ACQUISITION and TRANSFER of a LAMBDA-CYHALOTHRIN MICROCAPSULE FORMULATION by *BLATTELLA GERMANICA*

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Abstract The processes by which insects acquire toxic doses of the microencapsulated formulation of lambda-cyhalothrin (Demand CS) were studied using the German cockroach, *Blattella germanica* (L.). Cockroaches exposed to treated substrates acquired toxic doses of the insecticide rapidly, and HPLC analysis of cuticular washes of *B. germanica* established a linear relationship between exposure time and dose acquired during exposures of up to 4 minutes. These tests also showed that the pick-up process was highly efficient, with 3 times the LC_{90} dose acquired by cockroaches during <1 second contact with a treated unglazed tile. The mechanical attachment of capsules to insects was weaker than expected, at least for a proportion of capsules. Treated cockroaches exposed to untreated surfaces lost capsules, although the relationship between loss of insecticide and time was not strongly linear. The weak attachment of capsules proved advantageous and accounted for the observed transfer of lethal doses between insects exposed to a residual application of lambda-cyhalothrin and unexposed insects. The transfer of insecticide to untreated cockroaches was shown to occur as a result of direct physical contact and not from secondary pick-up of capsules lost to surfaces from contaminated insects. The effect of insecticide transfer on expellency was determined using computer-aided techniques. No immediate flushing effect was recorded when cockroaches contaminated with lambda-cyhalothrin were introduced into an arena containing a harbourage with untreated cockroaches within. However, there was an overall excitatory effect over several hours following the introduction of the treated cockroach and during this period transfer of lethal doses of lambda-cyhalothrin occurred.

Key Words Cockroach, behaviour, insecticide, flushing

INTRODUCTION

The German cockroach, *Blattella germanica* (L.) is a pest of domestic and commercial environments in almost all parts of the world. Strategies for its control principally consist of the placement of toxic baits and/or the use of residual applications of insecticides. Insecticidal baits can provide control of insects contacting the toxicant and also conspecifics that have not encountered the original source of toxicant via an inter-insect transfer process. This transfer process can take a number of forms, including contact (Buczkowski et al., 2001), trophalaxis (Schoknecht, et al., 1994), cannibalism (Gahlhoff et al., 1999), necrophagy (Le Patourel, 2000), and coprophagy (Silverman et al., 1991). It is amongst the social insects that these processes are most effective in distributing toxicant amongst inaccessible insects, although redistribution of lethal levels of toxicant has been demonstrated in gregarious insects such a cockroaches.

Transfer and redistribution amongst untreated insects of toxic doses of insecticide from residual applications has been studied in much less detail. However, toxicant transfer effects have been demonstrated to various degrees by Schneider and Bennett (1985), Adams et al. (1992), Le Patourel (1996), and Wege et al. (1999).

Promising transfer effects were demonstrated against both cockroaches and ants with a microcapsule formulation of lambda-cyhalothrin (Demand CS), which has been developed specifically for the control of public health and urban insect pests. Preliminary assays indicated that the pick-up of lambda-cyhalothrin microcapsules from inert surfaces by cockroaches was an efficient process (Wege et al., 1999), and that further investigation of the mechanics and efficiency of this process was clearly warranted to enable improvement of formulation design and to optimise treatment practices. This paper reports assays conducted to examine microcapsule pick-up, loss, and redistribution in relation to cockroach behaviour and control. Work was also conducted to determine whether transfer of insecticide could result in a flushing effect, which could enhance the insecticidal effect of the initial residual application.

MATERIALS and METHODS

Cockroaches

All bioassays were undertaken using adult male *Blattella germanica* taken from an established culture maintained under insecticide-free conditions for over 15 years at Jealott's Hill. The cockroaches were provided with grassmeal pellets and water *ad libitum* and maintained at 28°C.

Topical Application

Insecticide treatments were prepared by dissolving technical grade lambda-cyhalothrin in acetone and diluting to the required concentrations. Cockroaches were collected and held for 24 hours in plastic cups. Prior to treatment, insects were anaesthetised and placed onto a CO_2 table to assist with the insecticide application. Cockroaches were treated by applying 1ml of insecticide solution to the pronotum of each insect using a micro-applicator (Hamilton repeating dispenser). Insects were assessed for mortality (as measured by a complete lack of response to any stimulus) after 24 hours. Each treatment consisted of 5 replicates each of 10 insects. Data were subject to logit analysis using Syngenta proprietary software, ACSAP Win.

Tarsal Contact Bioassays

Squares (15 x 15 cm) of unglazed ceramic tile (Great Mills Ltd.) and cement were sprayed using a Potter Tower with Demand CS diluted to give surface concentrations in the range 0.5-2.0 mg ai/m^2. Deposits were allowed to dry for 24 hours prior to bioassays. Cockroaches were collected and held for 24 hours in plastic cups with rims treated with polytetrafluoroethylene (PTFE) emulsion (Fluon®) to prevent insect escape and covered with a fine net. Each cup was inverted onto an untreated surface with two vinyl tapes connecting it to a treated surface so that the cup rim was held slightly above either surface. The cup was then moved across to the treated surface so that the cockroaches maintained a normal posture during the transfer. After 30 seconds the cup was moved back to the untreated surface, a card inserted beneath the rim, and the cup turned upright to retain the treated cockroaches. The net was replaced and the cockroaches held for 24 hours at 28°C with access to water prior to mortality determination. Two or three replicates each of ten insects were tested at each of five concentrations. Data were subject to logit analysis using Syngenta proprietary software.

Pickup of Microcapsules from Treated Surfaces

Cockroaches were allowed to walk freely onto unglazed tiles treated with lambda-cyhalothrin at either 4 or 40 mg ai/m^2 within circular arenas (11 cm diameter) with the interior wall treated with PTFE emulsion. Following timed exposures, cockroaches were removed using a vacuum probe applied to the ventral thorax and transferred to a vial containing methanol (1 ml). Cockroaches were removed after 48 hours and rinsed with a further 1ml methanol. 200 ml of the wash solution were taken out and blown to dryness using a Techne sample concentrator then resuspended in 200 ml hexane. Samples were analysed for lambda-cyhalothrin content by capillary gas-liquid chromatography with mass selective detection (GC-MSD).

Loss of Microcapsules from Treated Surfaces

To assess the loss of capsules from an insect, cockroaches were exposed to a treated unglazed ceramic tile for 60 seconds, after which time cockroaches were transferred to an untreated surface for a timed interval of up to 10 minutes. The insect was then removed using a vacuum probe as previously described, anaesthetised by dipping into a jar flushed with CO_2, placed on its back under a microscope and the legs cut between coxa and femur. Legs and body were separately transferred to methanol (2 ml) for GC analysis as described above.

Effect of Concentration on Transfer of Insecticide

Groups of 5 cockroaches were acclimatised for 2 hours in a 7.5 cm diameter glass dish with walls treated with PTFE emulsion and containing a small moistened plug of cotton wool. A further male cockroach was collected from the culture and immediately introduced onto an unglazed ceramic tile treated with lambda-cyhalothrin at one of three rates. Exposure times up to 120 seconds were used. This cockroach was then removed from the surface by firmly grasping the antenna with forceps and transferred to the resting group. Mortality of exposed and unexposed insects was assessed at 24 hours. Each treatment (surface concentration and exposure time) was replicated ten times.

Effect of Group Size on Transfer of Insecticide

Plastic arenas (20 x 13.5 x 6.5 cm) were prepared by treating the walls with PTFE emulsion to confine the insects to the arena floor. Groups of adult male cockroaches were counted into each arena and allowed to acclimatise for 1 hour. After this time, a single cockroach was removed and exposed for 30 seconds to an unglazed tile treated at 15 mg ai/m^2. After exposure, the cockroach was immediately placed back into its group. Insects were assessed after 1 hour for knockdown; as measured by the inability of the insect to right itself when stimulated with a seeker, and mortality after 24 hours. Ten replicates each were set up to contain 5, 10, 20, or 40 cockroaches.

Route of Insecticide Transfer

Transfer of a toxic effect could occur through physical contact between insects or through secondary pick-up from surfaces of capsules lost from a contaminated cockroach. To test this hypothesis, plastic arenas (37 x 24 x 10 cm) were prepared by treating the walls with PTFE emulsion to prevent insect escape. A single cockroach was removed from the culture and exposed for 30 seconds to an unglazed tile treated with lambda-cyhalothrin at 15 mg ai/m^2. After treatment, the cockroach was immediately placed into an arena and allowed to move freely. Once the insect had become knocked-down it was removed. A group of nine untreated male cockroaches were then added to the same arena. Insects were assessed for knockdown at 1 hour and mortality at 24 hours after introduction into the arena. A control treatment consisted of a single cockroach exposed to the treated tile and then added to a group of ten males acclimatised in an identical arena. Knockdown was assessed after one hour and mortality after 24 hours. Each treatment was replicated 6 times.

The Effect of Insecticide Transfer on Group Behaviour

The inside wall of a plastic arena (37 x 24 x 10 cm) was treated with PTFE to confine insects to the floor. A small harbourage consisting of two plywood plaques (10 x 5 cm) separated by a 0.4cm gap was placed adjacent to the inside wall of the arena. Ten adult male *B. germanica* were introduced and allowed to acclimatise for one hour. After acclimatisation, a single cockroach was removed and exposed to a residual deposit of lambda-cyhalothrin at 15 mg ai/m^2 as described above and replaced into the arena. Movement in the arena was continually monitored through the use of a video analysis system. This comprised of an analogue 3CCD video camera the output of which was converted to a digital signal by a grabber board housed in a PC. Proprietary computer software developed to perform motion analysis was used to quantify movement within the whole arena. Assessment of all motion in the test arena was made every 5 seconds in order to generate an activity profile over the 24-hour test period. The mean movement level over each 30-minute period was subsequently calculated and the values from each of the 7 replicates were averaged. A further treatment was conducted without a harbourage present in the arena, but only knockdown and mortality assessments at 1 and 24 hours were conducted.

RESULTS

Topical Application and Tarsal Contact Bioassays

LC_{50} and LC_{90} values of 0.0074 (0.0066-0.0082) and 0.0182 (0.0155-0.0229) mg/insect were obtained 24 hours after topical application of lambda-cyhalothrin to adult male *B. germanica.* The efficacy of residual applications of lambda-cyhalothrin on two surfaces against *B. germanica* is presented in Table 1. The product exhibited high levels of toxicity to German cockroaches, with an LC_{90} value of 0.7 mg ai/m^2 on unglazed tiles, a model porous surface. The efficacy of the product on cement was approximately three-fold less than on unglazed tile, reflecting the difference in porosity and topography of this surface.

Pick-up of Microcapsules from Treated Surfaces

The pick-up of lambda-cyhalothrin by *B. germanica* from unglazed tiles treated with lambda-cyhalothrin is presented in Figures 1 and 2. On tiles treated at 4 mg ai/m^2 (Figure 1) there was a weak linear relationship between exposure time and dose acquired by the cockroaches (R^2 =

Table 1. Efficacy of Demand CS against adult male *B. germanica* exposed to various treated surfaces for 30 seconds

Surface	LC50 (mg ai/m^2)	95% CI (mg ai/m^2)	LC90 (mg ai/m^2)	95% CI (mg ai/m^2)	Slope	p
Unglazed ceramic tile	0.4	0.34-0.47	0.70	0.58-0.91	5.29	0.34
Cement	1.52	1.22-1.7	2.07	1.84-2.71	9.37	0.07

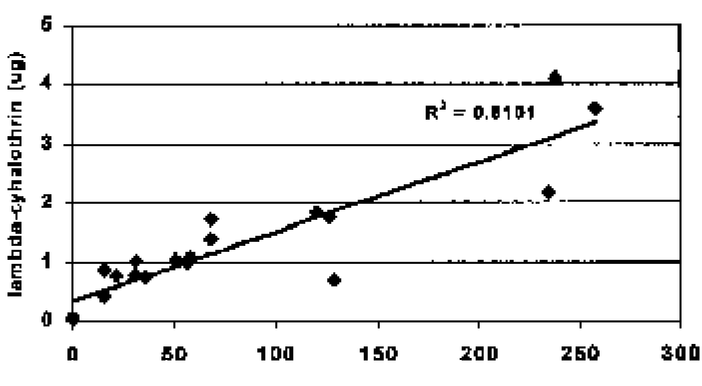

Figure 1. Pick-up of lambda-cyhalothrin by B. germanica *from an unglazed tile treated with Demand CS at 40mg ai/m^2.*

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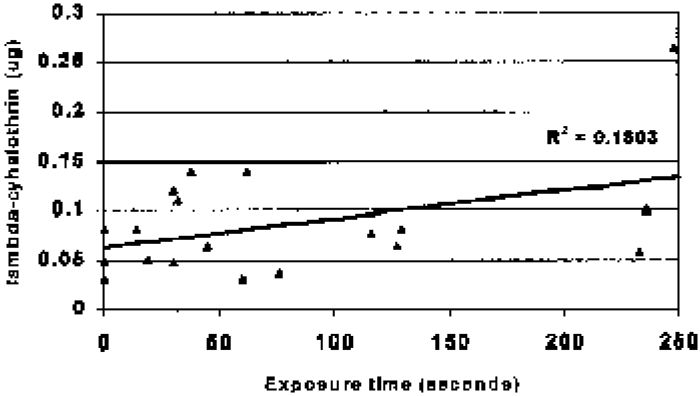

Figure 2. Pick-up of lambda-cyhalothrin by B. germanica *from an unglazed tile treated with Demand CS at 4mg ai/m²*.

0.18). Initial transient contact (<1 second) with the treated tile allowed insects to pick-up approximately 0.05 mg of lambda-cyhalothrin. Subsequently the rate of pick-up was slow, with a maximum of approximately 0.13 mg acquired after 4 minutes' exposure. At the higher rate of 40 mg ai/ m^2 (Figure 2) the initial dose acquired through transient contact (0.06 mg) was similar to that obtained at 4 mg ai/m^2. However, at the higher dose, there was a more convincing linear relationship between exposure time and dose acquired (R^2 = 0.81). The rate of acquisition of lambda-cyhalothrin was also higher at 40mg ai/m^2, with cockroaches picking up over 3 mg after 4 minutes exposure. Over 90% of the lambda-cyhalothrin acquired by the cockroaches was found on the legs (Figure 3), with only low levels of lambda-cyhalothrin found on the body.

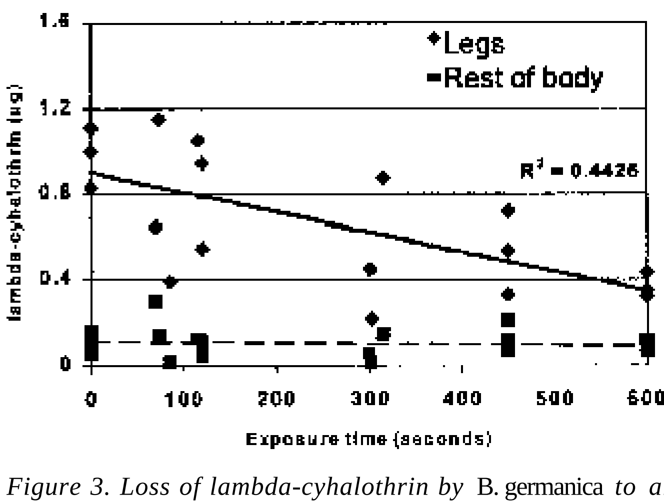

Figure 3. Loss of lambda-cyhalothrin by B. germanica *to an untreated surface following exposure to Demand CS.*

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Loss of Microcapsules From Treated Insects

The rate of loss of lambda-cyhalothrin from cockroaches placed onto an untreated unglazed tile after previous exposure to a tile treated with lambda-cyhalothrin is presented in Figure 3. Lambda-cyhalothrin was lost from cockroach legs over the duration of the test. The rate of loss was nominally linear (R^2 = 0.44) and, with only 0.05 mg lost after 10 minutes exposure to the untreated tile, was much slower than the rate of acquisition of the insecticide. Levels of lambda-cyhalothrin on the cockroach body remained low but did not appear to decline over the duration of the experiment. This result suggests that uptake of lambda-cyhalothrin into the insect was, by comparison, insignificant over this time period.

Effect of Concentration on Transfer of Insecticide

The effect of exposure time and concentration of lambda-cyhalothrin on the transfer of a toxic dose between exposed and untreated cockroaches is presented in Figure 4. The transfer of a toxic dose of lambda-cyhalothrin between cockroaches exposed to a residual application of lambda-cyhalothrin and previously unexposed insects was both dependent on rate and exposure time. Cockroaches exposed to the lowest rate of 1mg ai/m^2 did not induce significant levels of mortality amongst five untreated cockroaches regardless of the duration of exposure to the treated surface. Cockroaches required 60 seconds exposure to 4 mg ai/m^2 in order to acquire sufficient lambda-cyhalothrin to induce significant mortality amongst untreated insects, whereas *B. germanica* exposed to the highest rate of 10 mg ai/m^2 induced 100% mortality after only 15 seconds exposure to the treated surface.

Effect of Group Size on Transfer of Insecticide

The effect of cockroach numbers on the transfer of a toxic dose of lambda-cyhalothrin is presented in Table 2. The proportion of a cockroach population controlled by secondary transfer of lambda-cyhalothrin was related to the size of the population into which the contaminated cockroach was introduced. One contaminated cockroach was able to cause over 90% mortality amongst populations of 5, 10, or 20 cockroaches. When the population was increased to 40 cockroaches, the proportion killed was reduced to 41%. The transfer effect was rapid, with significant mortality observed after 1 hour amongst the smaller populations of 5 and 10 insects.

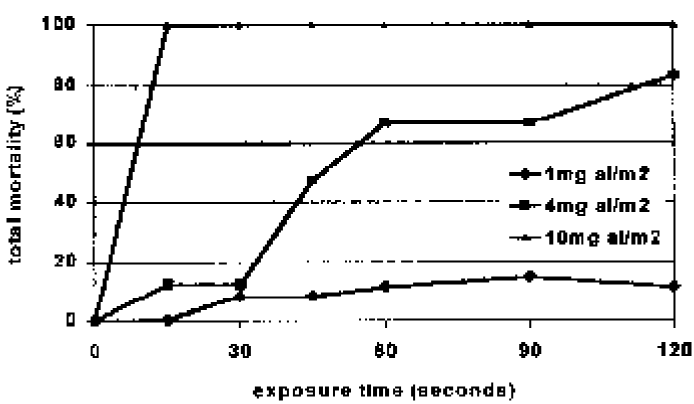

Figure 4. Effect of concentration of Demand CS and exposure time on transfer of toxic doses of lambda-cyhalothrin between treated and untreated B. germanica.

Table 2. Mortality of untreated *B. germanica* following introduction of a single cockroach previously exposed for 30 seconds to a residual treatment of Demand CS at 15mg ai/m² on an unglazed ceramic tile

Ratio	% mortality 1HAT (±S.E.M)	24HAT (±S.E.M)
1:5	48 (6.1)	100
1:10	43 (8.9)	97 (1.5)
1:20	24 (4.4)	92 (3.6)
1:40	5 (1.1)	41 (9.3)

Route of Insecticide Transfer

Table 3 shows the effects of transfer of lambda-cyhalothrin to cockroaches introduced into an arena after post-knockdown removal of a contaminated cockroach compared with the effect on a similar cohort of cockroaches into which a contaminated cockroach was introduced. No significant mortality was observed amongst *B. germanica* exposed to an arena from which a contaminated cockroach had been removed after knockdown. In contrast, introduction of a contaminated cockroach to an arena containing an untreated cohort of insects resulted in 90% mortality after 24 hours.

The Effect of Insecticide Transfer on Group Behaviour

The effect of including a harbourage in the arena on the transfer of a toxic dose between cockroaches is presented in Table 4. With the inclusion of a harbourage in the arena, the transfer

Table 3. Total mortality of adult male *B. germanica* introduced into an arena before or after the introduction of a cockroach contaminated with Demand CS by exposure to a residual application of 15mg ai/m² on an unglazed ceramic tile

Timing of addition of contaminated cockroach	% mortality 1 hour (±S.E.M)	24 hours ±S.E.M)
Added to untreated cohort	66.6 (14.9)	90 (8.1)
Removed post-knock-down before introduction of untreated cohort	0	3.3 (2.1)

Table 4. The effect of the presence of a harbourage on the mortality of untreated *B. germanica* following introduction of a single cockroach previously exposed for 30 seconds to a residual treatment of Demand CS at 15mg ai/m² on an unglazed ceramic tile

Ratio	% mortality 1HAT (±S.E.M)	24HAT (±S.E.M)
Harbourage	4 (2.02)	40 (9.2)
No Harbourage	73 (9.3)	100

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of a toxic dose between a contaminated cockroach and untreated conspecifics was both delayed and reduced compared to the effect amongst insects without a harbourage. Negligible knockdown was apparent after one hour in the presence of a harbourage compared with over 70% mortality in the arenas without a harbourage. Mortality levels increased over time such that complete mortality was obtained in arenas without a harbourage at 24 hours, but less than 50% kill was obtained in the presence of a harbourage.

The activity within an arena following the introduction of a single cockroach previously exposed for 30 seconds to a residual treatment of lambda-cyhalothrin at 15 mg ai/m^2 on an unglazed ceramic tile is presented in Figure 5. Low levels of activity were observed after the introduction of a single untreated cockroach after an initial period of acclimatisation. For at least 9 hours after the introduction, cockroaches remained in the harbourage. Further monitoring recorded low levels of movement corresponding to foraging activity throughout the remainder of the bioassay. In contrast to this, the introduction of a treated cockroach caused increased levels of activity within the arena demonstrating an overall excitatory effect compared to the control. The large erratic changes in amplitude are indicative of the rapid movement of insects.

The location and mortality of foraging insects was determined by viewing digital images (Figure 6). Control insects initially remained within the harbourage with limited foraging only occurring later in the bioassay, confirming the movement monitoring results (Figure 5). Introduction of a treated cockroach caused the number of insects remaining in the harbourage to decrease over time, such that after 24 hours, 48% had been expelled from the harbourage.

DISCUSSION

The topical application bioassay confirmed the potent insecticidal activity of lambda-cyhalothrin against *B. germanica*. The LC_{90} value of 18 ng/insect is consistent with results obtained by Valles et al. (1998) and Lee (1995). The microcapsule formulation of this active ingredient, lambda-cyhalothrin, also proved highly efficacious in surface residual tarsal contact bioassays with an LC_{90} of 0.7 mg ai/m^2. This dose is markedly lower than typical label rates of 15-30 mg ai/m^2 (0.03–0.06%). This margin of difference is required in practice in order to ensure a persistent insecticidal effect and to overcome strong adhesion or capsule availability associated with surfaces such as concrete.

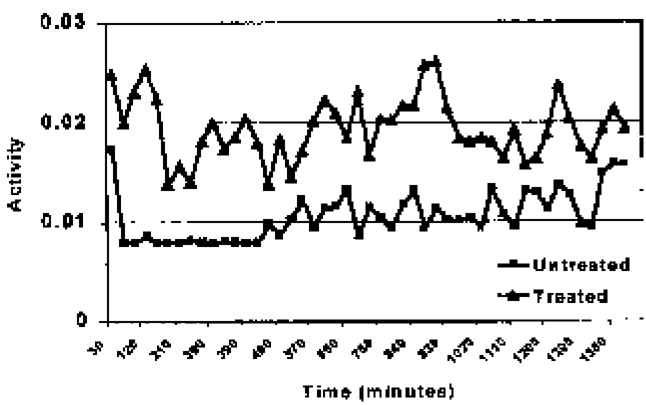

Figure 5. Effect of introducing an adult male B. germanica *treated with Demand CS on the mean activity of a group conspecifics within a bioassay arena.*

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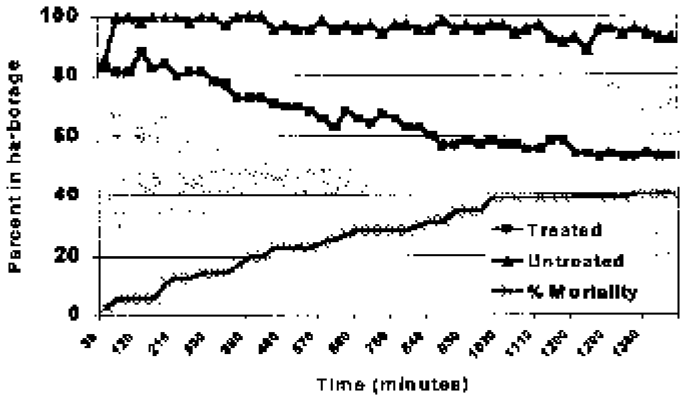

Figure 6. Effect of introducing an adult male B. germanica *treated with Demand CS on the proportion of conspecifics remaining within a harborage.*

The toxic effect of surface residual applications of lambda-cyhalothrin on cockroaches results from pick-up of intact capsules. This probably occurs in a manner similar to that described by Zhai and Robinson (1994) in that capsules are dislodged from the substrate by the spines and scales on the tarsal pads on to which they subsequently adhere. The waxy cuticle allows diffusion of the lipophillic capsule contents to occur, initiating uptake of the insecticide by the insect (Wege et al., 1999). The majority (90%) of lambda-cyhalothrin detected on *B. germanica* exposed to surfaces treated with lambda-cyhalothrin was found on the legs, confirming their role in the insecticide transfer process. The low residue levels found on the body indicated that redistribution of insecticide through grooming behaviour, such as reported by Scott (1990), was not significant.

The transfer of microcapsules from unglazed treated tiles was both highly efficient and extremely fast, presumably because at the time of first contact all pick-up sites on the tarsi are free. A dose of lambda-cyhalothrin 3 fold greater than the LC_{90} dose was acquired by cockroaches with less than one second of contact with surfaces treated with high (40 mg ai/m^2) or low (4 mg ai/m^2) doses of lambda-cyhalothrin. Subsequent acquisition of lambda-cyhalothrin was dependent on both dose and exposure time. With an exposure time of one minute on a tile treated with 40 mg ai/m^2, over 50 times the LC_{90} dose (approximately 1 µg) had been picked up. This is equivalent to approximately 2000 capsules and is broadly consistent with preliminary physical quantification of lambda-cyhalothrin capsule pick-up reported by Wege et al. (1999). A possible consequence of the efficiency of this pick-up process, which allows excessive doses of lambda-cyhalothrin to be acquired by cockroaches, may be manifest in superior control of resistant strains compared to an EC formulation (Koehler and Patterson, 1998).

Acquisition of lambda-cyhalothrin from surfaces treated with lambda-cyhalothrin continued to occur for the duration of the experiments (4 minutes), indicating that the saturation of pick-up sites reported by Gowers and Le Patourel (1984) for stored product insects or by Lewis and Hughes (1957) for *Phormia* is unlikely to ever limit the acquisition of lethal doses of lambda-cyhalothrin by *B. germanica*. This is impressive given the relatively small surface area of a cockroach leg (0.018 mm^2) in contact with the surface (Zhai and Robinson, 1994).

Detachment of particulate insecticide residues from the exterior of insects was reported by Barlow and Hadaway (1952). Our assays also found that the attachment of capsules to the cockroach was not strong, at least for a proportion of the capsules, and insects placed on untreated surfaces lost lambda-cyhalothrin at a rate of 0.05 µg/minute. This was markedly slower than the rate of acquisition of the compound from a treated surface, but demonstrated that a proportion of the cuticular deposits of lambda-cyhalothrin were dislodgable from cockroaches. Microcapsules detached in this manner were theoretically available for pick-up from surfaces by untreated insects. However, secondary pick-up of detached capsules by untreated cockroaches was shown to be insufficient to result in a lethal effect, and it could be concluded that this effect is unlikely to be important under field conditions.

Transfer of particulate formulations of insecticides between cockroaches through direct physical contact has been reported by Schneider and Bennett (1985), Adams et al. (1992), Le Patourel (1996), and Wege et al. (1999). The current tests showed that significant levels of mortality could occur through inter-cockroach transfer amongst populations of *B. germanica* following exposure of some individuals to residual deposits of lambda-cyhalothrin. This effect was clearly dependent on cockroaches acquiring sufficient insecticide; a process which was governed by the time of exposure to the treated surface and dose on the surface. The dose of lambda-cyhalothrin picked up by an adult male *B. germanica* from 15 seconds exposure to a surface treated at 10 mg ai/m^2 was sufficient to result in 100% mortality through transfer to five untreated cockroaches. At slightly higher rates (15 mg ai/m^2) and exposure times (30 seconds), one cockroach could pick-up sufficient lambda-cyhalothrin to cause mortality in approximately 20 other individuals, suggesting external dislodgable residues of approximately 0.3 µg were acquired.

Exposure times of 15 and 30 seconds may be somewhat optimistic with interior crack and crevice treatments given a walking speed of around 0.25m/second for *B. germanica* (Chadwick, 1985). However, with a concentrated band of lambda-cyhalothrin at the label rate (30 mg ai/m^2), a contact time of < 5 seconds should be adequate for acquisition of sufficient lambda-cyhalothrin to exert a lethal effect on several other insects. Furthermore, some control effects through transfer of sub-lethal doses may occur. Although this parameter was not examined in the present study, previous work by Abd-Elghafar and Appel (1992) and Lee (1995) showed that fecundity and longevity of *B. germanica* were adversely affected by exposure to sub-lethal doses of pyrethroid insecticide.

When a harbourage was added to the large arenas, the transfer effect was reduced (Table 4), with only 40% mortality achieved compared to 100% in its absence. Observations suggested that this was the result of behavioural effects. In the absence of a harbourage, cockroaches tended to aggregate in the corners of the arena, facilitating the transfer of insecticide. This contrasted with the situation in the other arenas where the harbourage provided adequate surface area for the cockroaches to rest without excessive contact and disturbance.

Rapid expellency (flushing) of cockroaches from their harbourages within an hour or so after treatment is a characteristic of pyrethoid insecticides and is considered useful in increasing the contact of otherwise hidden cockroaches with residual deposits of insecticide. Flushing results from direct contact with the spray droplets and is caused by the initial excitatory effects of pyrethroids causing a rapid, non-directional, and disoriented movement out of the harbourage. No rapid flushing effect was observed in the present tests, although a gradual expellent effect was clearly apparent, with cockroaches expelled from the harbourage over the 24 hours following the introduction of a contaminated cockroach. A similar, slow, low intensity expellent effect was observed in field trials of permethrin against *B. germanica* (Carter and Chadwick, 1978), where cockroaches were expelled from their hiding places over a period of several hours following application. Le Patourel (1996) also observed a similar phenomenon in arena trials with cypermethrin wettable powder. Inter-cockroach transfer of insecticide through physical contact may explain both observations.

The present work demonstrates that through a highly efficient pick-up process a single cockroach is able to acquire a dose of lambda-cyhalothrin from a surface treated with lambda-cyhalothrin which is sufficient to kill itself and up to 20 other conspecifics depending on the application-, exposure-, and post-exposure conditions. Levels of secondary mortality caused through this effect were significant and equivalent to levels obtained for some routes of transfer for bait toxicants (Galhoff et al., 1999). However, the contribution of inter-cockroach transfer of lambda-cyhalothrin microcapsules towards the control effect of a residual application requires confirmation under more realistic conditions. Studies by Miall and Le Patourel (1989) and Le Patourel (1998) suggest that the combination of a more challenging environment and the post-treatment behaviour of exposed cockroaches could negatively impact the contribution of inter-cockroach transfer of lambda-cyhalothrin to the overall control effect. Such further investigations will additionally provide useful information, which may aid the design of novel microcapsule formulations, which capitalise on transfer between social or aggregative conspecifics.

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