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Toxicity and dissipation of soil insecticides applied in the management of arecanut white grub, *Leucopholis burmeisteri* Brenk. (Coleoptera: Scarabaeidae)

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Abstract White grubs, *Leucopholis* spp. are subterranean pests of arecanut grown in South India. Grub infestation leads to yellowing, stem tapering, and crown size and yield reduction. Use of chemical insecticide to mage the white grubs gives varying degree of success. Hence an attempt was made to screen newer and safer insecticides. Imidacloprid (LC_{50} at 120 h = 16.849 ppm on III instar larvae), chlorpyriphos (LC_{50} = 14.242) and bifenthrin (LC_{50} = 12.797 ppm) were identified as effective insecticides. Evaluation of these insecticide in the field over two year period indicated the following efficacy in reducing larval population: chlorpyriphos @ 4 kg a.i/ha (83.31%) > bifenthrin @ 4 kg a.i./ha (82.83%) > imidacloprid @ 0.24 kg a.i./ha (75.84%) > bifenthrin @ 2 kg a.i./ ha (74.26%) > chlorpyriphos @ 2 kg a.i./ha (69.15%) > chlorpyriphos @ 1 kg a.i./ha (61.79%) > imidacloprid @ 0.12 kg a.i./ha (56.54%) > bifenthrin @ 1 kg a.i./ha (54.34%) > imidacloprid @ 0.06 kg a.i./ha (41.47%). Bifenthrin in soil persisted for a longer period than chlorpyriphos. On the day of application, 59.46 ppm bifenthrin residue was recovered from soil. On 10th day, it was 7.29 ppm which decreased to 2.59 ppm on 30th day and was beyond detection limit on 65th day. Chlorpyriphos exhibited a rapid degradation in the initial stage; 27.46 ppm residue on the day of application, which further reduced to 0.964 ppm on 10th day, and was below the detection limit on the 30th day. Growth of *Trichoderma harzianum* was not affected by bifenthrin even up to 40 ppm concentration. However, chlorpyriphos affected the growth of *Trichoderma* at higher than 5 ppm dose. Similarly, imidacloprid inhibited the colony growth from 2 ppm onwards. Having high lipophylic property and contact toxicity, bifenthrin would be an ideal alternative insecticide to chlorpyriphos for the management of white grubs in palm garden, which is safe and long persisting.

Keywords Arecanut · Bifenthrin · Dissipation · Field evaluation · Leucopholis · White grub · Trichoderma

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Introduction

Arecanut, *Areca catechu* L. (Arecaceae) is an important commercial crop in India and in the far Eastern countries. In India it plays a key role in part of ritual offerings in Hindu religion. The palm owes its rating of importance to the fruits known as arecanut or betel nut which form the principal chewing material. When arecanut is widely uses as mouth freshener, (either raw or after

processing) often in association with fresh betel leaf (*Piper betle* L.) and a little bit of lime producing dark orange colouration in the mouth. Chewed as a stimulant by at least 5% of the world's population and annual worldwide areca nut crop is valued around $300 million (Hegde and Deal 2014). This is believed to aid in better digestion. Arecanut is symbolic of great culture of some of the oriental nations such as India, Malaya and Indonesia. Betel nut chewing is as familiar as chewing gum to Americans (Raghavan and Baruah 1958). Globally it is grown in India, Bangladesh, China, Indonesia, Taiwan and Myanmar. India leads in production, followed by China and Bangladesh. Incidence of pests and diseases is the major constraints in arecanut production, among which white grubs are considered as key pests. White grub complex are perennial polyphagous pests of national importance. Palm based cropping systems of Southern and North Eastern parts of peninsular India is reported to be infested by white grubs belonging to the genus "*Leucopholis*". Veeresh et al. (1982) documented three species viz., *L. burmeisteri, L. lepidophora,* and *L. coneophora* as major white grubs associated with palms. Severely damaged palms can be uprooted with a small jerk, as the entire root system is damaged by the grubs. *Leucopholis lepidophora* is distributed along the Western Ghats and prefers clayey loam soil. Besides palm roots, it feeds on subterranean parts of tuberous and rhizomatous intercrops, rubber, sugarcane, rice, maize, banana, tapioca, groundnut, grasses, etc. Second and third instar larvae of *L. burmeisteri* are voracious feeders, ingesting 2.3 g areca root tissue / grub / day. Continuous feeding by grubs causes stem tapering, reduction in crown size, lack of production of inflorescence, nut fall in yielding palms and loss of palm vigor (Padmanabhan and Daniel 2003).

Currently, application of chlorpyriphos @ 2 kg ai / ha is being adopted by farmers (Anonymous 2000) with varying degree of success. Continuous exposure of same insecticide for long period leads to development of resistance in insects. Villani et al. (1988) reported reduced susceptibility of white grubs *Popillia japonica* against chlorpyriphos and other organophosphorus compounds. Therefore, an attempt was made to identify newer insecticides in management of *Leucopholis* grubs. Based on laboratory bioassays, three insecticides (bifenthrin, imidacloprid and chlorpyriphos) were selected for field evaluation. Since the use of pesticide could become a serious problem with concerns of environmental safety, a regular monitoring of pesticide residues in soil environment is indispensable. So, present study aims to find the dissipation pattern of promising insecticides. Pesticides, when applied to crops, come in contact with both the target and non-target organisms, and have been implicated to exert some effect, inhibitory or stimulatory, on the development of the non-target organisms (Kabana and Curl 1980; Schuster and Schroder 1990; Schumacher and Poehling 2012). *Trichoderma* spp. is a commonly used soil antagonistic fungus that is extensively exploited for biological control of soil borne plant pathogens (Elad et al. 1990). In palm garden it is applied for the management of basal stem rot and wilt diseases in intercropped black pepper. For sustainable crop protection judicious integration of chemical insecticides as well as biocontrol agents is inevitable. Hence an attempt was made to study the compatibility of insecticide with soil antagonistic fungus *Trichoderma harzianum* CPCRI TR – 28 isolate.

Methodology

Maintenance of insect culture

Field collected third instar *Leucopholis burmeisteri* larvae were used for bioassay. The larvae maintained individually in containers containing field collected moistened soil at 25 ± 2 °C for one week to get acclimatized with laboratory condition. Tapioca bits were provided as food. The substrate and food were replaced regularly once in two days. Prestarved (for 24 h) uniform sized grubs were used for bioassay. The instars were fixed based on the size.

Soil bioassay

Dry and solarised soil substrate (mixture of soil, sand and cow dung in 1:1:1 ratio) was used for soil bioassay. The insecticides used were imidacloprid, bifenthrin, thiamethoxam, emamectin benzoate, fipronil and chlorpyriphos. The doses to be tested were fixed by range finding assay and bioassay was done by using 6 concentrations. Each concentrations replicated into four with five grubs per replication (total number of grubs used per dose is 20). A known quantity of insecticide solution was poured to definite quantity of soil and calculated the amount of insecticide present in μg/g soil in order to get in ppm level. The observation on mortality was taken after 48 h and 120 h of treatment. Per cent

mortality was corrected using Abbott (1925) formula and corrected values were subjected to probit analysis (Finney 1971) to obtain LC_{50} values. The relative toxicity values were calculated by taking the LC_{50} value of the least toxic insecticide (thiamethoxam) as standard.

Field evaluation of promising insecticides

A field experiment was conducted to evaluate the efficacy of insecticides against arecanut white grub at Markanja in Sullia taluk, Dakshina Kannada district of Karnataka during October, 2012 to Sept. 2014. The climate is humid tropic with an annual rainfall of 3788 mm and the temperatures ranges between 37.7 °C in summer to 12.7 °C in winter. The experiment was conducted in 0.18 ha area of five year old under planted arecanut planted in 2.7 m × 2.7 m spacing @ 1370 palms / ha in triangular system of planting. The garden was infested by root grub, *L. burmeisteri*. Experiment laid out in Randomized Complete Block Design (RCBD) with three blocks. Adjacent blocks were separated by trenches of 30 cm width and 30 cm depth. Pretreatment population was estimated by random sampling and number of grubs present /m^2 area were recorded. Blanket application of the insecticides was given during the second week of August using a rocker sprayer, as the first round application. A second round application was given in the root zone area alone during third week of October. Six palms were maintained for each treatment in each block and the treatment allocation was done by drenching in root zone. Two treatments were separated by an untreated row of palms. Chlorpyriphos and bifenthrin (@ 4 kg ai / ha, 2 kg a i/ ha and 1 kg ai / ha), imidacloprid (@ 0.24 kg ai / ha, 0.12 kg ai / ha and 0.06 kg ai / ha) were the treatments at three doses each. Observation was taken 45 days after treatment. The corrected per cent mortality worked out using Henderson and Tilton (1955) formula.

Insecticide residues in soil

Insecticide residues (bifenthrin and chlorpyriphos) present in soil were estimated on 0th, 10th, 30th and 65th day post second round insecticide treatment. Insecticide residues were extracted by column chromatography and cleaned up using florisil column, which was further concentrated by gentle puff of nitrogen gas to 2 ml for GC - MSD analysis. A gas chromatograph-mass spectrometer (GC - MSD) was used as a detection device (Agilent 5975 C series GC-MSD system) for pesticide residue. The GC was programmed with initial temperature of 40 °C that was increased to 300 °C at 9 °C / min and held for 3.5 min. The carrier gas (helium 99.999%) flow rate was in constant flow mode at 1.1 ml / min. 1 μl of sample was injected in splitless mode.

Bifenthrin was eluted at 18.15 min and total run time was 30 min / sample. Technical grade standard of bifenthrin of 0.5 ppm, 1 ppm 2 ppm, 10 ppm were prepared in HPLC grade acetone and injected on GC - MSD before running the sample. The detection limit of the system was 2 ppm. As in the case of bifenthrin, technical grade standard of chlorpyriphos (0.5 ppm, 1 ppm, 2 ppm, 10 ppm) was injected before running the sample. Retention time of chlorpyriphos was 14.4 min and detection limit was 2 ppm.

Compatibility of insecticides to *Trichoderma harzianum*

The effect of bifenthrin chlorpyriphos and imidacloprid (at three doses) on growth of *Trichoderma harzianum CPCRI* (TR 28 isolate) was evaluated by poison food technique (Vincent 1927). For this, bifenthrin poisoned medium (40 ppm, 20 ppm, 10 ppm and 0 ppm concentrations) was prepared by mixing acetone dilution of technical grade standard in melted PDA medium at 50 °C. Melted poisoned medium was poured into petridish of 90 mm diameter. For each treatment five replications were maintained. The poisoned medium was seeded with 7 mm diameter agar disc of *Trichoderma harzianum* at the centre. Observations on radial growth was taken at 24 h interval in all the four treatments till the colony growth covered the entire petridish. Per cent inhibition was found out using the formula I = ((C-T) / C) * 100. Data on colony growth were subjected to 3x4x5! ANOVA. Similarly, the experiment was repeated using chlorpyriphos poisoned medium in three doses (20 ppm, 10 ppm, 5 ppm and 0 ppm concentrations) and control in five replications and four observations were taken. The data were analyzed by 4x4x5! ANOVA. Effect of imidacloprid on *T. harzianum* was tested at 4 doses and along with control (8 ppm, 4 ppm, 2 ppm, 1 ppm and 0 ppm). Three observations were taken at 24 h interval and data were subjected to 3x5x5! ANOVA.

Results and discussion

Insecticides bioassay

Among the six insecticides tested, imidacloprid had the lowest LC_{50} (47.605 ppm) against third instar larvae of *L. burmeisteri* at 24 h post treatment, which was followed by chlorpyriphos (LC_{50} of 57.044 ppm). Bifenthrin (LC_{50} of 63.052 ppm) and fipronil (LC_{50} = 68.302 ppm) were the next best in order. Emamectin benzoate (LC_{50} of 204.653 ppm) and thiamethoxam (LC_{50} of 1237.11 ppm) were the least active insecticides against the third instar larvae of *L. burmeisteri*. Similar trends were observed both at 48 and 120 h of treatment (Table 1). Imidacloprid was the most toxic insecticide and thiamethoxam was the least toxic one. Relative toxicity of bifenthrin was 19.62, 16.17 and 16.71, respectively at 24, 48 and 120 h of treatment. Fipronil had a relative toxicity of 18.11, 10.71 and 12.57, respectively at 24, 48 and 120 h post treatment which remained almost the same. Relative toxicity of emamectin benzoate was 6.05, 3.77 and 3.96 at 24, 48 and 120 h of treatment correspondingly which was the second least toxic insecticide next to thiamethoxam. Although, thiamethoxam belongs to the same insecticide class that of imidacloprid, its toxicity was 25.99 fold less than imidacloprid at 24 h of treatment and 17.04 and 100.68 folds less at 48 and 120 h of treatment, respectively. Similar trend of toxicities was observed by Stamm et al. (2011) on western chinch bug *Blissus occiduus* (Hemiptera: Blissidae) nymphs, which had 20 fold less toxicity than imidacloprid. The differences in physical and chemical properties might have influenced its toxicity. For instance, thiamethoxam has greater water solubility (4.1 g / liter) than imidacloprid (0.61 g / liter) (Tomizawa and Casida 2005), suggesting thiamethoxam would be a more effective systemic insecticide. However, in the present study, toxicity was tested by spiking the soil with insecticide that may be responsible for contact and oral toxicity that are difficult to delineate. Chlorpyriphos is an OP compound which was the second most toxic compound to *L. burmeisteri* at all tested intervals. It was followed by Bifenthrin, a third generation synthetic pyrethroid known for its toxicity as contact insecticide (Elliot et al. 1978). Bifenthrin was 0.755, 0.949 and 0.759 times toxic than that of imidacloprid at 24 h, 48 h and 120 h of treatment. Subaharan et al. (2001) reported that toxicity of a synthetic pyrethroid, tefluthrin to *L. lepidophora* was more than that of chlorpyriphos to all larval instars. From the bioassays it is evident that, chlorpyriphos and bifenthrin are effective, following the imidacloprid against III instar larvae of *L. burmeisteri*. As per Oliver et al. (2007), chlorpyriphos immersion of balled and burlapped maple trees in nursery was efficient in cent per cent elimination of third instar larvae of Japanese beetle at doses of 0.03, 0.06, and 0.24 kg a.i. in 100 l / tree.

Evaluation of field efficacy of insecticides

Field efficacy of insecticides evaluated against *L. burmeisteri* revealed that all the insecticides tested were superior to control. Higher doses of insecticides (*ie*., imidacloprid at 0.24 kg a.i. / ha, bifenthrin at 4 kg a.i. / ha and chlorpyriphos at 4 kg a.i. / ha) were on par with bifenthrin at 2 kg a.i. / ha and chlorpyriphos at 2 kg a.i. / ha that caused >60% reduction in *L. burmeisteri* larval population. Imidacloprid @ 0.24, 0.12 and 0.06 kg a.i. / ha caused 75.8, 56.5 and 41.5% reduction in larval population at 45 days after treatment (Table 2).

Table 1 Acute toxicity of insecticides on III[rd] instar *L. burmeisteri* larvae

Insecticide	*LC_{50} in ppm at different time period			Order of relative efficacy
	24 h	48 h	120 h	
Imidacloprid	47.605 (25.99)	29.733 (17.04)	12.797 (22.01)	1
Chlorpyriphos	57.044 (21.69)	31.096 (16.29)	14.242 (19.77)	2
Bifenthrin	63.052 (19.62)	31.322 (16.17)	16.849 (16.71)	3
Fipronil	68.302 (18.11)	47.282 (10.71)	22.396 (12.57)	4
Emamectin benzoate	204.653 (06.05)	134.229 (03.77)	71.041 (03.96)	5
Thiamethoxam	1237.114 (01.00)	506.524 (01.00)	281.606 (01.00)	6

*Values in parantheses are relative toxicity of insecticide with respect to thiamethoxam

Table 2 Mean reduction in *L. burmeisteri* larval population in areca garden at Sullia post insecticide treatment during 2012–2014

Insecticides	Treatments	Dose (kg a.i. / ha)	*Reduction of population (%) in Oct. 2012	*Reduction of population (%) in Aug. 2013	*Reduction of population (%) Oct. 2013	*Reduction of population (%) Aug. 2014	Mean reduction (%)
Imidacloprid	T_1	0.06	35.05 (36.167) [c]	54.13 (47.48) [b]	44.74 (41.97) [bc]	31.94 (34.36) [e]	41.47
	T_2	0.12	46.73 (42.967)[b]	71.22 (57.677) [ab]	50.25 (45.16) [bc]	57.94 (49.64) [cd]	56.54
	T_3	0.24	71.55 (58.167) [a]	77.62 (66.44) [ab]	80.30 (68.48) [a]	73.89 (59.43) [abc]	75.84
Bifenthrin	T_4	1 .00	51.94 (46.133)[b]	61.19 (52.2818) [b]	48.67 (44.26) [bc]	55.56 (48.27) [d]	54.34
	T_5	2.00	69.93 (56.733) [a]	80.31 (68.18) [ab]	81.83 (69.26) [a]	64.97 (53.94) [abcd]	74.26
	T_6	4.00	72.49 (62.300) [a]	93.33 (77.45) [a]	84.92 (71.25) [a]	80.56 (63.97) [a]	82.83
Chlorpyriphos	T_7	1.00	53.57 (46.90) [b]	71.32 (58.10) [ab]	42.06 (40.31) [bc]	60.48 (51.18) [bcd]	61.79
	T_8	2.00	68.43 (55.866) [a]	75.04 (60.26) [ab]	70.63 (57.62) [ab]	62.50 (52.44) [bcd]	69.15
	T_9	4.00	77.09 (60.400) [a]	89.91 (71.63) [a]	91.88 (80.18) [a]	76.35 (61.52) [ab]	83.81
	T_{10}	Control	00.00[d]	00.00[c]	00.00 [d]	00.00[f]	00.00

* Figures in parentheses are angular transformed values. Means superscripted by same alphabets are not significantly different (at 5% level) by DMRT

Imidacloprid 200 SL (17.8% a.i.) @ 0.15 kg a.i. / ha is recommended to manage *L. Lepidophora* in arecanut, which caused 60–65% reduction of the population (Anonymous 2011). It acts as an agonist on post synaptic membrane in the nerves of insects (Mullins 1993). It is effective against early instar larvae as the neonate ones are susceptible when they come in contact or when ingested (Potter 1998). However, root zone protection alone was achieved by second round insecticide application in October and third instar larvae were randomly present in the interspaces, bunds, walls of the drainage channels etc.

Greater reduction in third instar population (84.85%) was accomplished by chlorpyriphos @ 4 kg a.i. / ha. However, it was on par with bifenthrin application @ 2 kg ai / ha. Bifenthrin was effective in controlling neonates and young root weevil larvae, *Diaprepes abbreviates* (Coleoptera: Curculionidae) (McCoy et al. 1995, 2001; Shapiro and McCoy 2000; Shapiro et al. 1999). Nielsen and Cowles (1998) and Cowles (2003) reported that prophylactic incorporation of bifenthrin at 5–25 ppm in potting media gave complete control of Japanese beetle and black vine weevil larvae for up to two years. National plant board of US recommends bifenthrin in nursery for quarantine treatment of Japanese beetles and imported fire ants. Whereas, Subaharan et al. (2001) reported that toxicity of a synthetic pyrethroid, tefluthrin to *L. lepidophora* was more than that of chlorpyriphos to all larval instars.

Insecticide residues in soil and safety to antagonistic fungus *T. harzianum* (CPCRI TR - 28 isolate)

Insecticide residues analyses indicated the persistence of bifenthrin in soil up to 30 days after application, while chlorpyriphos residue was below detectable level (BDL) for the same period of observation. On the day of application, 59.46 ppm of bifenthrin was present in soil. On 10th day of application it reduced to 7.29 ppm and further decreased to 2.59 ppm on the 30th day. However, it was beyond detection limit on 65th day of treatment. Similarly, 27.46 ppm of chlorpyriphos was recovered from soil on the day of application. Further it was reduced to 0.964 ppm on10^{th} day of treatment and it was below the detection limit on the 30th day of treatment (Fig. 1). Cowles (2003) reported that bifenthrin in potting media had prolonged half-life for three years in temperate climate, which provided prolonged control of soil dwelling pests. Bifenthrin binds with soil organic material very tightly and movement is restricted once it is applied. Positive attributes of bifenthrin are its contact toxicity, high lipophylic nature a long half-life (ranging from 105 to 147 days) (FMC Corporation 1983). According to Bhaskara et al. (1999) the rate of degradation of bifenthrin was adequately described by a first order kinetic model ($r^2 = 0.93 \pm 0.97$). However, chlorpyriphos degradation was biphasic, showing an initial faster degradation followed by a slower rate. Bifenthrin residue dissipation in pulse followed first order kinetics,

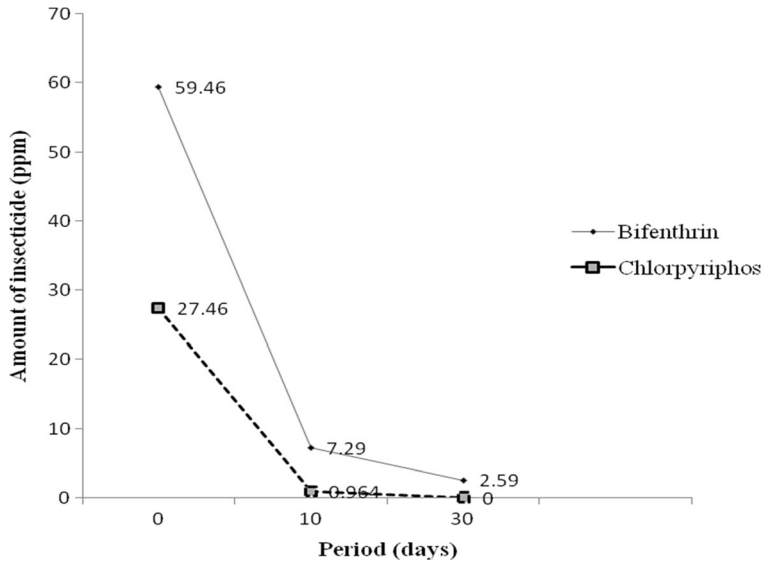

Fig. 1 Dissipation of insecticides in soil applied in arecanut garden

where as in soil the half- life was about 2–3 days (Mukerjee et al. 2010). Though bifenthrin dissipation was significantly high in planted soils than in unplanted ones, it persisted for longer period than chlorpyriphos (Xuan et al. 2011). Hence, blanket application of bifenthrin at 2 kg a.i. / ha by mixing with organic matter during second or third week of July, targeting first instar larvae which feed on organic matter.

Trichoderma harzianum TR- 28 isolate is a potential biocontrol agent of basal stem rot disease in palms and wilt diseases in pepper, which is a common intercrop in palm gardens of Kerala. Studies on effect of bifenthrin on soil antagonistic fungus, *T. harzianum* indicated that the growth was not affected by any of the tested) doses of bifenthrin at all tested time intervals. There was no significant difference between the growth of *T. harzianum* with respect to doses of bifenthrin (p value =0.4638) and also in interaction between dose and time period (p = 0.2203) (Table 3). Whereas, chlorpyriphos was safe only up to 5 ppm. As the dose increased, the colony growth rate decreased, there was a significant reduction in growth with increasing doses of chlorpyriphos (p value = < 0.0001) and also interaction effect between dose and time interval was strong (p value =0.0334). At 10 ppm concentration 5.72% mycelia growth was inhibited and at 20 ppm, it was 12.82% (Table 4). Stephen Jebakumar et al. (2000) reported that, chlorpyriphos at 10–40 ppm retarded radial growth of *T. harianum* to 50% at 24 h and 48 h but not at 72 h. Imidacloprid did not affect the colony growth at 1 ppm concentration. But at 2 ppm and higher doses, it inhibited the colony growth. Per cent inhibition was 22.55 at 8 ppm concentration, which was the tested highest dose (Table 5). Imidacloprid is reported to be toxic to non- targets viz., soil inhabiting arthropods, parasitoids of white grubs and honey bees. Rodriguez and Peck (2009) indicated that, soil application of imidacloprid at 0.37 kg a.i. / ha had a discernible impact on non-target arthropods and it suppressed the abundance of soil arthropods by 54–62%. Imidacloprid application in turf to manage *Popillia japonica* (Newman) reduced the parasitism by *Tiphia vernalis* Rohwer (Hymenoptera: Scoliidae) on over - wintered third - instar *P. japonica* larvae. When female *T. vernalis* were exposed to imidacloprid residues on turf cores under laboratory, its host finding ability was reduced (Rogers and Potter 2003). Moreover, honey bees exposed to sub

Table 3 Effect of bifenthrin on colony growth of *T.harzianum* CPCRI TR- 28 isolate

Insecticide	Dose (ppm)	*Colony diameter (in cm) after			#Mean
		24 h	48 h	72 h	
Bifenthrin	40	2.6	6.24	7.92	5.5867
	20	2.53	5.37	8.13	5.3467
	10	2.66	5.8	7.84	5.4333
	0	2.72	5.8	7.52	5.3467

* Mean of 5 observations

Means superscripted by same alphabets are not significantly different (at 5% level) by DMRT

Table 4 Effect of chlorpyriphos on colony growth of *T. harzianum* CPCRI TR- 28 isolate

Insecticide	Dose (ppm)	*Colony diameter (in cm) after				#Mean	Per cent inhibition
		24 h	48 h	72 h	96 h		
Chlorpyriphos	20	1.56	3.36	6.2	7.8	4.725[c]	12.82
	10	2.24	3.58	6.46	8.16	5.11[b]	5.72
	5	2.02	3.6	6.4	8.7	5.25[ab]	3.14
	0	2.48	3.8	7.2	8.2	5.42[a]	0

*Mean of 5observations

Means superscripted by same alphabets are not significantly different (at 5% level) by DMRT

lethal doses of imidacloprid exhibited colony collapse disorder (CCD) which was characterized by abandoning of hives by them (Lu et al. 2014) and increased level of pathogen, *Nosema* in their gut (Pettis et al. 2012, 2013).

Seasonal phenology of *Leucopholis* sp. indicates that, it has biennial life cycle with adult emergence coinciding with pre monsoon shower (June) which continues up to August (Abraham 1983; Abraham and Mohandas 1988; Mohan and Vidyasagar 1993). The success of chemical control relies on time and method of application. In the present study, first round insecticide treatment (as blanket application) was done in August, after subsiding south west monsoon, when the grubs were in second instar stage. A fewer number of older grubs might have survived in the field. When it attained third instar stage, it moved towards the root zone area and started feeding on palm roots. Due to second round root zone application of insecticides, root zone area protection alone was achieved by repelling the grubs. The grubs moved and survived in the interspaces, bunds and sides of the drainage channels. Rather than targeting third instar grubs, it would be more effective and economic to aim at the first instar stage itself. Moreover, late second and third instar grubs are susceptible to natural parasitism by dipteran and scoliid parasitoids (Channabasavanna 1954). Insecticide application during this stage will destroy the natural enemies. The establishment of third instar population can be avoided to a great extent by timing the first round treatment in such a way that, it coincides with the existence of I instar larval stage in the field. Incubation period of *Leucopholis* spp. egg is 14.7 days (Kumar 1997). By Middle of July, eggs hatch out and first instar larvae start feeding on soil organic matter and roots of grasses present in interspaces. They are highly susceptible and less amount of insecticide is sufficient to kill. Hence first round application of bifenthrin @ 2 kg a.i. / ha, by mixing with organic manure is advisable as blanket application in the month of July second / third week. Bifenthrin binds with soil organic material very tightly and movement is restricted once it is applied and persists for longer period in soil. At the same time it is safe to soil antagonistic fungus *Trichoderma* up to 40 ppm.

Table 5 Effect of imidacloprid on colony growth of *T. harzianum* CPCRI TR- 28 isolate

Insecticide	Dose (ppm)	*Colony diameter (in cm) after			#Mean	Per cent inhibition
		24 h	48 h	72 h		
Imidaclorpid	8	1.94	4.84	7.28	4.67[d]	22.55
	4	2.08	5.10	7.6	4.93[c]	18.24
	2	2.42	5.94	8.50	5.62[b]	06.79
	1	2.96	6.52	8.88	6.12[a]	-
	0	2.84	6.36	8.90	6.03[a]	-

*Mean of 5observations

Means superscripted by same alphabets are not significantly different (at 5% level) by DMRT

Being a synthetic pyrethroid, bifenthrin has high selective toxicity for insects compared to mammals, which is due to higher insect nerve sensitivity, lower mammalian skin absorption and more efficient mammalian hepatic metabolism. Hence the present study concluded that for the effective management of white grubs in palm garden, bifenthrin @ 2 kg ai/ ha can be used as an ideal alternative soil insecticide to chlorpyriphos as it also has a different mode of action, long persistence in soil, contact toxicity, high lipophylic property and being safe to biocontrol agent *T. harzianum*.

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