Influence of humidity on a silica dust-filled barrier tape for bed bug control

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Bed bug harbourage in bedding. Photo: Dr Richard Naylor

Bed bugs (*Cimex lectularius*) continue to pose significant challenges for pest managers all over the world. They thrive in urban centres where high human population density and high movement of people facilitates their transmission between hosts (Doggett et al. 2018).

Bed bugs cluster together in cracks and crevices, often within a metre of where the host sleeps. Typical locations include inside bed bases, behind fixed headboards, around the ends of bed slats and in countersunk screw holes. Over time, the crevices where they hide become well established harbourages, covered with black faecal material, cast skins and eggs.

Feeding occurs at roughly weekly intervals and normally after dark, while the host is sleeping. From within the harbourage, hungry bed bugs detect elevated carbon dioxide from the host's breath and emerge to feed. Guided by body heat from the host, the hungry bugs approach.

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They normally feed without walking onto the hosts skin, presumably to avoid detection, so bites typically occur where the host's exposed skin meets the surrounding bed clothes or covers, producing a characteristic bite pattern. Feeding takes a few minutes, after which the fully engorged bug returns to the safety of the harbourage.

A gradual reduction in the range of insecticide classes available for bed bug control has resulted in an overdependency on the few that remain. Most of the professional residual insecticides approved for bed bug control in the UK and EU are now based on pyrethroids. Overuse of this class of insecticide has selected for widespread resistance, resulting in a loss of residual efficacy (Romero et al. 2007, Davies et al. 2012, Zhu et al. 2010).

Without residually active products, bed bugs reinfest areas that have already been treated. This is particularly problematic in multiple occupancy buildings (eg hotels, hostels, apartments, sheltered housing, barracks and prisons), where bed bugs easily move back and forth between rooms or apartments, making it difficult to achieve building-wide control.

Silica-based desiccant dusts, such as diatomaceous earth (DE) and amorphous silica dioxide (SD), have been shown to be highly effective against bed bugs, causing death by desiccation (eg Benoit et al. 2009, Lilly et al. 2016, Anders et al. 2017, Oumarou 2024). Insect exoskeletons are covered by a layer of lipids and waxes which help to prevent water-loss. Desiccant dusts absorb these cuticular lipids and waxes leading to death by desiccation.

DE and SD are comprised of almost pure amorphous silica dioxide (SiO_2). DE is processed from naturally occurring diatomite; fossilised sediments of single-celled algae (diatoms), which are mined from the ground and milled into a fine dust. SD is produced synthetically by one of several chemical reactions. Both DE and SD are chemically very stable, so they have excellent residual properties. However, they can be messy and unsightly, making them less suitable for use in the hospitality sector, except in very discrete locations.

Chronic exposure to airborne silica dust over many years, in industries like mining and quarrying, is known to be the cause of the respiratory disease, silicosis, where the lungs become scarred and lose function (fibrosis) (Hughes et al. 1998, Akhoundi and Izri 2019). While this disease is not reported from the pest management industry, presumably due to much lower levels of exposure, care should be taken to avoid applying it in places where it may become airborne, such as around mattresses and seat cushions and across doorways.

A paper barrier tape, Nattaro Safe (Nattaro Labs, Sweden), has been developed to address these issues. The DE-coated internal surfaces are protected within the folds of the tape, so that the DE cannot easily be dislodged or become airborne (Figure 1). The coated surfaces are also protected from a buildup of dust and debris that might otherwise render the DE ineffective.

The barrier tape is designed to be applied in a continuous perimeter around the underside of the bed frame/base →

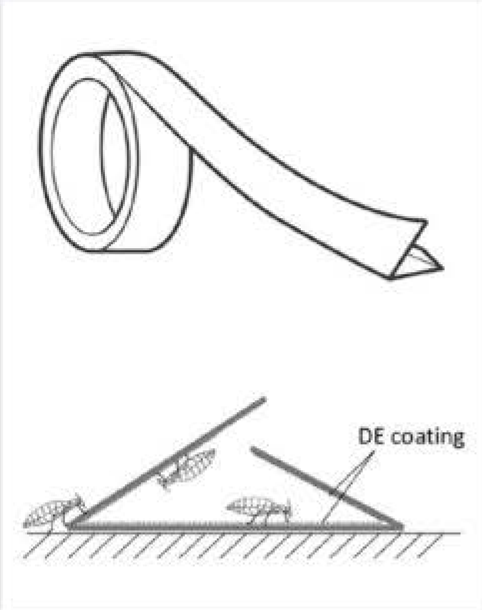


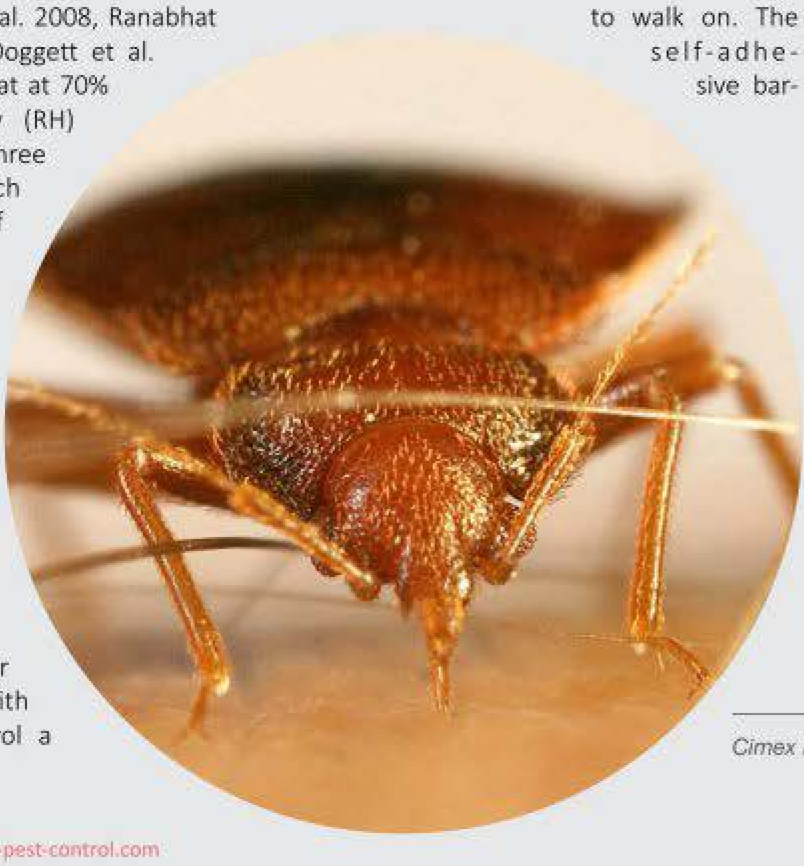
Figure 1. Cross section of barrier tape showing DE coated internal surfaces.

Figure 2. Paper lined 50l mesocosms (L x W x H: 43 x 35 x 33 cm) with barrier tape perimeters, corrugated cardboard harbourages and salt solutions to control humidity.

and across the back of the headboard, ideally separating the host from all potential bed bug harbourages. Bed bugs are therefore only exposed to the DE-coated surfaces when they cross the perimeter to feed, and again when they return to the harbourage. Because DE-exposure is brief and tied to feeding events, DE-exposed bed bugs may have the opportunity to replenish lost water, potentially delaying or preventing desiccation.

Previous studies have shown that humidity can greatly increase the time it takes for desiccant dusts to cause mortality (Doggett et al. 2008, Ranabhat & Wang 2020). Doggett et al. (2008) showed that at 70% relative humidity (RH) it took almost three weeks to reach 100% mortality of bed bugs that were continuously exposed to DE-coated surfaces.

The aim of our study was to determine how long it would take for weekly exposures to the desiccant-barrier tape, coupled with feeding, to control a population of bed bugs, at humidities ranging from low (37% RH) to very high (97% RH).



Cimex lectularius. Photo: Dr Richard Naylor

Methods

We compared the standard DE-lined Nattaro Safe barrier tape with a version lined with SD (ChinChex, Hong Kong) at the same application rate (0.2-0.4 g/m), and a dust-free control. Closed mesocosms (L x W x H: 43 x 35 x 33 cm) were lined with recycled brown paper to provide a natural substrate for the bed bugs to walk on. The self-adhesive barrier-tape was stuck to the floor of the mesocosms in a 20 x 20 cm square, which was mitred at the corners to ensure a continuous perimeter. Two pieces of corrugated cardboard (5 x 3 cm) were placed on the floor of each mesocosm, outside the barrier tape perimeter, to provide shelters for the bed bugs (Figure 2).

Five replicates of six controlled humidities, ranging from 37-97% RH, were set up for each of the three barrier tape variations (DE, SD, control), making a total of 90 mesocosms. Humidity was controlled with pots containing either silica gel, water, or a saturated salt solution. Data-loggers (Inkbird: IBS-TH1, Shenzhen, China) were used to monitor temperature and humidity in the mesocosms. The salt solutions used and resulting relative humidities in the mesocosms can be found in Table 1. All mesocosms were housed in the same test room. The temperature of the room was maintained at 20±1°C by a thermostatically controlled, wall-mounted fan heater. After setting up the mesocosms, they were left for one week for the humidities to stabilise before adding the bed bugs.

Cohorts of ten freshly fed adult bed bugs (5 male, 5 female) were released at the centre of each arena, within the barrier tape perimeter (Figure 2).

At weekly intervals all bed bugs were collected in, fed, and rereleased at the centre of the arenas. Because bed bugs

TABLE 1

HUMIDITY REGULATOR AND MEAN RELATIVE HUMIDITY ATTAINED IN THE MESOCOSMS.

HUMIDITY REGULATOR	MEAN % RH
Silica gel (SiO_2) - anhydrous	37
Potassium hydroxide (KOH)	44
Potassium carbonate (KCO_3)	55
Sodium bromide (NaBr)	65
Potassium chloride (KCl)	84
Water (H_2O)	97

are photophobic, and no shelter existed within the barrier tape perimeter, they were naturally encouraged to cross the perimeter to find the corrugated cardboard shelters.

Results

The results are summarised in Figures 3, 4 and 5. After 4 months (17 weeks) the experiment was terminated due to a growing problem with mildew in the high humidity mesocosms. At this point control mortality in the dust-free mesocosms ranged from 13 to 28% for humidities of ≤ 86% RH, and had reached 55% in the 97% RH mesocosms, suggesting that very high humidity is detrimental to bed bugs (Figure 3).

Weekly exposures to the DE barrier tape resulted in 100% mortality within 2 to 8 weeks for humidities in the range 37-55% RH. By week 17, when the study was terminated, mortality in the 65, 86 and 97% RH mesocosms had reached 98, 92 and 88% respectively (Figure 4).

Mortality of bed bugs exposed to the SD (ChinChex) barrier tape caused mortality much more rapidly. Cumulative mortality reached 100% in 2-4 weeks in the 37-65% RH mesocosms. By week 6, mortality had reached 100% in all mesocosms (Figure 5).

Discussion

Lilly et al. (2016) found that continuous exposure to DE and SD resulted in 100% mortality in 14 days and 3-4 days respectively. However, continuous exposure is not realistic in situations where the desiccant is used in a barrier tape, or as a →

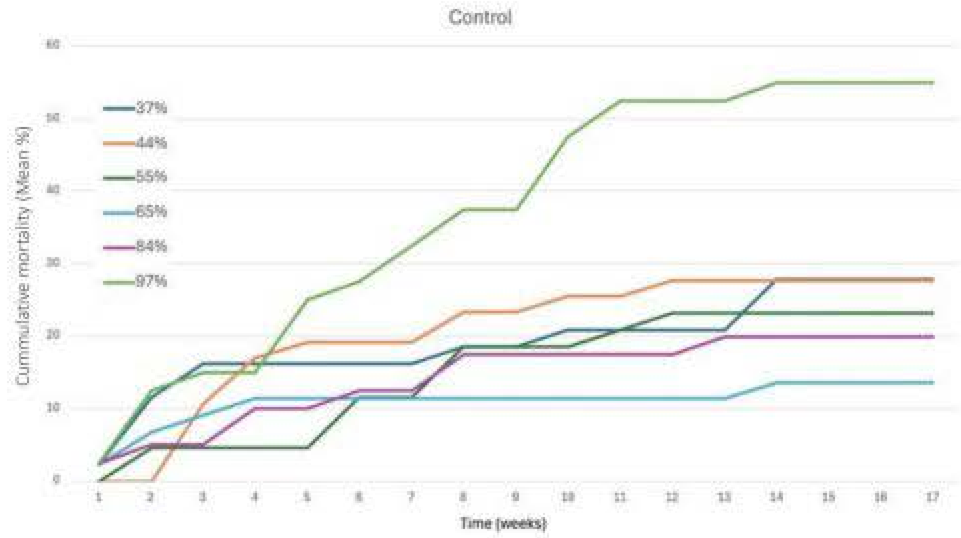


Figure 3. Effect of humidity on rate of mortality of bed bugs exposed to control (dust-free) barrier tape at weekly intervals coupled with feeding.

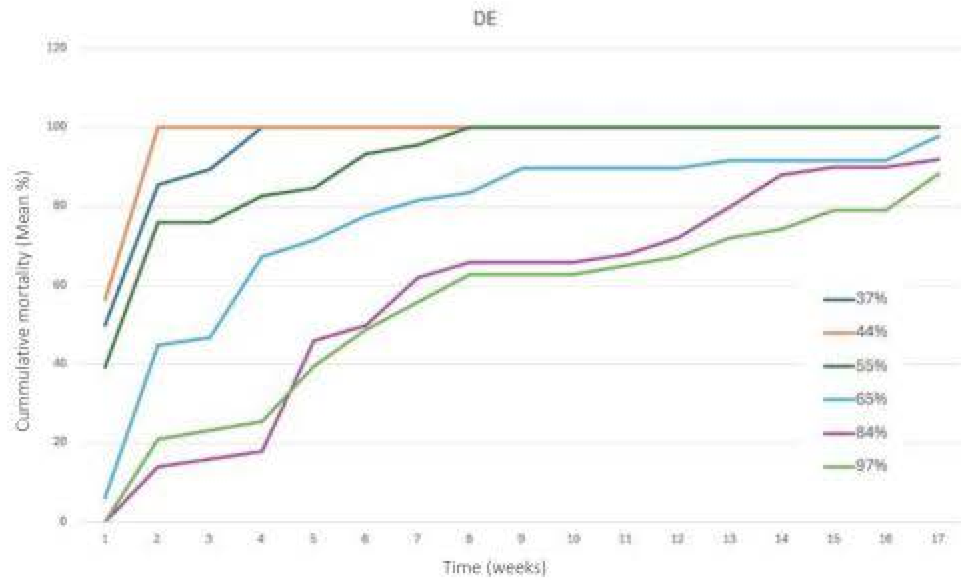


Figure 4. Effect of humidity on rate of mortality of bed bugs exposed to standard DE barrier tape at weekly intervals coupled with feeding.

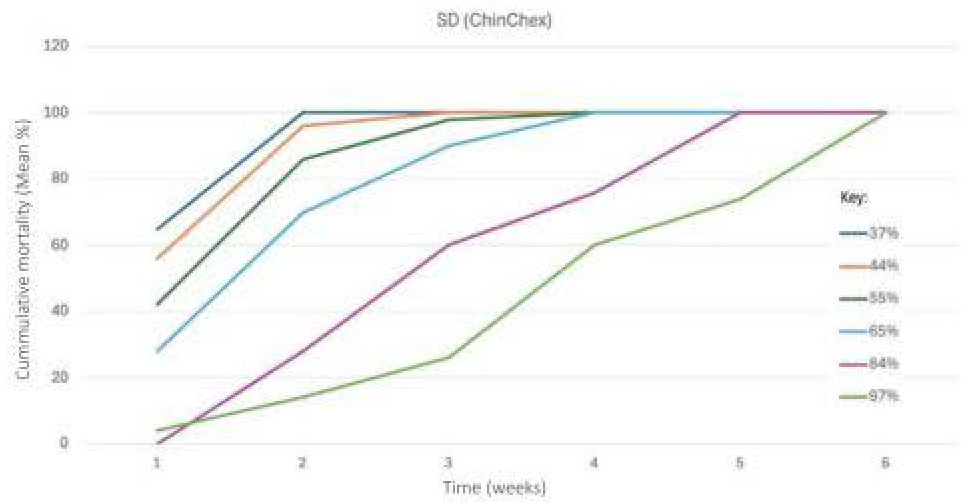


Figure 5. Effect of humidity on the rate of mortality of bed bugs exposed to SD (ChinChex) barrier tape at weekly intervals coupled with feeding.

Bed bug eggs. Photo: Dr Richard Naylor

barrier treatment, between the host and potential bed bug harbourages. In such cases exposure to the treated surfaces would be brief and coupled with feeding, when a bed bug could potentially replenish lost water. Our study sought to improve realism by exposing the bed bugs to the desiccant barrier at weekly intervals coupled with feeding. Unsurprisingly, the time it took for mortality to occur in our study was much greater than for previous studies based on continuous exposure.

Like previous authors, we find a clear correlation between ambient humidity and the time it takes for silica-based desiccant dusts to cause mortality. This may be due to several factors. Desiccants may become less absorbent to lipids and waxes as they become saturated with water from the environment. Both DE and SD become heavier and clumpier as they absorb humidity, which may affect how the dust transfers from the substrate to the insect's cuticle. High ambient humidity may also reduce the rate at which an insect becomes desiccated after cuticular waxes and lipids have been removed.

Our results indicate that the standard DE barrier tape (Nattaro Safe) is likely to perform well at controlling bed bug populations in low to moderate humidity environments (37-55% RH), but at higher humidities (≥65% RH) total control via the barrier tape alone could take more than four months to achieve. Mortality resulting from exposure to the SD (ChinChex) barrier tape occurred more rapidly. These differences became more pronounced at higher humidities where total mortality was reached in around a quarter to a third of the time.

This study suggests that silica-based desiccant dust barrier tapes, and barrier treatments, are likely to be effective for providing lasting residual protection against bed bugs, but that pest managers using desiccant dusts should be mindful of the impact of humidity. DE and SD are likely to perform well in conjunction with heat treatments, which dry out the building, reducing ambient humidity. But they may become less effective if used in conjunction with steam treatments or sprayed liquid insecticides, which increase humidity. At higher humidities (>65% RH), where the time for DE to take effect is greatly increased, pest managers should consider switching to SD, if local biocidal product regulations allow. ■

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