THE EFFECTIVENESS OF RESIDUAL INSECTICIDES AGAINST THE VARIED CARPET BEETLE *ANTHRENUS VERBASCI* (L.) AND THE IMPLICATIONS FOR CONTROL OF THIS PEST IN MUSEUMS

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Abstract—A number of species of carpet beetles (*Anthrenus* spp) that are household pests attack museum collections and can cause severe damage to natural history specimens, textiles and ethnographic objects. Many of the species such as the varied carpet beetle, *Anthrenus verbasci*, have their origin in birds' nests and may spread into collections from the nesting sites found on many museum buildings. Residual insecticides are commonly applied to control such infestations but these treatments have often met with limited success. Much of the laboratory testing of insecticides has been carried out against the adults, which appear to be relelatively susceptible to organophosphorous, carbamate and pyrethroid insecticides. However, tests against the larval stages have usually been carried out by confining larvae on treated woollen textiles and recording the damage to the fabric and the mortality of the insects that fed upon the material. To reflect accurately the need to kill larvae as they wander over treated surfaces we have evaluated the effects of wood panels treated with six insecticide formulations on late instar larvae of the varied carpet beetle. The test formulations were applied as residual sprays or dusts at comparable active ingredient levels. For some formulations there was survival of a few larvae even after 35 days continuous exposure to the recommended label dose of insecticide. It is, therefore, likely that some insecticide treatments applied in museums to control carpet beetle infestations and prevent damage to collections will not be effective and alternative control measures should be sought.

INTRODUCTION

Several species of carpet beetle can cause serious damage to objects in museum collections and to household carpets, textiles, clothing, and products of animal origin such as wool, fur, feathers and skins (Hinton, 1945). The major pest species, the varied carpet beetle *Anthrenus verbasci* (L), is known to be widespread in the UK. The normal habitat of this species includes birds' nests (Woodroffe and Southgate, 1951), and some infestations in museums and domestic premises have been reported as originating from this source. Damage is caused by the larval stage, which develops over one to two years depending upon environmental conditions (Blake, 1958). After pupation, the adults emerge in the late spring and early summer when they fly and actively seek certain species of flowers such as *Spirea* and hogweed (Parkin and Woodroffe, 1961; Woodroffe and Southgate, 1954). The adult beetles can be controlled by residual insecticides (Tyler and Binns, 1977), but the treatment have to be targeted to coincide with adult activity and egg laying. By comparison, the larvae are far more difficult to kill (Parkin and Woodroffe, 1961), not least because they often remain hidden within food sources. Much of the development and evaluation of residual insecticides for use against carpet beetles has concentrated on the proofing of fabric to prevent damage (Anon, 1977). Permethrin is one of the insecticides known to be effective in reducing damage from carpet beetles and clothes moths (Friedman *et al.*, 1979, Bry *et al.*, 1989), and has been widely adopted as an insect proofer for fabrics. However, although *Anthrenus* larvae can be controlled using this type of treatment, which impregnates the food material, it is not clear whether the same insecticide would be so effective against larvae crawling across residual surface deposits. The final larval stages of *Anthrenus* are very active and may wander over considerable distances perhaps to seek safe pupation sites. It is at this point in the life cycle, when they leave the food source, that residual insecticide applications may offer further potential for control. Experience of treatments carried out in some museums and their associated stores suggested that residual treatments of permethrin and bendiocarb were not as effective in controlling wandering *Anthrenus* larvae as would have been expected (Hillyer and Blyth, 1992). It was, therefore, decided to develop a test method to evaluate the performance of residual deposits against *Anthrenus* larvae and assess the relative efficacy of the most commonly used insecticides.

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MATERIALS AND METHODS

Insects

A. verbasci used in this study were obtained from cultures held in the CSL Insectary for over 20 years and have not been exposed to pesticides during that time. Cultures were reared on a diet of fishmeal, yeast, cholesterol (75:18:1) and wool felt at 20°C 70% rh. As there is no information available on the occurrence of pesticide resistance of *A. verbasci* in the UK, the resistance status of the strain used in this study is unknown.

All tests were carried out using late instar larvae removed from culture and held in 75 × 25 mm glass tubes (25 larvae per tube) for 24 hours immediately before testing. Test larvae were retained without food until the tests were completed.

Insecticides

Registered Trade Name	*Active ingredient*	*Formulation (active ingredient)*	*Rates recommended on the label expressed as active ingredient deposit per m^2*
Coopex WP	permethrin	Wettable Powder (25% w/w)	125 mg
Coopex Insect Powder	permethrin	Ready-to-use dust (0.5% w/w)	50 mg
Ficam W	bendiocarb	Wettable powder (80% w/w)	96 mg
Ficam D	bendiocarb	Ready-to-use dust (1% w/w)	100–200 mg
Empire 20	chlorpyrifos-methyl	Microencapsulation (20% w/v)	200 mg
Drione	pyrethrins + piperonyl butoxide	Ready-to-use desiccant powder (with pyrethrins at 1% w/v)	Up to 50 mg*

*refers to pyrethrins content only.

Test Substrate

Exterior grade 3 mm thick plywood panels 300 × 300 mm.

Insecticide application

Sprays

Coopex WP, Ficam W and Empire 20 formulations were diluted with water and sprayed onto the plywood substrates at a rate of 5 l/125m^2 using a small-scale laboratory sprayer (Morgan and Pinniger, 1987). Two plywood panels were treated for each formulation/dose whilst an additional two substrates were sprayed with water only (also 5 l/125m^2) as controls. The treated panels were then left overnight under test conditions to dry before testing the following day.

Dusts

Two plywood panels were used for each formulation/dose. Weighed quantities of Coopex Insect Powder, Ficam D or Drione powder formulations were applied directly to the plywood substrates within the bioassay arenas. The powders were distributed evenly within the arenas with the aid of cut-down squirrel hair brushes. Two additional untreated panels were used as controls. All the panels used in assessing dust formuations were acclimatised at the test conditions for 24 hours prior to treatment and immediate bioassay.

Insecticide deposits and assessment periods

Both spray and dust formulations were applied to give a comparative deposit of the active ingredient at a level similar to that which would be achieved in practice. But, because of the differences in application rates between formulations this does not necessarily correspond with the treatment rates recommended on the label.

All six formulations were assessed at 100 mg ai/m^2 with larvae exposed continuously on the

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treated surfaces for 5 weeks. Coopex WP and Ficam W formulations were also tested at deposit levels of 12.5 mg ai/m^2.

To ensure the accuracy of the sprayed deposits the application rate of the laboratory sprayer was checked immediately before and after treatment of the substrates. In all cases it was found to be within ± 10% of that intended.

Bioassay procedure

Bioassays were carried out by confining larvae within 100 mm diameter aluminium rings, treated with Fluon(TM) to prevent escapes, and placed directly onto the plywood substrates. Two rings, each containing twenty-five larvae, were positioned on each substrate. Bioassay assessments for KD and mortality were carried out 24 hours later (Day 1) and then at Days 7, 21 an 35. Insects were considered knocked down if they were unable to co-ordinate their locomotory movements and dead when no movement could be observed over a period of 3-4 minutes, even after gentle prodding with a fine brush. All assessments were performed with the aid of a low-power microscope.

All tests were carried out under low intensity lighting of approximately 20 lux at constant conditions of 20°C 70% rh.

RESULTS

Mortality and KD of larvae remained below 2% in all control replicates and none had pupated by the end of the tests.

Comparison of formulations applied at 100 mg ai/m^2

Of the six formulations tested at 100 mg ai/m^2, Coopex WP produced the most rapid KD with 100% of *A. verbasci* larvae knocked down within 24 hours of exposure to the treated surfaces (Figure 1). At this dose Coopex WP continued to achieve 100% KD through to Day 21. However, some recovery from KD was evident two weeks later with 91% of the larvae knocked down at test completion. Empire 20 also produced a relatively high KD of 95% at the day 1 assessment rising to 99% y Day 7. After that, KD remained unchanged through to test completion. In contrast, both Ficam W and Ficam D knocked down less than 20% at Day 1, and appeared to be the least effective formulations at this stage of the test. However, with both formations, KD rose to 100% at Day 35 and, moreover, Ficam W and Ficam D were the only formulations to achieve 100% KD at test completion. Of the other four formulations Coopex WP gave the lowest KD of 91% at Day 35 (Figure 1).

Mortality at the Day 1 assessment was negligible, with the highest (4%) recorded for larvae exposed to Empire 20. But, by Day 7, mortality was recorded for all the formulations with Drione producing the highest evel of 61% (Figure 1). After 21 days, mortality was greater than 65% for all the formulations with Drione again producing the highest kill at 91%. However, none of the formulations achieved 100% kill at the final assessment with similar mortalities recorded for all six formulations. These ranged between 89% for Coopex WP to 99% for Ficam D (one larvae KD but not dead) (Figure 1).

A. verbasci KD and mortality following exposure to Ficam W and Coopex WP applied at 12.5 mg ai/m^2

The KD and mortality of *A. verbasci* larvae to 12.5 mg ai/m^2 Ficam W and Coopex WP is shown in Figure 2.

Both Ficam W and Coopex WP resulted in less than 50% mortality even after 35 days continuous exposure to the 12.5 mg ai/m^2 deposits. Ficam W resulted in comparatively low larval mortalities of less than 5% through to Day 21 but this had risen to 48% by Day 35. Coopex WP resulted in 25, 41 and 40% kill recorded for Days, 7, 21 and 35 respectively. The apparent 'recovery of insects previously recorded as dead was an indication of the difficulty in assessing *Anthrenus* larvae when in a moribund state. Substantial differences in KD were also observed between the two formulations

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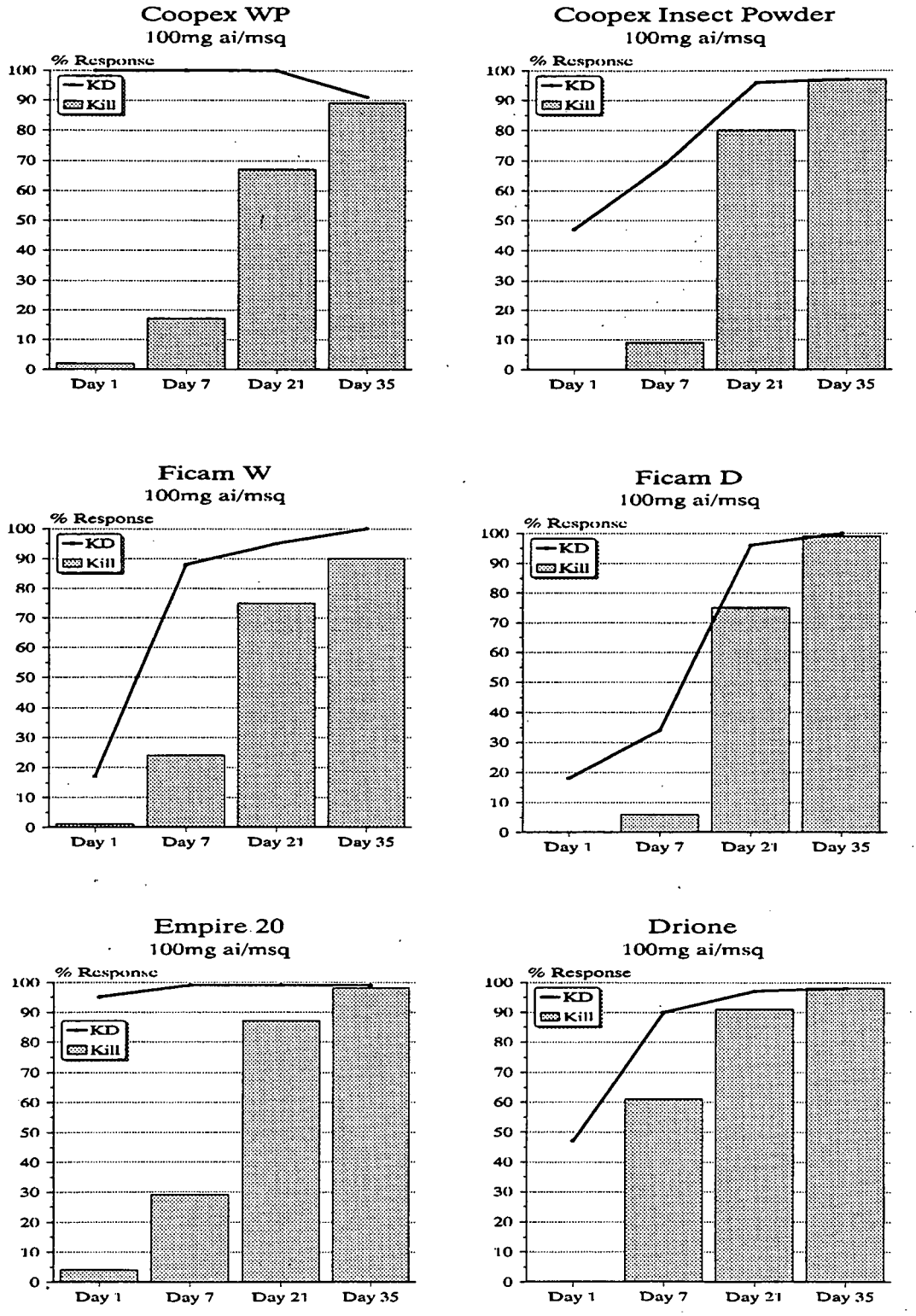

Figure 1. KD and kill of *Anthrenus verbasci* larvae exposed to 100 mg ai/m^2 deposits of six insecticide formulations applied to plywood substrates.

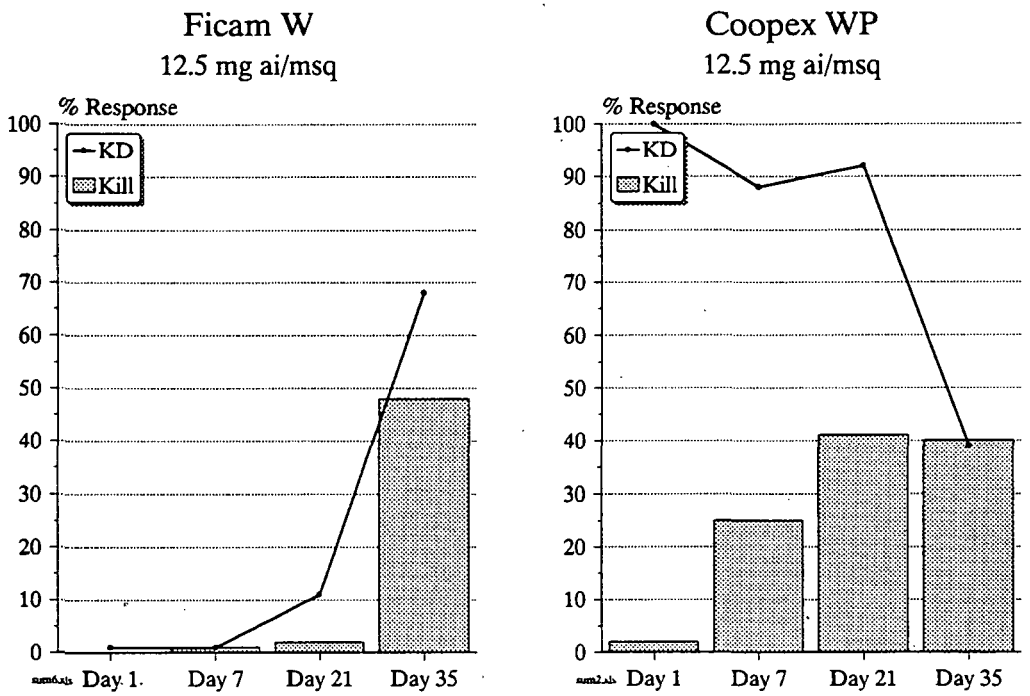

Figure 2. KD and morality of *Anthrenus verbasci* larvae exposed to plywood panels treated with 12.5 mg ai/m² Ficam W and Coopex WP.

when applied at the 12.5 mg ai/m² deposit level. KD of larvae exposed to Ficam W increased from 1% at Day 7 to 11% at Day 21 and 68% at Day 35. In contrast, Coopex WP had knocked down all of the larvae exposed to 12.5 mg ai/m² deposits by Day 1. However, recovery from KD then occurred with 88, 92 and 39% of larvae recorded as KD for Days, 7, 21 and 35 respectively.

DISCUSSION

The six formulations tested in this study produced similar levels of larval mortality depite large differences in the manufacturers' recommended treatment rates. None of the formulations tested acheved 100% mortality, even with the relatively long exposure period of five weeks. This confirms that larvae of *Anthrenus verbasci* are difficult to kill by exposure to surfaces treated with residual insecticides. This study also highlighted difficulties in assessing larval mortality. In some bases, particularly early in the series of tests, mortality was clearly over-estimated and this led to results that show an apparent recovery of 'dead' larvae. Considerable disparity was found between the results for larvae exposed to Coopex Insect Powder in this study and results previously published by Chadwick *et al.*, (1987) where 100% kill was recorded 6 days after a 30 minute exposure of larvae to 25 mg ai/m² deposits. Results from our work showed that 100 mg ai/m² deposits not only failed to achieve 100% mortality after 35 days continuous exposure but produced only 9% mortality at Day 7. A possible explanation of this discrepancy is that the moribund state recorded as KD in our study may have been recorded as death by Chadwick *et al.* In addition, the tests by Chadwick *et al.* were carried out at the higher temperature of 25°C and this may have increased the efficacy of the treatment. It is also possible that the large late instar larvae used in our study were more tolerant of insecticide than the stages used by Chadwick *et al.*

The effectiveness of impregnating materials with insecticide as a method for killing larvae and to prevent damage to fabrics has been widely investigated (Veer, *et al.*, 1989; Veer, *et al.*, 1991; Bry, *et al.*, 1984; Mayfield & O'Loughlin, 1980). However, very little work has been carried out on the investigation of insecticide applications as residual surface treatments and their toxicity to *Anthrenus* larvae. The morphology of *Anthrenus* larvae may contribute to the problems in controlling this pest by surface application of pesticides. *Anthrenus* larvae are covered in bristle-like

setae which may reduce the uptake of insecticide because less comes into direct contact with the cuticle. *Anthrenus* larvae also appear to have a tendency to assume diapause or a state of inactivity when they are exposed to insecticide deposits and the combination of these two factors may contribute to their recovery from KD and their ability to survive somewhat long exposures to treated surfaces. Ingestion of pesticide from treated fabric may explain the wide differences in efficacy between the treatment of fabrics and residual deposits on surfaces using the same insecticides.

Of the insecticide formulations tested in this study, many have label recommendations that specify a range of application rates (eg. Drione is recommended for application at rates up to 5 g of the formulation per m^2. For the purposes of this study 100 mg ai/m^2 was chosen as a comparative rate for all the formulations and to assess the relative toxicities. However, the implications of this study for practical control programmes are considerable. The differences between the label rates and those tested here should obviously be taken into account although the vagaries of field application may greatly reduce their significance. Other considerations of unevenness of treatment, type of surface treated and the breakdown of insecticide are also likely to influence the effectiveness of deposits.

Although similar in terms of mortality achieved after five weeks, the performance of the formulations tested in this study did differ in terms of KD of *A. verbasci* larvae. Coopex WP resulted in the quickest time to KD, producing 100% KD as early as Day 1 even at 10% of the recommended label rate. However, even at the high dose of 100 mg ai/m^2 some recovery had occurred after 3 weeks continuous exposure. The second most effective formulation in terms of KD performance was Empire 20 which, although it failed to achieve 100% KD, maintained a high level of KD through to the end of the test. As Empire 20 is intended for application at twice the rate tested, its performance may be improved when applied at the recommended label rate of 200 mg ai/m^2. Dust formulations are notoriously difficult to apply evenly and at an intended deposit rate yet they remain a convenient formulation for use in museums against carpet beetles. They are easy and convenient to apply, particularly for treatment of cracks and crevices, dead spaces, ducting and where the use of water sprays is not permitted. Of the dust formulations tested, both Drione and Coopex Insect Powder were applied at twice the label rate (calculated from the pyrethrin content of Drione only). Yet both failed to achieve 100% mortality of larvae, even after 5 weeks of continuous exposure. All tests were carried out at 70% rh and the observed effects on larvae exposed to Drione appeared to be due to the pyrethrin content. It is unclear what contribution the dessicant dust made to insect mortality or whether its effect would be greater at lower humidities. Similarly, Ficam D did not achieve 100% kill but as it has a recommended application rate of 100-200 mg ai/m^2 it may be more effective at the maximum dose allowed.

This work confirms the practical observations that *Anthrenus verbasci* larvae may survive residual insecticide treatments in practical situations. There is, therefore, a need to evaluate the performance of insecticides against other Dermestid beetle species such as the Guernsey carpet beetle (*Anthrenus sarnicus* Mroczkowski) and the brown carpet beetle (*Attagenus smirnovi* Zhantiev). In view of the importance of these pests in UK museums it is essential to ensure that all other factors such as hygiene and good pest management are recognised to enable control treatments to achieve some success.

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