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Original article (Orijinal araştırma)

Toxicity and repellency of different insecticides to *Odontotermes obesus* (Rambur, 1842) (Blattodea: Termitidae: Macrotermitinae)[1]

Odontotermes obesus (Rambur, 1842) (Blattodea: Termitidae: Macrotermitinae)'a karşı farklı insektisitlerin zehir ve kaçırıcı özellikleri

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Abstract

Fungus-growing termites are important pests for buildings and agriculture in Asia and Africa. This study assessed four insecticides (fipronil 5% SC, imidacloprid 20 SL, thiamethoxam 25 WG and chlorfenapyr 360 SC) for their toxicity and repellency to the fungus-growing termite, *Odontotermes obesus* (Rambur, 1842) (Blattodea: Termitidae: Macrotermitinae). The study was conducted at Ghazi University, Dera Ghazi Khan, Pakistan from September-October, 2016 and was undertaken to identify effective termiticides along with their optimal concentrations for future use in baits and localized treatments. The chemicals assessed were differed significantly in their toxicity. Chlorfenapyr and thiamethoxam were more toxic and faster acting with lower LC_{50} and LT_{50} values than imidacloprid and fipronil. The four chemicals were statistically similar at each concentration. *Odontotermes obesus* was not repelled by 0-20 mg/l chlorfenapyr, 0-40 mg/l fipronil, 0-80 mg/l imidacloprid or 0-20 mg/l thiamethoxam. These results suggest that chlorfenapyr, imidacloprid and thiamethoxam may be used as soil termiticides, whereas fipronil can be used both as soil termiticide and in termite baiting programs.

Keywords: Fungus-growing termites, neurotoxins, soil treatment, termite baiting

Öz

Mantar yetiştiren termitler, Asya ve Afrika'daki tarımsal bölgelerin ve binaların önemli zararlılarıdır. Bu çalışmada, dört farklı insektisitin (fipronil 5% SC, imidacloprid 20 SL, thiamethoxam 25 WG ve chlorfenapyr 360 SC) mantar yetiştirici termit, *Odontotermes obesus* (Rambur, 1842) (Blattodea: Termitidae: Macrotermitinae) üzerindeki zehir ve kaçırıcı etkileri değerlendirilmiştir. Çalışma, yemlerin ve yerel uygulamaların gelecekteki kullanımları için etkili termisitlerin belirlenmesi ve bunların optimal dozlarının saptanması amacıyla Eylül-Ekim 2016'da Pakistan'ın Dera Ghazi Khan şehrindeki Ghazi Üniversitesi'nde yürütülmüştür. Değerlendirilen kimyasalların zehirliliklerinde önemli farklılıklar görülmüştür. Chlorfenapyr ve thiamethoxam daha düşük LC_{50} ve LT_{50} değerleri ile daha fazla zehirli ve daha etkili olurken; imidacloprid ve fipronil daha yüksek LC_{50} ve LT_{50} değerleri ile nispeten daha az zehirli ve daha az etkili olarak tespit edilmiştir. Dört kimyasal da istatistiksel olarak her bir dozda birbirleriyle eşit miktarda bulunmuştur. *Odontotermes obesus* için kaçırıcı olmayan veya çok az kaçırıcılık gösteren chlorfenapyrin 0-20 mg/l dozları, fipronilin 0-40 mg/l dozları, imidacloprid 0-80 mg/l dozları ve thiamethoxamın 0-20 mg/l dozlarında herhangi bir tercih edilmeme durumu görülmemiştir. Bu sonuçlar, Chlorfenapyr, imidacloprid ve thiamethoxam toprak termitisitleri olarak ve fipronilinin ise hem toprak termitisiti olarak hem de termit yem programlarında kullanılabileceğini göstermektedir.

Anahtar sözcükler: Mantar yetiştirici termitler, sinir zehirleri, toprak uygulaması, termit yemi

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Introduction

Termites are important pests of timber, wood products, trees and agricultural crops in tropical and subtropical and warm temperate areas of the world (Su & Scheffrahn, 2000; Scholz et al., 2010; Rouland-Lefèvre, 2011). Their infestation may be prevented or controlled by various methods in different countries (Howick & Staunton, 2017). Until the 1950s, this was mainly achieved by using wood preservatives, by chemical dusting and fumigation but all these control methods were mostly replaced by the application of soil termiticides with the advent of cyclodienes after World War II (Ware, 1999). The low cost and ease of use made soil termiticides a dominant management technique, especially in buildings (e.g., Findlay, 1962; Hickin, 1971). The cyclodienes provided effective control of termites for decades until their use was prohibited by the US Environmental Protection Agency (EPA) in the 1980s, mainly due to perceptions of their harmful effect on the environment and public health (Walker & Newton, 1998). After their suspension, cyclodienes were replaced by organophosphates and synthetic pyrethroids but these insecticides were not ideal as soil termiticides due to their short residual activity and their minimal impact on termite populations (Grace et al., 1993; Forschler, 1994). To address such problems, chitin synthesis inhibitors (CSIs, e.g., hexaflumuron) and newer neurotoxins (e.g., imidacloprid, fipronil) came into the market.

Current termite management methods for buildings include selective soil treatments (interior and/or exterior perimeter treatment or spot treatments) and baiting with slow-acting and non-repellent chemicals (Curl, 2004; Web, 2017; Iqbal & Evans, 2018). In these applications, foraging termites absorb a lethal dose when they pass through treated zones and/or consume a bait matrix, thereby transferring it to the colony members during trophallaxis and mutual grooming processes (Esenther & Gray, 1968; Su, 1994). The aim of both techniques is to use only small amounts of active ingredients with a consequent reduction in environmental contamination.

The scavenging termite, *Odontotermes obesus* (Rambur, 1842) (Blattodea: Termitidae: Macrotermitinae), is a fungus-growing higher termite. This species is highly problematic in agriculture, forestry and buildings (Akhtar & Kausar, 1991; Uys, 2002). There are some laboratory and field studies that have been conducted against this particular species involving different insecticides but with different objectives and methodologies (Kumawat, 2001; Ahmed et al., 2007; Bhagawati et al. 2017; Rasib et al. 2018). Previous studies aimed to determine if a repellent concentration(s) of a specific insecticides or plant extract for creating soil barrier treatment would keep the termites away from the structure or building thus killing only a small fraction of termite individuals. Consequently, the aim of this study was to assess the four insecticides, chlorfenapyr, imidacloprid, fipronil and thiamethoxam, for their suitability either as spot/soil barrier treatments or bait active ingredients against *O. obesus*.

The aim was to determine the optimal concentrations of a suitable insecticide with a delayed toxicity and non-repellency, this property is necessary for acquiring and transfer of insecticide either through feeding of bait or passing through a treated zone. The ultimate goal of this study was to identify the active ingredient and a concentration for use in the future for soil treatments or baiting programs against *O. obesus* and related pest termite species, and thereby provide a new environmentally benign tool for termite management.

Materials and Methods

Collection of *Odontotermes obesus*

Workers of *O. obesus* were collected from monitoring stations installed at the Airport Campus, Ghazi University Dera Ghazi Khan, Pakistan as a bait station preference experiment. Three types of aggregation stations were installed, viz., small (0.5 L), medium (3 L) and large stations (8 L) during May 2016. The stations were plastic containers filled with wood (*Bombax* sp.). The termites were collected weekly during September-October 2016 and were immediately placed in plastic boxes (14 × 8.5 × 6 cm) containing a moist paper towel. The boxes were brought to the laboratory (located at the Airport Campus, Ghazi University, Dera Ghazi Khan, Pakistan) with a great care to avoid injuries to individuals and workers then they were separated from the debris following the method of Gay et al. (1955) with little modification. The apparatus consists of a rectangular container (75 × 60 × 15 cm) that held a glass sheet (48 × 32 cm) with glass rods supporting it from below. The workers of *O. obesus* were released on the top of glass sheet and allowed to travel. The healthy traveling workers fell down into the rectangular container and were collected in glass Petri dishes for use in the experiments.

Insecticides

Fipronil (Regent 5% SC, Bayer CropScience, Leverkusen, Germany), imidacloprid (Confidor 20 SL, Bayer CropScience), chlorfenapyr (Squadron 360 SC, FMC United, Philadelphia, PA, USA), thiamethoxam (Actara 25 WG, Syngenta, Basel, Switzerland) were purchased from a commercial source for the toxicity and repellency studies.

Lethal concentration and lethal time estimation

No-choice feeding bioassays were performed to determine the trends in mortality of *O. obesus*. Five concentrations (causing between 0 and 100% mortality) were prepared by serial dilution for each of the insecticides. Two ml of concentration was spread on Whatman No. 1 filter paper which was placed on the base of a rectangular plastic box (14 × 8.5 × 6 cm). Filter paper moistened with the same quantity of distilled water was used as a control. Filter papers were dried in a fume hood for 24 h, then 150 healthy workers of at least the third instar plus 10 soldiers were introduced into the box. Each concentration was replicated four times. There were four control boxes for each insecticide. The boxes were then maintained at 25±2ºC and 70±5% RH, and a filter paper beneath the cover of the box was dampened with distilled water daily during treatment. Workers mortality was recorded after 12, 24, 36 and 48 h of exposure. Workers were considered dead when they showed no movement when probed with a fine brush. From this data, lethal time was also calculated.

Laboratory repellency test

Repellency of different concentrations of the insecticides to *O. obesus* was tested following the methods of Iqbal and Evans (2017). The following concentrations were prepared in distilled water: chlorfenapyr 0, 1.25, 2.5, 5, 10 and 20 mg/l; fipronil 0, 2.5, 5, 10, 20 and 40 mg/l; imidacloprid 0, 5, 10, 20, 40 and 80 mg/l, and thiamethoxam 0, 1.25, 2.5, 5, 10 and 20 mg/l.

For the repellency study, filter paper pieces (4.5 cm^2) were cut and placed on a glass sheet. Then 0.5 ml of each insecticide concentration was applied to the filter paper with a micropipette and replicated three times. The treated filter papers were allowed to dry overnight and were then randomly placed in rectangular plastic boxes (14 × 8.5 × 6 cm). Each box contained all the concentrations of a single insecticide. Then a total of 150 healthy workers and five soldiers of *O. obesus* were released into the middle of each plastic box with each receiving workers and soldiers from separate colonies. These plastic boxes were placed into dark conditions in a large plastic tray along with moist tissue paper. The workers were allowed to settle on any treated filter paper of their choices for 30 min and then examined at 30 min intervals for 150 min. The total numbers of workers that settled on each treated paper and those not on any paper were recorded by photographs taken at each observation.

Data analysis

The mortality data were corrected using Abbott's formula (Abbott, 1925), if the mortality rate in the control was more than 5%. Median lethal concentrations (LC_{50}) and lethal times (LT_{50}) were determined by probit analysis using SPSS software (IBM SPSS Statistics for Windows, Version 23.0, IBM Corp, Armonk, NY, USA).

LC_{50} and LT_{50} values were considered to be significantly different based on non-overlapping of 95% confidence limits. For the repellency experiment, the mean numbers of workers at each concentration of insecticide were calculated and subjected to Friedman's two-way nonparametric analysis of variance using Statistix 8.1 (Statistix, Tallahassee, FL, USA) for comparison.

Results and Discussion

Lethal concentration estimation (LC_{50})

Based on concentration lethal 50% of treated workers of *O. obesus* (LC_{50}) after 12, 24, 36 and 48 h, the toxicity of the insecticides differed significantly as indicated by non-overlapping 95% confidence limits. Chlorfenapyr was the most toxic insecticide with the lowest LC_{50} followed by thiamethoxam, fipronil and imidacloprid. The LC_{50} of chlorfenapyr were 11.2, 2.3 and 1.03 after 12, 24 and 36 h respectively. All workers were dead after 48 h at almost all of the concentrations of chlorfenapyr. The raw LC_{50} of imidacloprid after 24-48 h ranged from 6.9 to 39.8 mg/l (Table 1).

Table 1. Toxicity (LC_{50}) of four insecticides against workers of *Odontotermes obesus* at different exposure time (h) on treated filter paper

Insecticide	Time (h)	LC_{50}[a] (mg/l) (95% CL[b])*		df	χ^2 [c]	P	N[d]
Chlorfenapyr	12	11.2 (10.30-12.40)	A	3	3.20	0.35	2279
Fipronil	12	39.8 (30.10-57.60)	C	3	2.87	0.42	1752
Imidacloprid	12	39.0 (33.00-48.10)	C	2	3.39	0.18	1466
Thiamethoxam	12	19.4 (15.10-27.20)	B	3	5.06	0.16	1828
Chlorfenapyr	24	2.3 (2.00-2.60)	A	3	3.48	0.32	2279
Fipronil	24	6.8 (6.30-7.50)	C	3	4.49	0.21	1752
Imidacloprid	24	15.2 (13.90-16.60)	D	2	3.72	0.11	1466
Thiamethoxam	24	4.9 (4.10-5.80)	B	3	1.45	0.69	1828
Chlorfenapyr	36	1.03 (1.02-1.39)	A	3	3.89	0.27	2279
Fipronil	36	3.4 (2.70-4.10)	C	3	5.44	0.14	1752
Imidacloprid	36	9.7 (8.90-10.50)	D	2	3.70	0.15	1466
Thiamethoxam	36	2.0 (1.60-2.40)	B	3	0.98	0.81	1828
Chlorfenapyr	48	-	-	-	-	-	-
Fipronil	48	2.1 (1.50-2.60)	B	3	6.58	0.08	1752
Imidacloprid	48	6.9 (4.40-9.10)	C	2	4.96	0.08	1466
Thiamethoxam	48	1.3 (1.00-1.50)	A	3	0.42	0.93	1828

* Confidence limits followed by the same letter are overlapping so the LC_{50} are not statistically different;
[a] LC_{50}, concentration lethal to 50% of the population; [b] CL, confidence limits; [c] Chi-square; [d] number of workers exposed.

Lethal time estimation

The insecticides differed significantly in terms of LT_{50} values at all concentrations on the basis of non-overlapping confidence limits. The LT_{50} values decreased with the increase in concentrations of all insecticides with minimum values recorded for chlorfenapyr (24.2 h at 2.5 mg/l and 9.2 h at 20 mg/l) followed by thiamethoxam (31.1 h at 2.5 mg/l and 12.5 h at 20 mg/l), fipronil (42.9 h at 2.5 mg/l and 14.8 h at 20 mg/l) and imidacloprid (193 h at 2.5 mg/l and 20.0 h at 20 mg/l) (Table 2).

Table 2. Time mortality response (LT_{50}) of *Odontotermes obesus* to different insecticides

Insecticide	Concentration (mg/l)	LT_{50}[a] (h) (95% CL [b])*		df	χ^{2} [c]	P	N [d]
Chlorfenapyr	2.5	24.2 (23.1-25.5)	A	1	1.26	0.26	390
Fipronil	2.5	42.9 (34.4-66.7)	BC	2	5.27	0.07	283
Imidacloprid	2.5	193.0 (118.0-527.0)	D	2	3.31	0.19	255
Thiamethoxam	2.5	31.1 (28.2-34.6)	B	2	2.56	0.27	289
Chlorfenapyr	5	17.2 (16.2-18.1)	A	1	1.62	0.2	380
Fipronil	5	29.3 (27.6-31.3)	C	2	0.61	0.74	298
Imidacloprid	5	70.8 (59.4-91.4)	D	2	1.77	0.41	297
Thiamethoxam	5	21.2 (19.1-23.2)	B	2	0.17	0.92	299
Chlorfenapyr	10	13.0 (12.0-13.9)	A	1	0.78	0.37	415
Fipronil	10	20.4 (19.4-28.2)	C	2	2.09	0.35	290
Imidacloprid	10	35.4 (32.6-39.0)	D	2	3.09	0.21	343
Thiamethoxam	10	17.4 (15.7-19.0)	B	2	2.08	0.35	310
Chlorfenapyr	20	9.23 (8.24-10.1)	A	1	0.86	0.35	449
Fipronil	20	14.8 (13.9-15.6)	BC	2	0.14	0.92	330
Imidacloprid	20	20.0 (18.5-21.4)	D	2	2.72	0.32	301
Thiamethoxam	20	12.5 (10.7-14.0)	B	2	3.55	0.16	305

* Confidence limits followed by the same letter are overlapping so the LT_{50} are not statistically different;
[a] LT_{50}, time for 50% of the population to be killed; [b] CL, confidence limits; [c] Chi-square; [d] number of workers exposed.

Laboratory repellency study

Repellency of chlorfenapyr

Most workers of *O. obesus* had settled on different concentrations of chlorfenapyr after 60 min. The numbers of workers on different concentrations after 60, 90, 120 and 150 min were not significantly different (Friedman's statistic = 6.43; df = 6; P-value, $\chi2$ approximation = 0.376) (Figure 1a). However, after 60 min, maximum numbers of workers were found on filter paper pieces treated with 5 mg/l (27.88) and 20 mg/l (26.98). At 90, 120 and 150 min, maximum numbers of workers were observed on filter paper pieces treated with 0 mg/l (28.6), 20 mg/l (29.2) and 20 mg/l (32.3) of chlorfenapyr, respectively (Figure 2a).

Repellency of fipronil

The movement of workers in the treatment and control boxes was minimal after 60 min. The numbers of workers settled on 0-40 mg/l treated filter paper after 60, 90, 120 and 150 min were not statistically different (Friedman statistic = 4.07; df = 6; P-value, $\chi2$ approximation = 0.667) (Figure 1b). The maximum numbers of workers were recorded on 20 mg/l at 90 min (39.7) followed by 10 mg/l at 120 min (34.1) and 60 min (32.7), and 2.5 mg/l at 150 min (31.9) (Figure 2b).

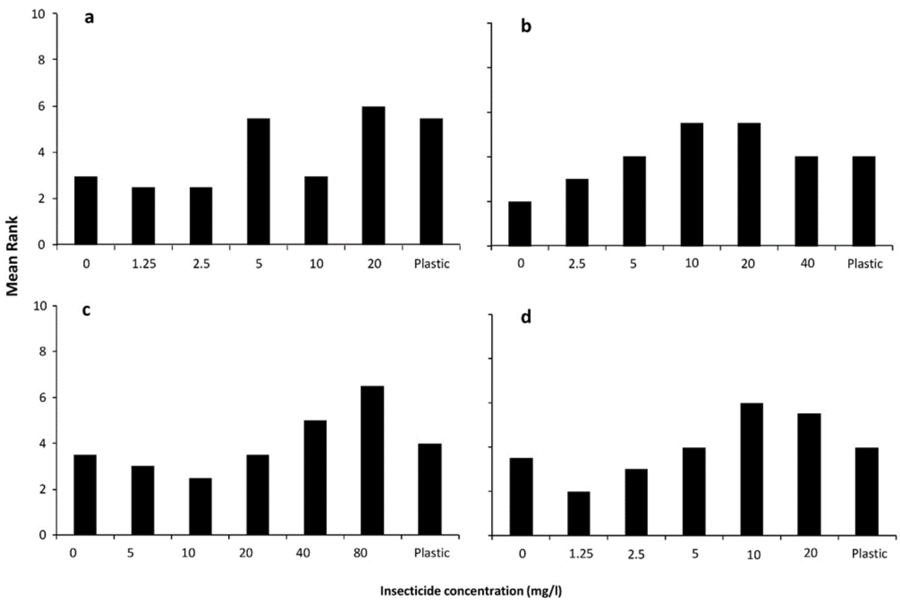

Figure 1. Friedman's test indicating mean ranks of numbers of workers of *Odontotermes obesus* on filter paper pieces treated with different concentrations of chlorfenapyr (a), fipronil (b), imidacloprid (c) and thiamethoxam (d) after 60, 90, 120 and 150 min of exposure in repellency tests. "Plastic" indicates termites not settling on any treated paper.

Repellency of imidacloprid

The workers of *O. obesus* became stable and there was little movement in the imidacloprid treated boxes after 60 min. The numbers of workers settled on different concentrations after 60, 90, 120 and 150 min and did not differ significantly (Friedman's statistic = 4.71; df = 6; P-value, χ2 approximation = 0.581) (Figure 1c). The repellency of *O. obesus* to different concentrations of imidacloprid showed maximum numbers on 80 mg/l followed by 5 mg/l, 40 mg/l after 60, 90, 120, and 150 min (Figure 2c).

Repellency of thiamethoxam

After 60 min the workers had settled in the thiamethoxam-treated boxes with no significant difference in numbers of workers settling on the filter paper treated with different concentrations of thiamethoxam (Friedman's statistic = 4.92; df = 6; P-value, χ2 approximation = 0.553) (Figure 1d). The maximum numbers of workers of *O. obesus* were observed at the 10 mg/l after 60 min, 120 min and 150 min. However, at 90 min, maximum workers were recorded on 0 mg/l (Figure 2d).

The efficacy of newer insecticides either in baits or in soil treatments is determined by their slow-acting and non-repellent properties (Su et al., 1987; Saran & Rust, 2007; Vargo & Parman, 2012). If the insecticide kills the foraging populations quickly the exposed workers will die in the tunnel before returning to their colony (Saran & Rust 2007). Whereas, slow-acting insecticides allow cross contamination from exposed to unexposed termites in the colony causing significant impact (Rust & Saran, 2006).

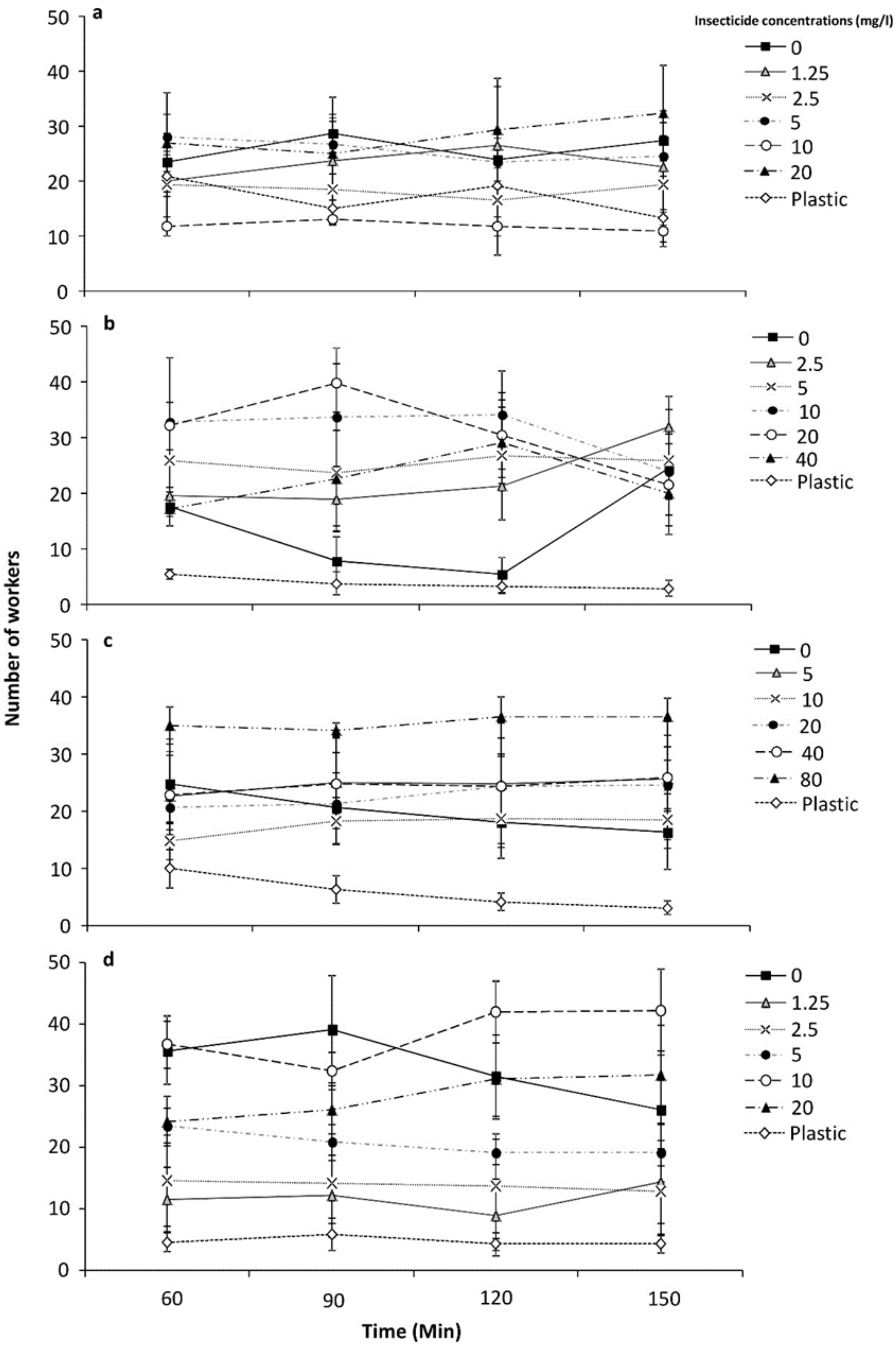

Figure 2. Mean (±SE) numbers of *Odontotermes obesus* workers on filter paper treated with chlorfenapyr (a), fipronil (b), imidacloprid (c) and thiamethoxam (d) over time in a laboratory repellency experiment. "Plastic" indicates termites not settling on any treated paper.

Although, four newer insecticides were evaluated against *O. obesus* to determine their slow-action and non-repellent properties under laboratory conditions, the use of termites in laboratory bioassays is not as straightforward as some researchers might like to think (Lenz, 2009). Reported here are preliminary findings showing that chlorfenapyr and thiamethoxam caused high mortalities and were fast-acting, whereas fipronil and imidacloprid were comparatively less toxic and slower-acting. Workers of *O. obesus* were not repelled by any concentration of chlorfenapyr, fipronil, imidacloprid or thiamethoxam.

All concentrations of chlorfenapyr (0-20 mg/l) were non-repellent to the workers of *O. obesus* but the mortality of the workers was very fast in comparison with the other three insecticides. Workers remained exposed to treated filter papers until the end of the experiment. However, in the two previous studies using *Reticulitermes flavipes* (Kollar, 1837) and *Reticulitermes hesperus* Banks, 1920 (Blattodea: Rhinotermitidae), chlorfenapyr was reported as being slow-acting and non-repellent. This could be due to differences in the methodology. Rust and Saran (2006) reported that chlorfenapyr was transferred from exposed to unexposed workers of *R. hesperus* but the mortality rate was dependent upon the concentration and exposure time, with faster action with increased concentration and exposure time (Shelton et al., 2006; Rust & Saran, 2006). The rapid death of exposed workers limits the horizontal transfer of chlorfenapyr. Moreover, it was suggested that a lethal concentration of chlorfenapyr is rapidly acquired by the workers due to non-repellency and that it negatively affects the foraging behavior of the exposed workers within 4 h (Rust & Saran, 2006). This will result in fewer workers returning to the colony for horizontal transfer, thus chlorfenapyr is not suitable for perimeter treatment and baiting to cause colony elimination at the tested concentrations.

The results presented here suggest that fipronil is slow-acting and non-repellent to *O. obesus* at 0-20 mg/l. These results are similar to many previous studies (Gautam et al., 2012; Li et al., 2016) and confirms that it has the potential to be transferred to unexposed workers due to non-repellent and delayed toxicity (Bagnères et al., 2009; Li et al., 2016). Moreover, Saran & Rust (2007) reported no changes in behavior of *R. hesperus* during the first 8 h in both the brief and continuous exposure studies. Henderson (2003) also showed similar results, indicating normal tunneling activity for up to 9 h after exposure to low concentrations of fipronil in soil. Remmen & Su (2005a) reported non-repellency of fipronil against *Coptotermes formosanus* Shiraki, 1909 (Blattodea: Rhinotermitidae) and *R. flavipes*. The efficacy of fipronil as a bait active ingredient has also been tested against three fungus-growing termitid termites, *Macrotermes gilvus* (Hagen, 1858) (Blattodea: Termitidae) in Singapore (Iqbal & Evans, 2018), *Microtermes mycophagus* (Desnoux, 1906) (Blattodea: Termitidae) in Pakistan (Iqbal & Saeed, 2013) and *Odontotermes formosanus* Holmgren, 1912 (Blattodea: Termitidae) in China (Huang et al., 2006), as well as one non-fungus-growing *Reticulitermes* species in the USA (Forschler & Jenkins, 2000). In all four field-baiting studies, fipronil baits successfully eliminated termite colonies. Based on all of these studies, fipronil can be used in soil treatments (both spot and barrier) as well as in baits, using even higher concentrations (20-40 mg/l) to eliminate termite colonies.

Imidacloprid has been found to be slow-acting and non-repellent to various termite species across the globe (Thorne & Breisch 2001; Luo, 2010; Manzoor et al., 2014). Although it may appear to be suitable for baiting on the basis of those assessments, in practice imidacloprid baits have failed to eliminate termite colonies (Iqbal & Evans, 2018). Imidacloprid has been reported to cause a cessation of termite feeding on baits, trophallaxis and mutual grooming (Boucias et al., 1996; Tomalski & Vargo, 2004; Iqbal & Evans, 2018). Feeding inhibition caused by imidacloprid could results in its slow action in termites. This is because imidacloprid has been reported to cause minimal toxicity when administered through acute dermal and inhalation routes as compared to oral administration (Sheets, 2010). Several other studies have reported confused and erratic movement of workers after exposure to this chemical (Thorne & Breisch, 2001; Quarcoo et al., 2010, 2012). In other studies, workers became immobile or showed decreased movement when exposed to even small quantities of imidacloprid (Henderson, 2003; Luo, 2010). Similar patterns were also observed in imidacloprid-treated boxes. The reduced bait-feeding and the negative impact of imidacloprid on termite movement make it unsuitable for termite baiting. However, it could be an effective soil treatment at 40-80 mg/l and provide residual control for 5-10 years against a wide range of termite species (Reid et al., 2002).

Based on the results present here, thiamethoxam was faster-acting than chlorfenapyr but showed non-repellency to the workers of *O. obesus.* In previous studies, thiamethoxam caused fast mortality of *Coptotermes gestroi* (Wasmann, 1896) (Blattodea: Rhinotermitidae) workers at 50 mg/l while it showed delayed transfer toxicity 0.25-25 mg/l at higher concentrations in a laboratory trial (Acda, 2014).

The results presented here are similar to the studies of Remmen & Su (2005a, b) who reported thiamethoxam as fast-acting active ingredient than fipronil against *C. formosanus* and *R. flavipes* with no repellency to the workers. Although this was not tested in the present study, it is suspected that thiamethoxam, being a neonicotinoid insecticide, would also affect the foraging activity of workers in the field, resulting in an inability of sufficient workers to return back to the colony for horizontal transfer of this termiticide to other workers. Like imidacloprid, thiamethoxam has also been reported to reduce feeding intensity in higher termites (Delgarde & Lefevre, 2002), making it unsuitable for use in termite baits. However, it can be used effectively as a soil barrier treatment.

This study indicates that fipronil and imidacloprid are slow-acting and non-repellent to *O. obesus*, whereas, chlorfenapyr and thiamethoxam are fast-acting and non-repellent. Based on previous studies in Pakistan and other countries, it is concluded that fipronil can be effectively used in baits and soil treatments for *O. obesus* and other fungus-growing termites. However, chlorfenapyr, thiamethoxam and imidacloprid should only be used as soil termiticides that will kill termites through direct contact. However, further laboratory and field studies are required to test the suitability of some other concentrations of these active ingredients for baiting as were reported by Aihetasham & Iqbal (2012) for wood feeding preference to *Microcerotermes championi* (Snyder, 1933) (Blattodea: Termitidae).

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