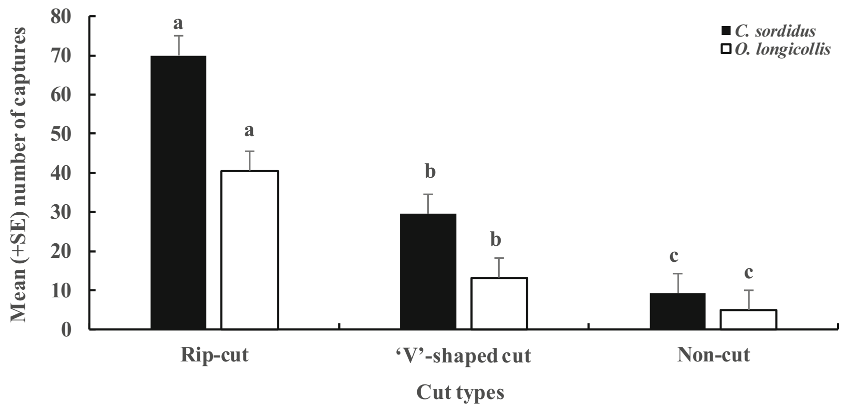

Fig. 4 Mean (+SE) number of captured *C. sordidus* and *O. longicollis* individuals using pseudostem traps with rip-cut, 'v'-shaped cut and non-cut. Different lower-case letters indicate significant differences between treatments (one-way ANOVA using Poisson analysis, least-square means, $P < 0.05$)

Effect of cut style More of the captures of *C. sordidus* were caught in rip-cutting pseudostem traps, followed by the 'v'-shaped cutting traps, and this result was similar for *O. longicollis* ($F = 25.05$, $df = 19$, $P < 0.05$, Fig. 4).

Effect of pseudostem variety Pseudostem traps constructed of *M. acuminata* stems caught significantly more weevils (both *C. sordidus* and *O. longicollis*) than those constructed of *M. formasana* ($F = 18.64$, $df = 19$, $P < 0.05$, Fig. 5).

Effect of watering and covering Pseudostem traps with watered cut sections captured significantly more *C. sordidus* and *O. longicollis* individuals than those without. Additionally, pseudostem traps covered with banana leaves caught significantly more *C. sordidus* and *O. longicollis* individuals than those without ($F = 22.93$, $df = 19$, $P < 0.05$, Fig. 6).

Pheromone traps

Effect of trap colour Brown ramp traps caught the most *C. sordidus* individuals, followed by black and grey traps, and the above three colours were more attractive to *C. sordidus* than those of any other colour tested. No difference was found in the number of catches among the yellow, purple, pink, white and green traps, but these colours attracted more *C. sordidus* than the blue and red traps ($F = 53.94$, $df = 19$, $P < 0.05$, Fig. 7).

Effect of trap covering and shading Pheromone traps covered with banana leaves captured significantly more *C. sordidus* than did those without ($F = 16.08$, $df = 19$, $P < 0.05$, Fig. 8). Likewise, pheromone traps located in the shade of banana plants caught significantly more than similar traps placed in the sunlight ($F = 12.05$, $df = 19$, $P < 0.05$, Fig. 9).

Effect of pheromone-based traps The catches of *C. sordidus* trapped between pheromone-baited pseudostem traps and pseudostem-baited pheromone traps were not significant ($F = 36.57$, $df = 19$, $P > 0.05$, Fig. 10). Those two types of pheromone-based traps caught more *C. sordidus* than did pheromone traps and single-use pseudostem traps ($F = 53.64$, $df = 19$, $P < 0.05$, Fig. 10). Additionally, pheromone traps captured significantly more *C. sordidus* than pseudostem traps ($F = 45.50$, $df = 19$, $P < 0.05$, Fig. 10).

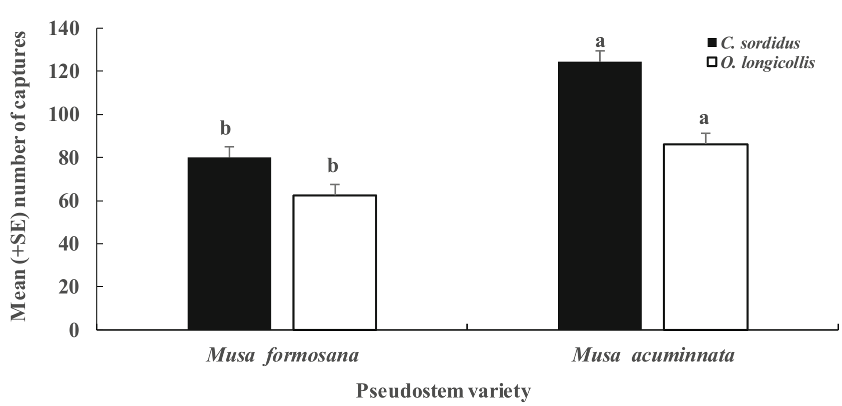

Fig. 5 Mean (+SE) number of captured *C. sordidus* and *O. longicollis* individuals using two banana pseudostem varieties, *M. acuminata* and *M. formasana*. Different lower-case letters indicate significant differences between treatments (one-way ANOVA using Poisson analysis, least-square means, $P < 0.05$)

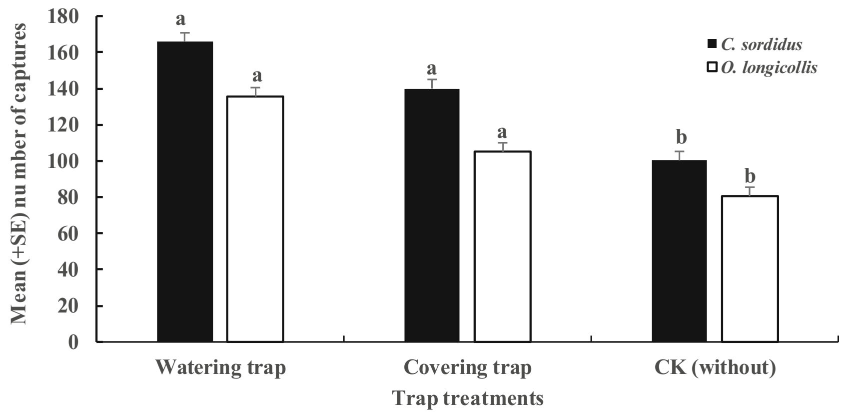

Fig. 6 Mean (+SE) number of captured *C. sordidus* and *O. longicollis* individuals by using different pseudostem traps with watering, covering and without. Different lower-case letters indicate significant differences between treatments (one-way ANOVA using Poisson analysis, least-square means, $P < 0.05$)

Discussion

In the present study, trap types constructed of banana pseudostems were used to simultaneously determine capture efficacy for both *C. sordidus* and *O. longicollis*. Our results revealed that horizontal-pseudostem traps were found to be effective in the trapping of *C. sordidus*, and vertical traps with above ground cut sections from 60 to 100 cm high caught more *O. longicollis* adults than did those of 20 cm. These results suggest that the type of pseudostem traps could impact the capture efficacy, which is consistent with previous studies on *C. sordidus* (Masanza 1995; Reddy et al. 2005). The different performance of pseudostem traps for catching *C. sordidus* and *O. longicollis* might be attributable to the different biological traits and behavioural preferences of the two weevils, as *C. sordidus* prefers to locate itself in the roots of banana plants, while *O. longicollis* locates itself in the stems (Gold et al. 2001; Reddy et al. 2008). To date, the trapping methods for *O. longicollis* remain poorly understood, while our findings represent the first step towards developing pseudostem traps for *O. longicollis*.

Trap type is known as a key factor influencing the capture efficacy of many insects (Ali 1993; Reddy et al. 2005, 2009; Guarino et al. 2011, 2013; Al-Saoud 2013). In the current study, pseudostem traps constructed of *M. acuminata* stem were more effective in trapping *the two weevils compared to M. formasana*, indicating that the species of banana stem strongly affected the capture efficacy of the weevils. This finding might be due to the weevils having different host plant preferences (Ravi and Palaniswami 2002; Prasuna et al. 2008) as a result of different volatile organic compounds produced by the two banana species. Thus, *M. acuminata* might produce kairomones that attract the weevils. In support of this, the palm weevil *Rhynchophorus ferrugineus* (Olivier) is known to be attracted to particular volatiles produced by palms (Guarino et al. 2011; Peri et al. 2017). Moreover, this study also revealed that pseudostem traps with rip-cutting were superior to other cut types, and watering or covering the pseudostem traps largely increased their weevil *capture efficacy*. Some of the above results are in accordance with previous works, which have reported that *C. sordidus* captures were higher during rainy periods (Alpizar et al. 1999; Reddy et al. 2008). This is mainly because the banana weevils prefer areas of high humidity, which results in increasing trap catches when the pseudostem traps are watered or covered.

Some previous studies have demonstrated that pheromone (sordidin)-baited traps are successful in the control of *C. sordidus* (Alpizar et al. 1999; Degraaf et al. 2005; Reddy

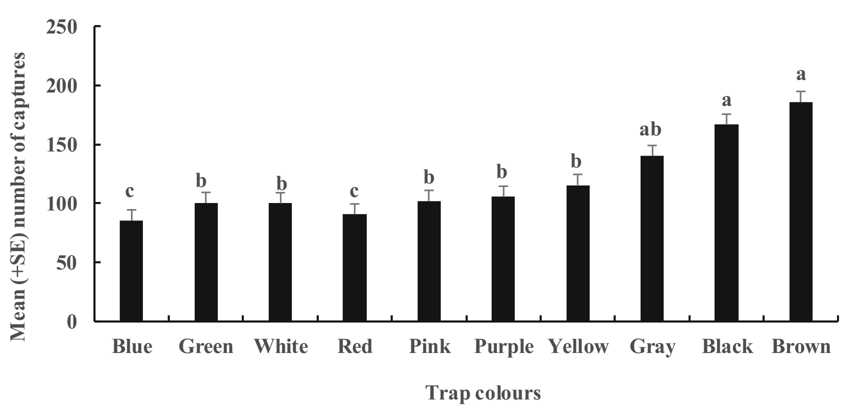

Fig. 7 Mean (+SE) number of *C. sordidus* individuals captured in pheromone ramp traps of different colours. Different lower-case letters indicate significant differences between treatments (one-way ANOVA using Poisson analysis, least-square means, $P < 0.05$)

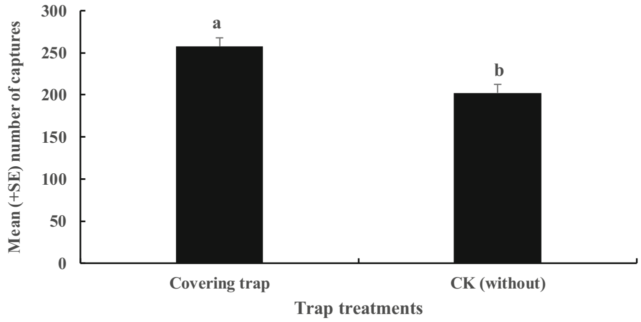

Fig. 8 Mean (+SE) number of captured *C. sordidus* individuals using pheromone traps with and without a covering. Different lower-case letters indicate significant differences between treatments (one-way ANOVA using Poisson analysis, least-square means, $P < 0.05$)

et al. 2009; Reddy and Raman 2011), while other studies have reported that pheromone traps failed to reduce the *C. sordidus* population in some regions (Gold et al. 2001; Tinzaara et al. 2005). In this context, the optimization of the factors that can influence pheromone trap captures is crucial important for the use of these tools in IPM programs for *C. sordidus* and *O. longicollis*.

In the study reported here, the result showed that brown or black pheromone ramp traps caught more *C. sordidus* individuals than other colours tested. This result was largely consistent with previous studies (Reddy et al. 2009; Reddy and Raman 2011), that showed *C. sordidus* clearly prefer brown traps over yellow, red, gray, blue, white, and green traps. Moreover, black-coloured traps recorded significantly higher captures of another important weevil species, *R. ferrugineus* (Al-Saoud 2013), while Silva et al. (2018) reported that yellow traps were most effective for capturing the cranberry weevil *Anthonomus musculus* (Say).

Trap location, size, surface texture and some other factors have been known to influence the trap captures of *C. sordidus* (Gailce et al. 2008; Reddy and Raman, 2009; Palanichamy et al. 2011; Alpizar et al. 2012; Uzakah et al. 2015). Our results clarified that pheromone ramp traps with covering or placed in the shade were more effective in trapping *C. sordidus* than those traps without. Similarly, Reddy et al. (2009) showed that pheromone-baited mahogany brown ground traps positioned in the shade of banana plants caught more *C. sordidus* adults than did similar traps placed in sunlight. Thus, trap captures can be influenced also by their placements. More importantly, the obtained findings from our study can largely optimize the use of pheromone traps for better control of the weevils.

In a previous study, Alpizar et al. (2012) showed that pheromone traps were more effective in trapping *C. sordidus* than pseudostem traps. Similarly, the current study also showed pheromone traps caught more *C. sordidus* individuals than pseudostem traps. These results could be due to the greater efficiency of pheromone traps. Thus, monitoring *C. sordidus* population by using pheromone traps has been considered to be better than pseudostem traps, mainly because they became saturated at higher weevil populations (Alpizar et al. 2012). In addition, our results also revealed that either pheromone-baited pseudostem traps or the addition of pseudostems to pheromone traps increased *C. sordidus* captures compared to pheromone traps. In contrast, Jayaraman et al. (1997a, b) reported that pitfall pheromone traps captured about two and a half times more *C. sordidus* than sordidin baited pseudostem traps. Tinzaara et al. (2007) demonstrated that the addition of pseudostem to pitfall traps did not significantly increase *C. sordidus* capture rates. These differences are possibly due to the different trap types used in the experiments and the weevil density within the field.

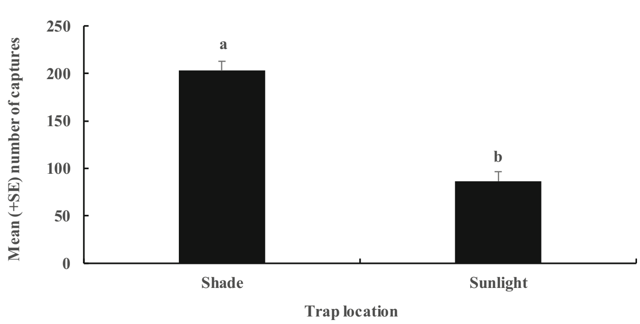

Fig. 9 Mean (+SE) number of *C. sordidus* individuals captured in pheromone ramp traps placed in shade and in sunlight. Different lower-case letters indicate significant differences between treatments (one-way ANOVA using Poisson analysis, least-square means, $P < 0.05$).

Conclusion

Three important findings have been found in the present study. First, horizontal-pseudostem traps for *C. sordidus,* and vertical-pseudostem traps with cut sections above ground from 60 to 100 cm high for *O. longicollis*, are suitable tools for trapping these pests. Second, brown or black pheromone baited traps and the addition of pseudostem to pheromone ramp traps have a great potential for controlling *C. sordidus*. Third, traps with watering, covering and placed in the shade can increase trap catches. Taken together, these findings improve the understanding of the pseudostem and pheromone trapping system and provide appropriate information to optimize the trapping system for the control of *C. sordidus* and *O. longicollis*.

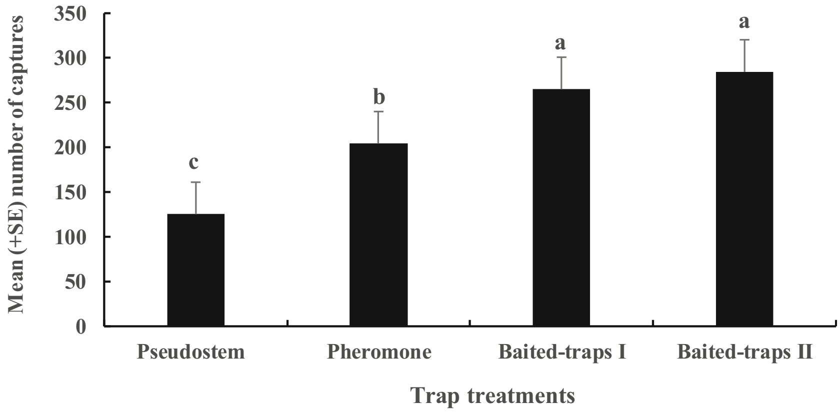

Fig. 10 Mean (+SE) number of captured *C. sordidus* individuals using pseudostem traps, pheromone traps and pheromone-based traps. Baited-trap I represents pheromone-baited pseudostem traps, and baited-trap II represents the addition of pseudostem to the pheromone ramp traps. Different lower-case letters indicate significant differences between treatments (one-way ANOVA using Poisson analysis, least-square means, $P < 0.05$)

Acknowledgements This research was supported by the National Key Research and Development Program of China (Project No. 2017YFD0202105-02-2) and partly supported by the Earmarked Fund for China Agriculture Research System (Project No. CARS-32-04). We would also like to acknowledge the anonymous reviewers and editors for their constructive and valuable comments.

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