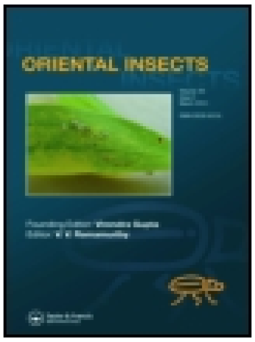

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Factors affecting catch of the black-headed caterpillar, *Opisina arenosella* Walker in sex pheromone-baited traps and evidence for population suppression by mass trapping

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ABSTRACT

The black-headed caterpillar, *Opisina arenosella* Walker (Lepidoptera: Oecophoridae) is a major and most destructive pest of coconut palm. Feeding habit and spatially segregated distribution with a discrete flight period of 32.44 ± 4.45 (Mean ± SD) days per generation make it difficult to employ insecticide sprays. In this study, we explored the utility of sex pheromone by exploiting its distribution and flight behaviour. The pheromone trap colour, its suspended height, density and design were evaluated. White cross-vane traps suspended in the middle of the palm canopy at a density of 40–120 traps ha^{-1} proved to be the most effective among tested. White cross-vane traps baited with synthetic pheromone, (*Z,Z,Z*)-3,6,9-Tricosatriene for three consecutive moth emergence periods and trapped 1,34,084, 9012 and 4126 moths in Nittur, Nelamangala and Bidadi, respectively. Further, there was a reduction in larvae per leaflet from 2.28, 1.17 and 0.83, to 0.11, 0.12 and 0.06, in the three respective sites. There was subtle to no change in the larval abundance in the control plots across the generations. Our results suggest suitable mass trapping technique may substantially suppress the *O. arenosella* population on coconut.

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Coconut; discrete flight; *Opisina arenosella*; *Z,Z,Z*-3,6,9-Tricosatriene; mass trapping; sex pheromone

1. Introduction

The black-headed caterpillar, *Opisina arenosella* Walker (Lepidoptera: Oecophoridae), is a key insect pest in major coconut (*Cocos nucifera* L.) cultivable areas (Perera 1989; Bao-Qian et al. 2013). *O. arenosella* larvae feed and

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confine themselves to the lower surface of leaflets, construct galleries with silk, frass and chewed matter. Early instar larvae feed gregariously, and late instar larvae singly on the leaf tissue, leaving upper epidermis intact with a dried or scorched appearance. From a distance, infested orchards give the appearance of leaves being burnt. Severe infestation of *O. arenosella* have an aftermath effects like retarded palm growth and premature nut fall (Mohan et al. 2010). Current practices in India to manage *O. arenosella* are removal of the infested fronds, root-and-stem injection of synthetic insecticides and release of natural enemies (Rao et al. 1948; Shivashankar et al. 2000), used either separately or in combination. However, these practices are shown to affect palm's vigor (Nirula 1956; Joy and Joseph 1972), insecticide treatments are often dangerous to natural enemies and exacerbates problems of toxic residues in both tender and dried coconut (Kanagaratnam and Pinto 1985). Biological control has not been successful due to the constraints associated with the multiplication of parasitoids, availability, perpetuation and the logistics/mechanics of their establishment in the field conditions (Nagarkatti 1973). In other words, none of the current management practices, except insecticides, has been found to be effective against *O. arenosella*.

Lepidopteran sex pheromones are usually species-specific and require only minute quantities of pheromone compound in the lure. Pheromone-based pest management is an environmentally friendly technology (El-Sayed et al. 2006), and are used widely for the management of insect pests (Witzgall et al. 2010). Mass trapping of males using the pheromone traps is aimed at reducing the targeted pest population in the subsequent generations. The biology and behaviour of *O. arenosella* (ie spatially segregated populations, discrete moth emergence cycles, female-biased sex ratio [1:1.17], protandry, periodicity with regard to adult emergence, female calling, courtship and mating, single mating among females and multiple mating among males) are more favourable for executing the mass trapping of male moths using sex pheromone (Perera 1989; Ramkumar et al. 2006; Muralimohan and Srinivasa 2008, 2010; Bhanu et al. 2013; Chandrashekharaiah et al. 2014; Kumara et al. 2015). Pheromone mass trapping alone shown to be effective on *Phthorimaea operculella* (Zeller), *Cydia pomonella* (L.), *Lymantria dispar* (L.), *Grapholita molesta* (Busck), *Rhynchophorus palmarum* (L.), *R. ferrugineus* (Olivier), *Ips duplicatus* Sahlberg and *Calliphora vicina* Robineau-Desvoidy (Hallett et al. 1999; Oehlschlager et al. 2002; Schlyter et al. 2003; Witzgall et al. 2010; Aak et al. 2011). Sex pheromone component, (*Z,Z,Z*)-3,6,9-Tricosatriene (Bhanu et al. 2009) produced by female *O. arenosella* shown to attract male in the field study (Bhanu et al. 2011), however, no studies on mass trapping of *O. arenosella*. In several mass trapping studies, only lures and traps are considered as key factors affecting moth catches (Witzgall et al. 2010) and least attention to the trap colour, design, trap placement height in coconut palms which potentially alters the male moth capture rate. Here, we studied the factors that affect male moth responses to sex pheromone-baited traps, pheromone mass trapping and its consequences on the *O. arenosella* population.

2. Materials and methods

2.1. Study site and pheromone lure

Studies were conducted in 10 coconut groves near Bengaluru (12.97°N,7.56°E, 920 m AMSL), India (Table 1). (*Z*,*Z*,*Z*)-3,6,9-Tricosatriene of >99% pure (confirmed through Gas-Chromatography) was (Cabrera and Urdaneta 2007) synthesised at BCRL, PCI, Bengaluru, India. All types of traps used in the studies are commercially available at BCRL, PCI, Bengaluru. Plastic vial dispensers were loaded with 100 μg of pheromone [with the release rate of 80 days (Chandrashekharaiah 2013)] and used in the field studies.

2.2. Trap height

Four different trap heights were tested over two generations of *O. arenosella*. Ten white wing vane traps baited sex pheromone were placed on 10 randomly select palms at different heights: (a) 0.8 m above the ground (fixed to the palm trunk), (b) just below the palm canopy (tied to the lower frond), (c) in the middle of the palm canopy (tied to the posterior part of middle frond) and (d) suspended from a bamboo pole that extended 1 m above the palm canopy (Figure 1(A)–(D)).

2.3. Trap colour

To study the effect of trap colour on moth catches, coconut palms from two plantations (n = 75 from each) were selected in the fields at Bidadi. Wing vane traps of five colours – white, blue, grey, green and yellow (Figure 2(A)–(F)), were suspended in the middle of palm canopy on randomly select palms. Traps were set up at a density of 1 per three palms. Each trap colour was replicated five times.

2.4. Trap density

The entire field was divided into six blocks with 15 m distance between each block (Field 1 in Table 1). The six blocks consisted of 220, 220, 60, 60, 60 and 30 palms, respectively. Pheromone traps were installed: Block 1 = 10 trap in 220 trees at a density of 5 ha^{-1} (1 trap/24 trees), Block 2 = 30 traps in 220 trees at a density of 15 ha^{-1} (1 trap/8 trees), Block 3 = 15 traps in 60 trees at a density of 30 ha^{-1} (1 trap/4 trees), Block 4 = 20 traps in 60 trees at a density of 40 ha^{-1} (1 trap/3 trees), Block 5 = 30 traps in 60 trees at a density of 60 ha^{-1} (1 traps/2 tree) and Block 6 = 30 traps in 30 trees at a density of 120 ha^{-1} (1 trap/tree). In each block, the border rows were avoided to eliminate edge effect. Ten pheromone traps were designated to record moth catches. Due to the field constraints, weekly moth catches of three consecutive periods during peak emergence period were considered as replication in the statistical analysis.

Table 1. Details of experimental localities, study period, coconut palm details used in the study.

Location		Area (in ha)	No. of palms	Infested fronds (%) ($n = 15$)*	Age of palms (years)	Attributes evaluated	Study period (2011–2013)
Bidadi	Field 1 (13°12′05.24″ N77°17′50.08″E, 896.112 m AMSL)	6.0	720	64.00	25	Trap colour	18/10/2011 to 23/11/2011
						Trap type	7/1/2012 to 28/1/2012
						Trap density	15/12/2011 to 14/02/2012
	Field 2 (12°45′45.77″ N77°26'36.91″E, 711.0984 m AMSL)	0.75	90	28.00	15	Trap colour	25/12/2011 to 28/01/2012
	Field 3 (12°45′62.13″ N77°25′49.63″E, 703.7832 m AMSL)	0.37	45	43.00	20	Trap height	20/9/2011 to 27/01/2012
Thyamagondlu	Field 4 (13°12′05.24″N 77°17′50.08″E, 896.112 m AMSL)	0.6	80	41.00	25	Trap type	01/04/2012 to 15/05/2012
Nittur	Field 5 (13°1915′94″N 76°51′12.67″E, 795 m AMSL)	14.2	1700	50.00	10–25	Mass trapping	01/07/2012 to 5/02/2013
	Field 6 (13°19′40′94″N 76°51′46.20″E, 795 m AMSL)	2.50	300	50.00	25	Control	01/07/2012 to 5/02/2013
Nelamangala	Field 7 (13°19′47.72″N 77°21′12.59″E 877.824 m AMSL)	2.33	270	43.00	15	Mass trapping	20/08/2012 to 5/04/2013
	Field 8 (13°05′45.35″N 77°21′13.05″E 877.824 m AMSL)	2.50	300	43.00	20	Control	20/08/2012 to 5/04/2013
Bidadi	Field 9 (12°45′38.21″N77°25′50.51″E 703.7832 m)	1.10	128	40.00	25–30	Mass trapping	20/06/2012 to 11/02/2013
	Field 10 (12°45′32.89″ N77°25′48.63″E, 702.8688 AMSL)	2.5	300	52.00	25	Control	20/06/2012 to 11/02/2013

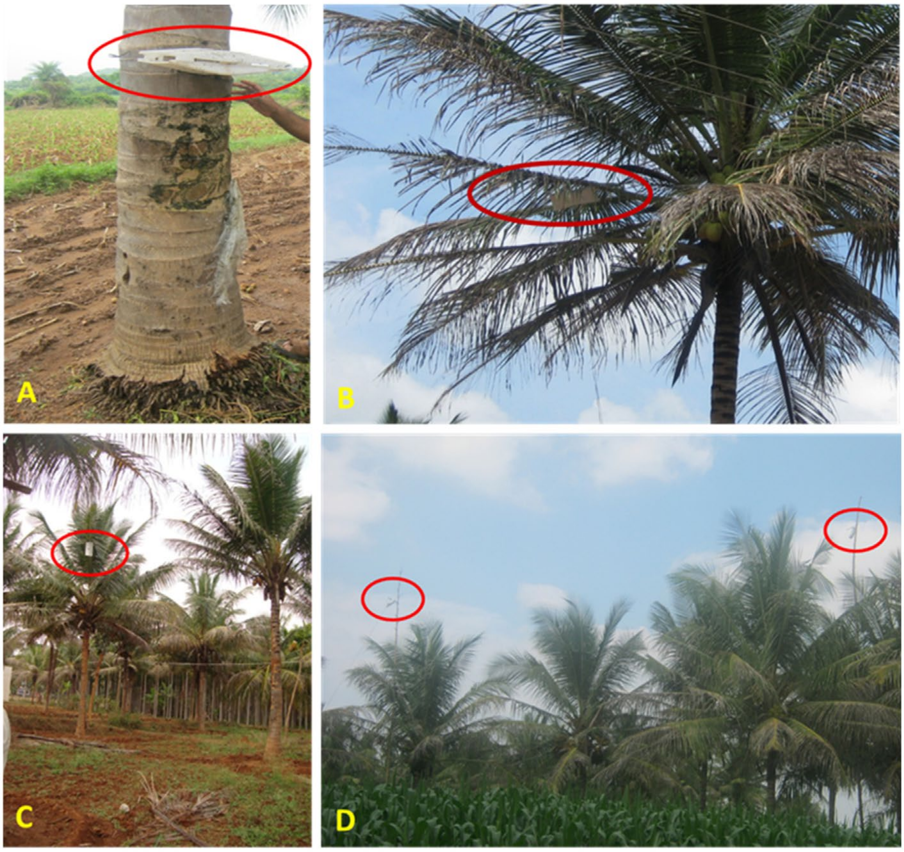

Figure 1. Traps suspended at different heights: A, 0.6–0.8 m above the ground; B, below the palm canopy; C, middle of the palm canopy; D, above the palm canopy.

2.5. *Trap design*

White colour traps captured more male moths. Here, we tested different designs of white colour traps, the cross-vane (20 × 25 cm, adhesive all over the trap), delta trap (20 × 20 cm, adhesiveness inside the trap at the bottom), wing vane (7.5 × 5 × 20 cm, adhesiveness inside the trap at the bottom), open wing vane (7.5 × 5 × 20 cm, adhesiveness inside the trap at the bottom and wide open at all sides) and funnel traps (non-sticky) were tested for moth catches at Bidadi and Thyamagondlu. Each trap type was replicated five times on randomly selected palms at a density of 1 trap per three palms and the traps were installed uniformly in the middle of the palm canopy.

2.6. *Mass trapping*

Mass trapping was conducted at three different sites (Nittur, Nelamangala and Bidadi) near Bengaluru, South India. At Nittur, Bidadi, and Nelamangala 680,

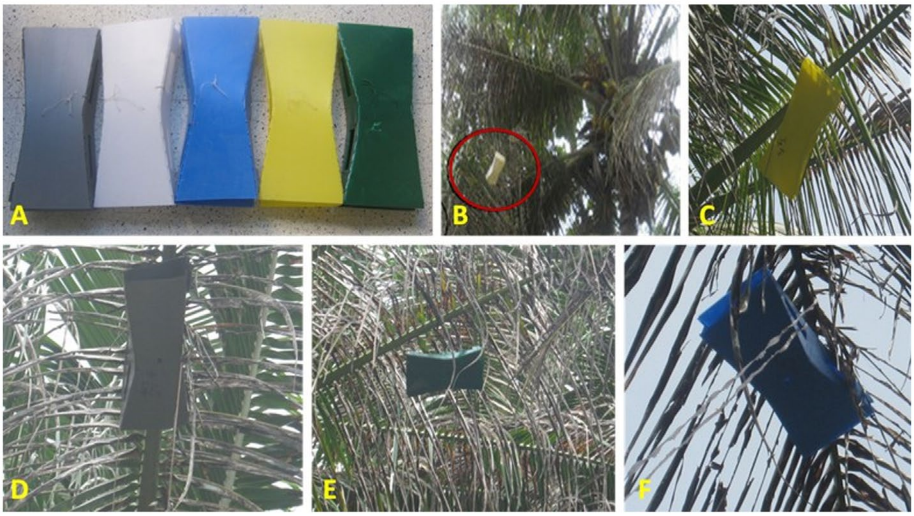

Figure 2. Different colours of wing vane traps used in the study (A) and trap placement in the palm canopy (B–F): B, white; C, yellow; D, grey; E, green; and F, blue.

129 and 93 white cross-vane traps were installed , respectively, in the middle of palm canopy at a density of 40 ha^{-1} (Fields 5–10, Table 1) for three consecutive generations of the pest. The lures were changed at 80 days interval that coincides with the moth emergence. Preliminary experiments caught no moths in the control plots, so we excluded control treatment in mass trapping. Moth catches were recorded at weekly intervals during the moth emergence periods, and traps were rotated to minimise influences of position.

2.7. Flight activity periods

The moth flight activity was recorded at Nittur, Nelamangala and Bidadi (Fields 5, 7 and 9, respectively). In total 14, 5 and 5 pheromone traps were designated for the regular (7–10 days) recording of moth catches at Nittur, Nelamangala and Bidadi, respectively.

2.8. Larval density and pupal parasitisation

Ten coconut palms ha^{-1} were selected randomly, 1 frond from the lower canopy and other from the middle of the canopy were removed and 20 leaflets in each frond were selected to record the larval counts. To estimate natural parasitisation (mass-trapped fields [5, 7 and 9] and control fields [6, 8 and 10]), 300 infested leaflets from 15 selected coconut palms were pooled and brought to the Behaviour Testing Lab, BCRL, PCI, Bengaluru. The larvae were provided with fresh coconut leaves until pupation. Pupae were sexed and placed in separate plastic boxes (30 × 20 × 20 cm) lined with tissue paper. Adult parasitoids were identified up to species level in the laboratory using the taxonomy keys.

2.9. Statistical analysis

Weekly trap counts were pooled for each treatment and data was Log (x + 1) transformed. The effects of trap colour, height, density, design and mass trapping on moth catches were analysed using Generalized Linear Models, followed by Tukey's test for multiple comparisons (SPSS 13.0). Pair-wise test (t-test) used for comparing the larval reduction as well as per cent parasitisation between control and treatment sites for the respective flight period.

3. Results

3.1. Trap height

Mean catches of *O. arenosella* in traps placed at middle of the palm canopy was significantly more in both the first (F = 17.59; p < 0.001; df 3,36) and second (F = 2.619; p = 0.03; df 3,36) generations (Figure 3) compared to other heights. Traps at the middle of the palm canopy trapped 66.00% (first generation) and 69.67% (second generation) of the total moths trapped in their respective generations.

3.2. Trap colour

Among five trap colours tested in two localities, white colour traps caught significantly more moths (p = 0.015 for the location I, and p = 0.04 for the location II; Table 2). At Field 1, mean catch did not differ significantly among white, and

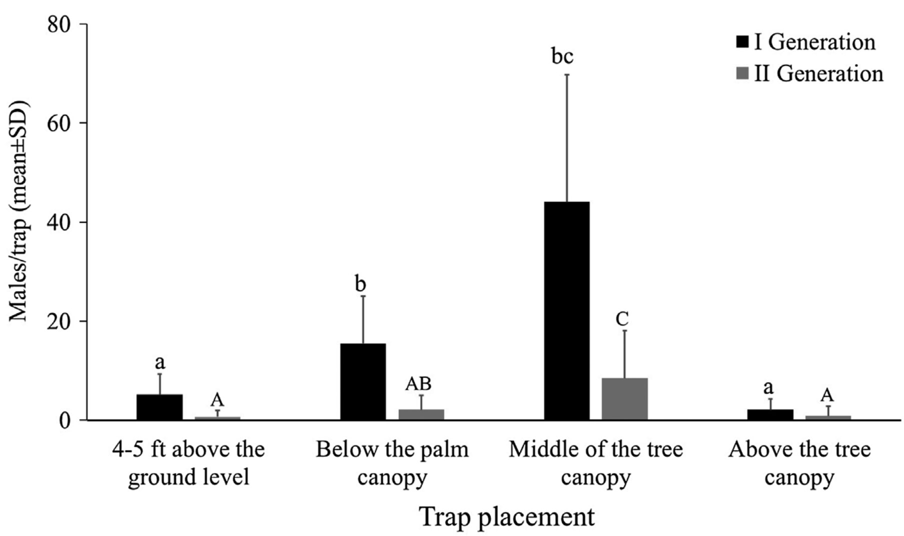

Figure 3. Influence of trap placement height on *O. arenosella* captures (Mean ± SD). Trap counts were transformed by Log (x + 1) and analysed using generalized linear models (GLM). Within each generation different letters indicate a significant difference at p < 0.01 by Tukey's comparisons.

blue traps but each caught significantly more moths than did yellow, grey and green traps. At Field 2, however, white and grey traps captured significantly more moths (mean ± SD; 25.20 ± 3.36) than any other colour tested. From the results, it is evident that white traps were more attractive to *O. arenosella* moths.

3.3. Trap density

Moth catches per trap were decreased from 128 at a density of 5 traps ha^{-1} to 36.68 in the plot at a density of 120 traps ha^{-1} (Figure 4). But, the total number of moths trapped were increased as the trap density per unit area increased. In trap densities of 40, 60 and 120 traps ha^{-1}, there was no significant variation in moth catches per trap ($p > 0.05$). Regression analysis indicated a linear relationship between moth catches and trap density ($y = -16.453x + 119.59$ $R^2 = 0.7659$; $p < 0.001$), where increase in the trap density ha^{-1} was reflected in a reduction in moth catches per trap.

Table 2. Male moth captures to sex pheromone-baited traps of different colours from two locations in Bidadi, Bengaluru, India.

	Moths /trap (Mean ± SD)	
Trap colour	Location I	Location II
Yellow	30.20 ± 11.17^{ab}	4.60 ± 1.86^{c}
White	41.40 ± 10.64^{a}	25.20 ± 3.36^{a}
Blue	36.80 ± 10.56^{a}	13.00 ± 4.95^{b}
Grey	27.20 ± 11.72^{bc}	6.20 ± 1.63^{c}
Green	24.20 ± 7.32^{c}	4.60 ± 1.03^{c}

Notes: Comparisons were made between the trap colours within the plantation, different letters within each location indicate significant differences among trap colour types (Tukey's test $p = 0.05$).

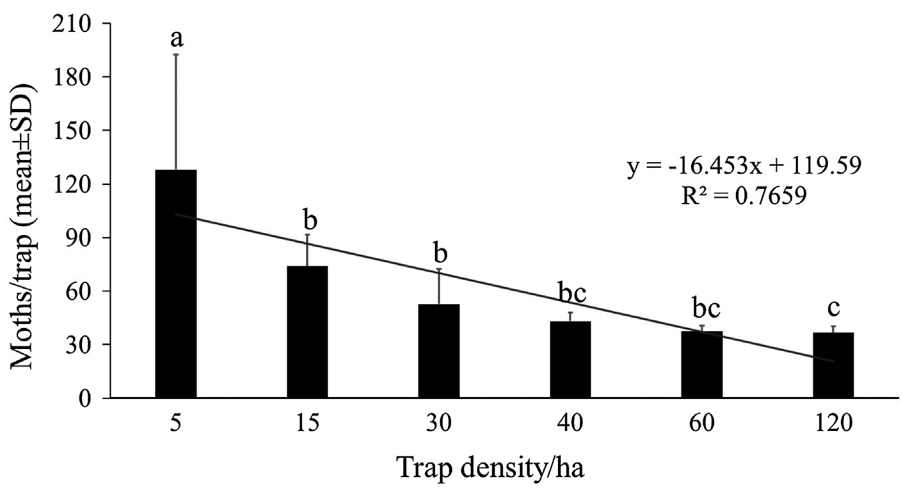

Figure 4. Effect of trap density on *O. arenosella* catches per trap at Bidadi. Different letters indicate significant differences among treatments ($p < 0.001$).

3.4. Trap type

Mean moth catches at both sites were more in the cross-vane traps, and least in the funnel and delta traps. Mean moth catches differed significantly among all five traps types at the Bidadi site which had higher population density ($F = 36.96$, $p < 0.001$), whereas there was no difference in catches in Thyamagondlu site (low moth density) among wing vane, open wing vane and delta traps (Figure 5).

3.5. Mass trapping

3.5.1. Nittur

A total of 1,34,084 moths were trapped during mass trapping. Of these, 54.99, 39.07 and 5.93% were caught during the first, second and third periods of mass trapping, respectively ($F = 1664.01$; $p < 0.001$) (Table 3). Large number of moths were caught in the first period of mass trapping, and a reduction of 28.95%, and 89.21% moth catches in the second, and third mass trapping, respectively. Density of larvae also reduced after first ($t = 2.04$; $p = 0.03$), second ($t = 3.33$; $p = 0.005$) and third ($t = 5.24$; $p = 0.001$) mass trapping (Table 3). Reduction in larval counts were significantly different from the plots with control treatment.

3.5.2. Nelamangala

A maximum of 8857 moths were trapped in the first period of mass trapping. Moth catches in the three successive trapping trials varied significantly ($F = 663.12$; $p < 0.001$) (Table 3). A reduction in moth catches of as much as 98.92% in the second and 99.32% in the third period of mass trapping was observed. Similarly,

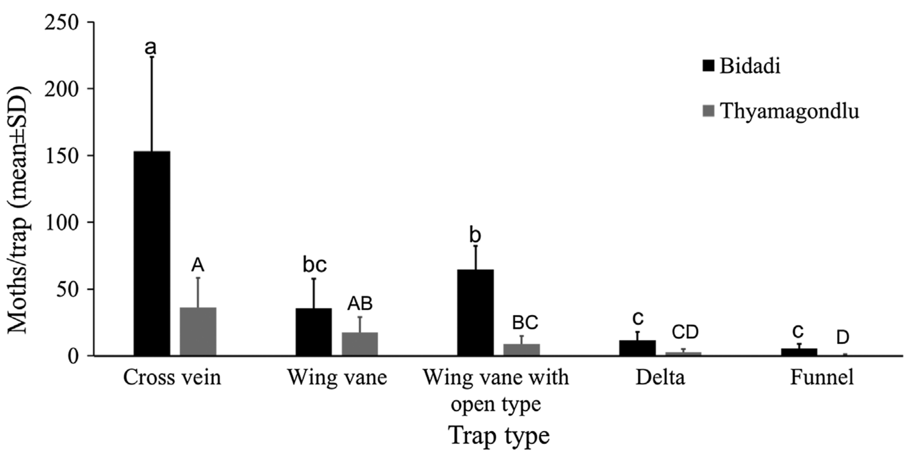

Figure 5. The effect of different trap types tested on *O. arenosella* moth catches at different localities (A = Bidadi; B = Thyamagondlu). Within each locality different letters indicate a significant difference ($p < 0.01$).

Table 3. Total number of male *O. arenosella* moths captured in each mass trapping. Pupal parasitisation (%) and larval reduction (Mean ± SD) in the mass-trapped plots at three different localities tested. MT – mass-trapped, C – control.

Place	Generation cycle	Total moths	Pupal parasitisation (%)		Larvae per leaflet (Mean ± SD)	
			MT	C	MT	C
Nittur	I	–	11.18	12.50	2.28 ± 0.34	1.86 ± 1.20
	II (1st MT)	73,739	05.03	11.23	1.32 ± 0.08	1.72 ± 0.87
	III (2nd MT)	52,392	11.16	10.50	0.12 ± 0.03	1.53 ± 1.05
	IV (3rd MT)	7953	10.56	11.50	0.11 ± 0.02	1.46 ± 0.77
Nelamangala	I	–	19.00	15.00	1.17 ± 0.15	1.44 ± 0.11
	II (1st MT)	8857	16.50	11.23	0.25 ± 0.06	1.49 ± 0.22
	III (2nd MT)	95	17.00	10.50	0.15 ± 0.05	1.47 ± 0.27
	IV (3rd MT)	60	18.60	11.50	0.11 ± 0.04	1.29 ± 0.21
Bidadi	I	–	10.55	12.15	0.83 ± 0.29	0.91 ± 0.12
	II (1st MT)	1409	9.33	8.25	0.34 ± 0.15	0.94 ± 0.84
	III (2nd MT)	2691	6.33	12.60	0.18 ± 0.11	0.84 ± 0.32
	IV (3rd MT)	26	11.96	15.50	0.06 ± 0.03	0.82 ± 0.31

significant larval reduction in mass-trapped plot after first (t = 13.07; p < 0.001; df_8), second (t = 24.44; p < 0.001; df_8) and third (t = 13.01; p < 0.001; df_8) mass trapping compared to control (Table 3).

3.5.3. Bidadi

Total moth catches were reduced significantly after every mass trapping (F = 102.24; p < 0.001; $df_{2,27}$) (Table 3). Larval reduction was also significantly differed in the mass-trapped area [first (t = 6.75; p < 0.001; df_8), second (t = 11.33; p < 0.001; df_8) and third (t = 10.56; p < 0.001; df_8)] mass trapping] in comparison with the control plot (Table 3).

3.6. Generation cycle

Three moth emergence cycles were recorded in Nittur, Nelamangala and Bidadi over a period of eight months. Moths were active during three different periods lasting 4–6 weeks (5 July–5 August, 5 October–10 November and 10 January–2 February) separated by 8 weeks of no moth activity in between (Figure 6). The pheromone trap catches precisely coincided with the beginning and the end of moth emergence. Meticulous and close observations of the moth emergence pattern in three locations indicated the spatial and temporal occurrence of segregated discrete moth emergence cycles in *O. arenosella* (Figure 6).

3.7. Pupal parasitisation

Parasitoids, *Meteoridea hutsoni* (Nixon), (Hymenoptera: Braconidae), *Brachymeria nephantidis* Gahan (Hymenoptera:Chalcididae) *Xanthopimpla punctata* Fabricus (Hymenoptera: Ichneumonidae) were recorded on pupae sampled in all fields. Pupal parasitisation did not vary significantly between mass-trapped and control plots (t = 0.35; p = 0.36; df_9).

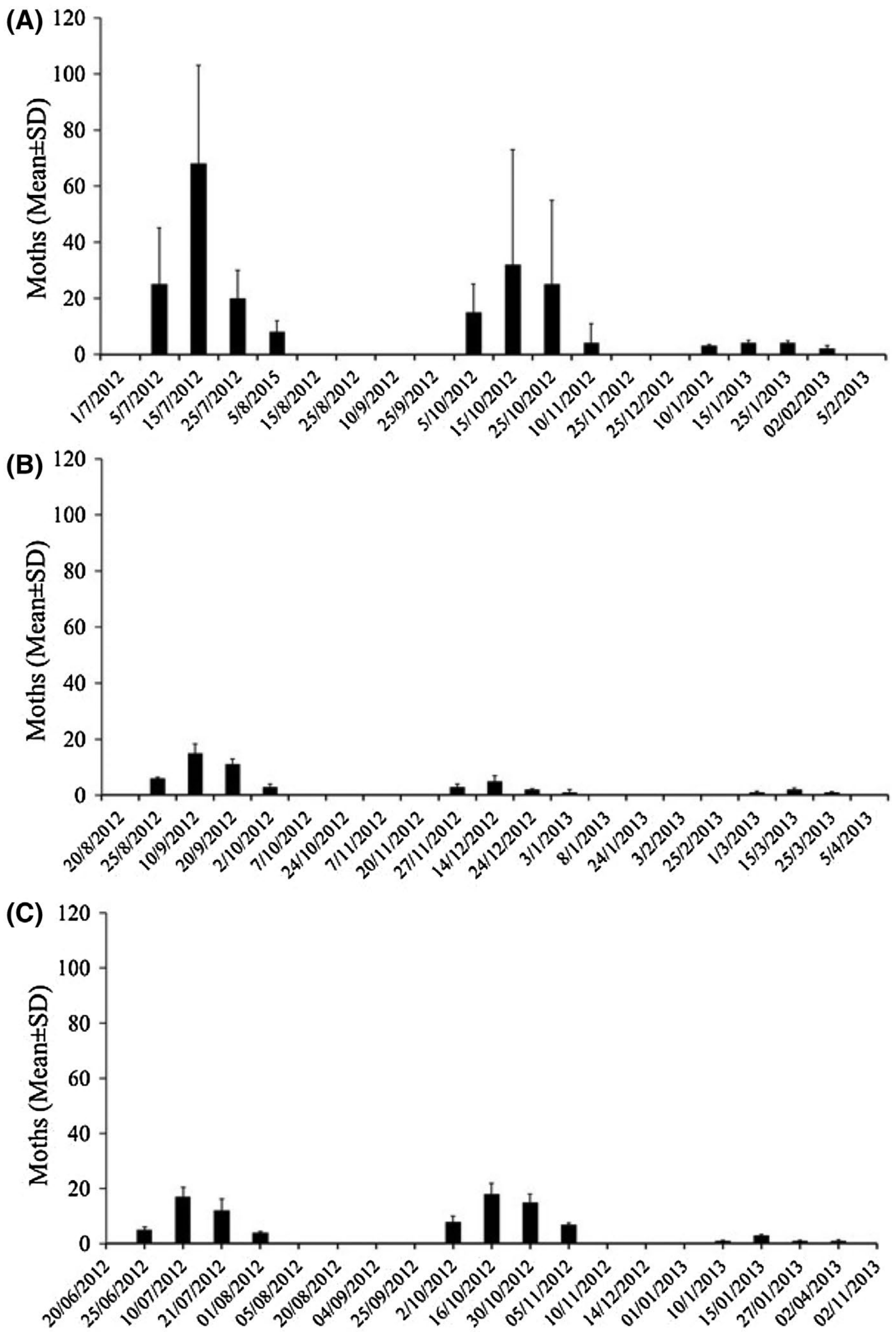

Figure 6. The activity pattern of *O. arenosella* monitored using pheromone trap captures at Nittur (A), Nelamangala (B) and Bidadi (C).

4. Discussion

Visual cues are known to be a vital factor affecting the close-range orientation of male or female moths (Castrovillo and Carde 1980). Sukovata et al. (2009) tested the effect of barrier sticky traps with blue, green and white colour on *Cameraria ohridella* Deschka & Dimic (Lepidoptera: Gracillariidae) and found that white barrier traps were more effective than other traps. Myers et al. (2009) found no differences in the capture of obliquebanded leafroller, oriental fruit moth, tufted apple bud moth and codling moth between plastic LepTrap® traps of various colours and standard unpainted white delta-style traps. The influence of trap colour on the capture of noctuid pests in sex pheromone traps has been extensively studied (Mitchell et al. 1989). McLaughlin et al. (1975) found that traps with low spectral reflectance were more effective on *Trichoplusia ni* (Hubner) and *Chrysodeixis includens* (Walker), while such traps were less effective with regard to *Anticarsia gemmatalis* Hubner and *Spodoptera frugiperda* (J.E. Smith) (Mitchell et al. 1989). Observations indicated that white traps were attractive to *O. arenosella*. The response in *O. arenosella* to different colour might be related with the selection of resting site, as they prefer to rest at whitish-grey background in the natural conditions (personal observation). Further studies on spectral sensitivity of *O. arenosella* to different wavelengths, synergistic effect of trap colour and sex pheromone on male orientation may help in refining the traps colour.

We observed reduction in the *O. arenosella* moth captures in traps placed either above or below the palm canopy, whereas traps placed in the middle of the palm canopy captured more moths. Pushpalatha (1991) studied the distribution of *O. arenosella* within the palm canopy from base to top, and recorded low population in lower and upper canopies than that in middle canopy. So that, trapping can be effective if the traps are placed at the middle of the coconut palm canopy. Similar results have also been shown in pheromone trap captures of other moth species, *Cydia pomonella* L. and *Grapholita molesta* (Busck) (Knight and Light 2005; Kovanci et al. 2006). Borden (1931) recorded the mating and flight activity of codling moths around the upper third of an apple tree canopy. The responses of the male *S. lituralis* were optimal when traps were suspended, regardless of the crop height, near the top foliage (Kehat et al. 1976). Females use host plant to lay their eggs and males use plant volatiles as a cue to find their conspecifics (Landolt and Phillips 1997). There is an evidence that host plant volatiles synergise male behavioural response to pheromone (Reddy and Guerrero 2004). Increase in moth captures in the traps suspended from the canopy explain the possibility of pheromone and plant volatile interaction and *O. arenosella* may exploit this information, which needs to be tested.

Linear regression revealed rapid decrease in moth catches per trap as the trap density increased. These results are an indication of the competitiveness of *O. arenosella* in response to pheromone traps. However, placement of over-optimal number of traps lead to less compitativeness. Similar results have also been found in *C. pomonella* (L.), *Euzophera semifuneralis* (Walker), *Synanthedon exitiosa* (Say) and *Synanthedon pictipes* (Groeten) (Miller et al. 2006; Teixeira et al. 2010). Physiologically less competiveness can be exlapined, olfactory receptor neurons (ORNs) are highly sensitive to low concentrations of pheromone components produced by their conspecifics. Pheromone ORNs tuned to the pheromone components are adapted to higher concentrations or fail to detect sub-optimal concentrations of pheromone in the natural conditions (de Bruyne and Baker 2008). From the observations, we infer 40 traps ha^{-1} are optimal to trap maximum number of moths.

The most commonly used traps for lepidopteran insect pests are delta and wing vane types that rely on a sticky surface for capture. These traps have a limited surface, which can become rapidly saturated either with the target pests (where there are high pest populations) or with non-target pests (Gray et al. 1991; Schmidt and Roland 2003). In this study, cross-vane traps caught large number of moths. Cross-vane traps have a wide sticky area with the pheromone lure at the centre and trap male moths immediately after initial landing. In contrast, surface area in the wing vane and delta traps is limited, thus possibility of escape after landing on the trap.

Large-scale mass trapping at Nittur, Nelamangala and Bidadi resulted in considerable number of larval reduction. *O. arenosella* found to infest secondary hosts in the absence of primary host coconut like *Borassus flabelliformis* Murr. *Corypha umbraculifera* Linn., *Phoenix sylvestris* Roxb., *Livistona* sp., *Caryota urens* L., *Careodon oleraces* and *Hyphaene thebaica* Mart. in South India (Rao et al. 1948). However, these hosts are restricted to forest tracts and are not cultivable. *O. arenosella* remains confined to contiguous coconut patches, thus mass trapping was successful in our study. The success of mass trapping was mainly due to the trap type, trap density and their suspension in the palm canopy. In addition, factors like discrete moth emergence cycles, protandry, female-biased sex ratios, single mating and low mating success of late emerging females may also been shown to contribute to the success of mass trapping (Muralimohan and Srinivasa 2008, 2010). Trap design and the timing of trapping in accordance with moth emergence had a cumulative effect in population reduction. El-Sayed et al. (2006) and Witzgall et al. (2010) outlined the importance of integrating population biology and life history factors in the success of mass trapping. Mass trapping has been tried on a variety of crop pests both as a stand-alone technique and/or in combination with insecticides (Oehlschlager et al. 1993; El-Sayed et al. 2006). In this study, a significant larval reduction was achieved at Nittur, Nelamangala and Bidadi due to continuous trapping of male moths.

In South India, *O. arenosella* has often reached epizootic proportions on coconut palms since 1920 (Nagarkatti 1973). Parasitoids like *Goniozus nephantidis* Muesebeck (Hymenoptera: Bethylidae) and *Bracon brevicornis* Wesmael (Hymenoptera: Braconidae) have frequently been released by the Agriculture Department for the suppression of *O. arenosella* (Nagarkatti 1973) in the Southern India, but without success. Stem and root feeding of synthetic insecticides have also commonly been practiced (Shivashankar et al. 2000). But, insecticides have proved to exacerbate the pest problem, escalating the costs. We conclude mass-trapping is effective with involvement of farming community of entire region, and placement of pheromone traps that coincides with moth flight activity may bring down moth population below economic threshold level. Further studies are necessary to evaluate the cost–benefit ratio with the use of pheromone mass trapping alone and/or in combination with insecticide application.

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Disclosure statement

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