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The small hive beetle *Aethina tumida*: A review of its biology and control measures

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Abstract The small hive beetle *Aethina tumida* is an endemic parasitic pest and scavenger of colonies of social bees indigenous to sub-Saharan Africa. In this region this species rarely inflicts severe damage on strong colonies since the bees have developed strategies to combat them. However, *A. tumida* has since 'escaped' from its native home and has recently invaded areas such as North America and Australia where its economic impact on the apiculture industry has been significant. Small hive beetle, should it become established within Europe, represents a real and live threat to the UK bee keeping industry. Here we review the biology and current pest status of *A. tumida* and up to-date research in terms of both chemical and biological control used against this honey bee pest [*Current Zoology* 59 (5): 644–653, 2013].

Keywords *Aethina tumida*, pesticides, biological control, population development, honey bees

1 Introduction

As global travel and transportation of goods increase, biological invasions are likely to happen more frequently (Cassey et al., 2005; Cuthbertson and Brown, 2009). Introduced pathogens and parasites often have the capability to switch hosts, thus posing new threats to native species which lack any innate ability for parasite challenge. Instead, native species must rely on generalistic methods of defence, which may or may not be sufficient to provide adequate protection against the new threat. The small hive beetle (SHB) (*Aethina tumida* Murray, Coleoptera; Nitidulidae), is a classic example of such a parasite, having been moved to new locations by the global trade in honey bee and hive products. Small hive beetles are native to sub-Saharan Africa where they exist as both scavengers and symbionts in colonies of African subspecies of Western honey bees (*Apis mellifera* L.) (Lundie, 1940[1]; Neumann and Elzen, 2004). The beetle belongs to the family Nitidulidae. Most Nitulid species feed on decaying fruits, fermenting plant juices, fungi, carrion, flowers or pollen (Neumann and Elzen, 2004; Stedman, 2006[2]). It would appear that the beetle has switched hosts to honey bee colonies opportunistically, after foraging on rotten fruit (Ellis, 2002; Ellis et al., 2002; Arbogast et al., 2009a; Neumann and Elzen, 2004; Spiewok and Neumann, 2006a). In its native range, the SHB is a colony scavenger, feeding on a mixture of pollen, honey and bee brood (Neumann and Elzen, 2004). In most cases the impact on the parasitized colony is minimal. However, in extreme circumstances, beetle larvae may act as beneficial predators that destroy diseased colonies (Ellis and Hepburn, 2006). In Africa, beetle reproduction is maximised in bee colonies that abscond (abandon the nest leaving pollen, honey and partially cannibalized brood behind). In this instance, the SHB confers a positive benefit, disposing of weakened/diseased hives or abandoned nests that can harbour disease organisms. However, Western honey bees tend to abscond less frequently than their African counterparts and also leave more resource behind, thereby offering increased opportunities for beetle population growth (Spiewok et al., 2006).

During the past decade the small hive beetle has been introduced into several countries around the world including the USA, Canada and Australia (Elzen et al.,

[1] Lundie AE, 1940. The small hive beetle Aethina tumida. Science Bulletin 220, Entomological Series 3. Dept. of Agriculture and Forestry, Pretoria, South Africa. 30 pp.

[2] Stedman M, 2006. Small Hive Beetle (SHB): Aethina tumida Murray (Coleoptera: Nitidulidae). Government of South Australia. Primary Industries and Resources for South Australia. Factsheet 03/06, 13pp.

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1999a; Fore, 1999; Mostafa and Williams, 2002; Animal Health Australia, 2003; Brown and Morton, 2003; Clay, 2006). Though Neumann and Elzen (2004) record the detection of the SHB in Egypt in 2000 and, since then, in a number of apiaries along the Nile Delta, a survey by Hassan and Neumann (2008) recorded no damage symptoms or any adult SHB in a total of 1,239 colonies sampled. There has been no recorded presence of the small hive beetle in the UK or indeed within Europe where it is a notifiable pest (Cuthbertson et al., 2008a, 2010; Cuthbertson and Brown, 2009; Commission Decision 2003/881/EC). The only incidence to date was the discovery in 2004 of SHB larvae in a consignment of *A. mellifera* queens imported illegally from Texas into Portugal (Murilhas, 2005). Upon this discovery, the colonies into which these queens were introduced were immediately destroyed. In North America and Australia the beetle has become well established (Hood, 2004, Neumann and Elzen, 2004) and its spread in these new ranges has been facilitated by the managed and feral honey bee populations. Honey bee subspecies from Europe appear to be more susceptible to small hive beetles than African ones, that is, they suffer greater damage from infestations and colonies collapse more often (Elzen et al., 1999a, 2000), thus enhancing beetle reproduction. However, while managed honey bee colonies constitute a good resource for beetle development, switching to alternate hosts (such as bumble bees, feral *Apis* sp.) could present a viable survival strategy when honey bee hives are less abundant or temporarily unavailable (Spiewok and Neumann, 2006b; Hoffmann et al., 2008). Adult hive beetles are active flyers (Elzen et al., 1999a) and are known to frequently migrate between colonies within the same apiary (Ellis et al., 2003a) regardless of colony strength (Lundie, 1940). The beetle reproduces mostly in weak colonies or in abandoned honey bee nests (Lundie, 1940; Schmolke, 1974[3]), but small numbers are able to complete development to mature larvae in strong colonies (Arbogast et al., 2012). Adult small hive beetles often hide on the bottom of cells, in the hive debris which collects at the bottom of the hive, or in small cracks that are often present in beekeeping equipment (Lundie, 1940; Schmolke, 1974; Neumann and Elzen, 2004). Inside the nest, hive beetles, seem to aggregate at certain hiding or rendezvous sites (Lundie, 1940; Schmolke, 1974). The brood nest is a commonly preferred within hive location of eggs, larvae and adult beetles because of the combination of being an oviposition substrate (Ellis et al., 2004a) and the preferred food source (Elzen et al., 2000). It has been suggested that hive beetle distribution is influenced by the presence of worker bees, which have been postulated (Neumann and Elzen, 2004) to actively reject intruding hive beetles from the nest (Lundie, 1940; Spiewok et al., 2007).

2 Biology of the Small Hive Beetle

Adult small hive beetles (Fig. 1) average 5.7 mm in length and 3.2 mm in width (Ellis et al., 2002; Cuthbertson et al., 2013). The beetles vary in size, probably due to relative availability of food resources and variations in climate (Ellis, 2004). They are strong fliers and are capable of flying several kilometres (Somerville, 2003[4]), aiding their natural spread. Beetles fly before or after dusk (Schmolke, 1974), and males have been reported to fly at earlier times than females. The adult beetles are thought to be attracted to honey bee colony odours (Elzen et al., 1999b; Suazo et al., 2003; Torto et al., 2005) but may also be attracted to bee pheromones. A number of chemicals identified from honey volatiles have been shown to be attractive to SHB (Torto et al., 2005). In olfactometric and flight-tunnel bioassays, adult SHB were found to be attracted to volatiles from adult worker bees, freshly collected pollen, unripe honey and slumgum (Suazo et al., 2003). Torto et al. (2007) showed that irrespective of age, when SHB's feed on a mixture of pollen and honey, volatiles that attract hive beetles are released. The release of these volatiles is due to fermentation by microorganisms including the yeast *Kodamea ohmeri*, previously isolated

Fig. 1 Adult small hive beetle *Aethina tumida* (UK Crown Copyright ©).

[3] Schmolke MD, 1974. A study of *Aethina tumida*: the small hive beetle. Project Report, University of Rhodesia, South Africa, 181pp.

[4] Somerville D, 2003. Small hive beetle in the USA. A report for the Rural Industries Research and Development Corporation. Pub. No. 03/050: 57.

from the beetle feeding on pollen (Teal et al., 2006; Benda et al., 2008). Traps baited with *K. ohmeri* dough were shown to be more effective in detecting/trapping adult SHB in honey bee colonies than were traps baited with pollen dough alone (Arbogast et al., 2007; Torto et al., 2010). Effective traps employed by Arbogast et al. (2012) were also able to detect numbers of emigrating larvae that were too small to be readily observed in the hives. Placing traps baited with yeast-inoculated pollen dough captured more beetles in the shade than in partial shade and the frequency of capture was shown to decline with distance from the hive (Arbogast et al., 2009b). Therefore, the probability of detecting SHB in apiaries can be maximised by placing the traps in full shade and as near as possible to the hives.

Small hive beetles are sexually mature at about one week following emergence from the soil (Ellis, 2004). Adult females will oviposit directly on pollen or brood comb if unhindered by worker bees. Schmolke (1974) estimated that female beetles may potentially lay up to 1,000 eggs in their lifetime although other estimates range up to 2,000 eggs (Somerville, 2003). When nucleus honey bee colonies were inundated with adult small hive beetles, female beetles were observed chewing holes in capped bee brood and ovipositing eggs on bee pupae (Ellis, 2004). In addition, adult beetles were reported to oviposit into capped bee brood through slits they chewed in the side of adjacent empty cells (Ellis, 2004).

Small hive beetle eggs (Fig. 2) are approximately 1.4 mm long by 0.26 mm wide, pearly white and normally laid in clusters of between 10≥30 in number (Stedman, 2006). Female beetles lay eggs in cracks and crevices around the periphery of the inside of a highly populated bee colony, but they will lay eggs in the brood area if unhindered by adult bees. Most beetle eggs hatch in about three days but the incubation period can continue for up to six days (Lundie, 1940). Egg hatching viability is reduced by decreases in relative humidity (Somerville, 2003, Stedman, 2006).

Fig. 2 Small hive beetle eggs laid in between glass slides (UK Crown Copyright ©).

Beetle larvae are creamy-white in colour and emerge from the egg through longitudinal slits made at the anterior end of the egg (Lundie, 1940). The larval period lasts an average 13.3 days inside the bee colony and anywhere between 15–60 days in the soil depending on soil temperature (Stedman, 2006). Under cooler soil conditions pupation takes longer (Stedman, 2006). De Guzman and Frake (2007) stated that larvae exposed to 34°C accelerated their development. Eischen et al. (1999) reported beetle larvae reaching maturity in 5–6 days under favourable conditions. Beetle larvae are about 1 cm in length when fully grown (Lundie, 1940). The length of mature larvae is variable. Smaller larvae with poorer diets mature more slowly than large, well fed individuals (Lundie, 1940). Once larval feeding is complete, mature larvae enter a wandering phase (Fig. 3). Predominantly these larvae migrate at dusk from colonies, in search of suitable pupation substrates (Stedman, 2006). Wandering larvae have been recorded as being able to survive for up to 48 days after feeding ceases and then still develop into viable adults (Cuthbertson et al., 2008a, 2010).

Fig. 3 Small hive beetle wandering larvae (UK Crown Copyright ©).

On exiting the colony, mature SHB larvae enter the soil to pupate (Fig. 4) (Fore, 1999; Cuthbertson et al., 2013); a process that lasts anywhere from eight days (Schmolke, 1974) until two months (Taber, 1999). Small hive beetles spend >75% of their developmental time in the soil (De Guzman and Frake, 2007) and edaphic environmental factors such as soil type, soil moisture, soil density, field slope, drainage, rainfall and temperature greatly affect their biology (De Guzman et al., 2009). Female beetles pupate slightly faster than

males (Ellis, 2004). Young pupae are white to brown in colour and are mostly affected by soil moisture rather than soil type (Ellis, 2004). Soil type was found to have little effect on pupation survivability (Ellis, 2004). However, De Guzman et al. (2009) found more beetles survived in areas that were predominantly silty clay and silty clay loam compared to most sandy loam and loam soil areas. Dryer soils would seem to impede pupation success rates. Torto et al. (2010) found that larvae burrow deeper into the soil for pupation during drier seasons. However, De Guzman et al. (2009) concluded that beetle pupation could occur in any soil type. Ellis (2004) demonstrated that pupation rates varied by 6% in various soil types provided the soil was moist. This implies that beetle pest problems can be expected regardless of soil type in areas where soil moisture remains high during the year. Therefore, soil moisture appears to be a major limiting factor in beetle reproduction, and ultimately population build-up. This may explain in part why the SHB is not a major problem in honey bee colonies in sub-Saharan Africa because much of Africa (except equatorial Africa) is semi-arid to arid (Ellis, 2004). The dryer soil conditions would be expected to have a negative affect on beetle pupation rates (Ellis, 2004). De Guzman et al. (2009) also observed that the majority of beetles pupate in the first 10 cm of soil (mostly under the surface), only a few at 20 cm and none at 30 cm. These observations on soil depth agree with those of Schmolke (1974) and Pettis and Shimanuki (2000), indicating that most beetles pupate at <10 cm or below the soil surface. This preference of the uppermost layer for beetle pupation was probably due to the presence of decaying litter or loose organic materials that are easy for larvae to burrow into as well as adults to emerge from (De Guzman et al., 2009). Soil density was also found to affect pupation rates, with high density soils having a negative effect on pupation rates (Schmolke, 1974). Pupae are known to be vulnerable to adverse weather conditions, soil-borne fungal infection, nematodes and soil cultivation.

Fig. 4 Larvae on ground surface beginning to burrow down seeking pupation sites (UK Crown Copyright©).

Development of the SHB is known to be affected by temperature (Schmolke, 1974). At 34°C, De Guzman and Frake (2007) observed a total development time of 23 days. At a range of 18–25°C the length of developmental cycle has been reported to be 41.32 ± 1.34 days (Mürrle and Neumann, 2004) and at 17–24°C, 49 ± 0.11 days (Neumann et al., 2001). Meikle and Patt (2011) found adults to emerge after 32.7 days at 21°C and after only 14.8 days at 35°C. Lundie (1940) described development periods of about 80 days at unreported temperatures while Cuthbertson et al. (2008a) observed viable adult emergence after 84 days in temperatures ranging from 20–30°C. Annand (2011)[5] found that temperatures of ≤15°C and ≥45°C prevented oviposition. In addition, when SHB eggs were exposed to these temperatures they did not hatch. These findings match those of Meikle and Patt (2011) who determined the minimum temperature for development of eggs was 13.5°C. Relative humidity of ≤34% also prevented egg survival (Annand, 2011[5]). Temperatures exceeding 35°C cause high mortality of all life stages of SHB (Meikle and Patt, 2011). This confirms that changes in temperature can significantly impact SHB abundance, with development being slower at lower temperatures (De Guzman and Frake, 2007). In population development SHB displays the classic female-biased operational sex ratio (Neumann et al., 2001; Ellis et al., 2002; Mürrle and Neumann, 2004; Cuthbertson et al., 2008a). It is known that nutrition also plays a role in adult beetle development and reproduction, with honey being important to insect longevity; honey-fed adults live the longest (Ellis et al., 2002). Dadd (1985) stated that carbohydrate (especially sugar) utilisation is very important in insect longevity. Adult beetles have been shown to survive for between 5 and 9 days without food and water (Pettis and Shimanuki, 2000; Ellis et al., 2002). Wandering larvae have been shown to survive for at least 48 days (Cuthbertson et al., 2008a).

3 Control Measures for the Small Hive Beetle

Numerous authors have investigated various methods

[5] Annand N, 2011. Small Hive Beetle Biology: Providing control options. Report for the Australian Government Rural Industries Research and Development Corporation. 58pp.

for controlling all SHB life-stages, ranging from prevention of infestation to complete sanitation (Thomas, 1998; Elzen et al., 1999a; Waite and Brown, 2003). These methods include: maintenance of strong colonies and good husbandry (Waite and Brown, 2003); boosting natural hygienic behaviour in honey bee colonies (Ellis et al., 2003b); the narrowing of hive entrances to repress beetle excess (Ellis et al., 2002); mechanical control – using in-hive trapping tools (Hood and Miller, 2003) and light traps (Baxter et al., 1999); chemical control in-hive using coumaphos and fluvalinate (Elzen et al., 1998; Sanford et al., 1999; Mostafa and Williams, 2002); and soil treatments using permethrin (Baxter et al., 1999; Hood, 2000). Kanga and Somorin (2012) confirmed that SHB adults were susceptible to fenitrothion, chlorpyrifos and methomyl. Fenitrothion proved most toxic to larvae. They concluded that these chemicals were more toxic than coumaphos (the active ingredient in CheckMite+). However, many (including permethrin) are also very toxic to other (non-target) insect species as well as honey bees and can lead to the development of resistant populations of beetles (De Guzman et al., 2011). The effects of organic acids were investigated by Schäfer et al. (2009) and Buchholz et al. (2011) who concluded that treatments of SHB-infested honey/pollen combs with acetic acid significantly increased mortality of adult beetles and that treatments with formic acid significantly reduced larval infestation.

Small hive beetle is stated to be successfully treated in beehives with CheckMite+ Strips™ (Elzen et al., 1999a) containing coumaphos, which is also used to control the parasitic mite *Varroa destructor* Anderson and Trueman (Elzen and Westervelt, 2002). Elzen et al. (1999a) attached trapping devices made of corrugated cardboard and CheckMite+ strips (10% w/w coumaphos) to the hive bottom boards. They reported a high efficacy with up to 90.2% mortality of adult hive beetle. However, Elzen et al. (1999a) evaluated only the number of hive beetles on the bottom boards of colonies. Since hive beetles are also found in other areas of the hive (e.g. on the combs, underneath the crown board lid or in small cracks in the hive walls (Lundie, 1940; Schmolke, 1974; Neumann and Elzen, 2004)), a quantification of hive beetle restricted to the bottom boards underestimates the overall infestation levels and, correspondingly, treatment efficacy. Therefore, in order to evaluate the efficacy of CheckMite+ Strips™ against natural infestations of the SHB it is crucial to inspect whole colonies for its presence, both before and after treatment (Neumann and Hoffmann, 2008). Levot (2007)[6] developed and successfully field trialled a SHB harbourage that comprised a two piece, tamperproof plastic housing for a fipronil-treated corrugated cardboard insert. The harbourages perform well, with reductions in beetle numbers of up to 96% in hives in which a single harbourage was deployed (Levot, 2008). The harbourage has since now been commercialised (Levot, 2012[7]) under the trade name Apithor™ and used widely throughout Australia and other areas for SHB control.

Lundie (1940) reported the use of carbon disulfide as a fumigant to control beetles in stored comb. More recently, Paradichlorobenzene has been suggested also as a fumigant for beetle control in stored comb (Mostafa and Williams, 2002). Household bleach was recommended as an effective material for killing beetle adults and larvae in honey houses (Park et al., 2002). Various soil treatment materials have been tested to control small hive beetles when they enter the soil to pupate. In South Africa, soil treatment tests were conducted using HCH (benzene hexachloride), carbaryl, chlordasol and salt solutions. Chlordasol was found to be most effective in this study. GardStar® (a.i. 40% permethrin) has been registered for over 10 years in many beetle infested states in the USA. The product is a soil drench that will kill beetle larvae and pupae when applied to the ground in front of bee colonies. GardStar® has also been recommended to kill the residual soil-burden of SHB pupae in treated apiary sites after beetle infested colonies have been removed (Delaplane, 1998). In Australia, the National Registration Authority (NRA) issued a permit to allow soil treatment with Farmoz Permex EC insecticide plus other registered products containing 500 g/l permethrin (White, 2003). Pettis and Shimanuki (2000) recommended pesticide soil treatments under and extending out 90–180 cm from the hive in all directions to control beetles. Placement of colonies on stands or blocks is recommended to prevent soil pesticide fumes from entering hive entrances (Hood, 2000).

Powdered limestone and slaked lime, also known as hydrated lime [$Ca(OH)_2$], have been tested for beetle

[6] Levot G, 2007. Insecticidal control of small hive beetle. Project report No. DAN 216A for Australian Government Rural Industries Research and Development Corporation. 27pp.

[7] Levot G, 2012. Commercialisation of the small hive beetle harbourage device. Project report No. PRJ-004606 for Australian Government Rural Industries Research and Development Corporation. 33pp.

pest control (Vittum, 1984, 1985; Abdalla, 1991; Watson et al., 2003). As slaked lime is characterised as hydrophilic and both substances increase pH-level, they may affect SHB pupation or serve as an alternative control agent for use in beetle traps in the hive. Buchholz et al. (2009) showed that slaked lime and a diatomaceous earth product (FS 90.0s) are suitable alternatives to conventional chemical control of SHB. While slaked lime hindered wandering larvae from pupating, diatomaceous earth was lethal for both adults and larvae when applied in traps within the bee colony and for larvae in laboratory trials. It is assumed that soil treated with, for example, slaked lime is unsuitable for larvae pupation due to its properties (high pH-level, dehydration). Buchholz et al. (2009) observed wandering larvae to survive for at least 35 days on soil unsuitable for pupation. This high longevity of wandering SHB larvae is in line with observations that they can remain alive even without soil, for up to 48 days (Cuthbertson et al., 2008a). According to Ellis et al. (2004b), soil moisture is one of the most important parameters for pupation. Due to the hydrophilic properties of slaked lime it is thought that the lime absorbs water from the soil and thereby disturbs the ability of SHB larvae to pupate. Abdalla (1991) described symptoms such as shrinking and desiccation of grubs of the scarabid beetle *Tropinota squalida* after contact with the water-absorbent lime. In Buchholz et al. (2009) SHB larvae showed no sign of shrinkage after lime exposure, probably due to the fact the larvae are post-feeding and therefore would not ingest any lime. When a slaked lime/soil mixture was applied as a layer, a high (>80%) proportion of wandering larvae completed their development in the untreated soil beneath (Buchholz et al., 2009). No dosage of pulverised limestone had any controlling effect on SHB (Buchholz et al., 2009). This is in line with findings that limestone had no effect on larvae of the Japanese beetle *Popillia japonica* (Vittum, 1984).

More recently biological control has been explored for the containment of the SHB (Ellis et al., 2004c). Biological control, using microbial pathogens and in particular entomopathogenic fungi, has the potential to act as an alternative to chemical insecticides (Lacey et al., 2001). Indeed, fungal pathogens are often highly host-specific and nontoxic to vertebrates (Lacey et al., 2001). Small hive beetle (adults and larvae) feed on fruit (Ellis et al., 2002) and decaying or fermenting hive products and reproduce readily on old and mouldy combs. These observations suggest that the SHB may be tolerant to a variety of microbial pathogens, which naturally occur in its environment. However, Lundie (1940) first reported a potential unidentified fungal control agent when noticing high mortality of adult beetles during laboratory rearing. Similarly, Ellis et al. (2004c) found a 32% SHB pupae mortality rate after contact of post-feeding larvae with pupae killed by a pathogen(s). Five fungal species were identified in a complex isolated from the pathogen-killed pupae: two of these were *Aspergillus niger* van Tieghem (Eurotiaceae) and *A. flavus* Link:Grey (Eurotiaceae). Both species are cosmopolitan soil fungi that appear to infect the SHB pupal stage when post-feeding larvae exit the host honey bee colony and burrow into the surrounding soil for pupation. Mortality of adult small hive beetle caused by an unidentified fungus was also observed during mass rearing of beetles (Müerrle and Neumann, 2004). A study by Leemon and McMahon (2009)[8] demonstrated that various isolates of both *Metarhizium* and *Beauveria* had good efficacy against larvae and adult SHB in laboratory assays. Generally the *Metarhizium* isolates performed best against larvae while the *Beauveria* isolates performed best against adult beetles. Three isolates of *Metarhizium* killed more than 70% of larvae by day 7, while 2 individual *Beauveria* isolates produced 99 and 100% mortality of adult beetles respectively 14 days after treatment. The fungal genera *Beauveria*, *Metarhizium*, *Hirsutella* and *Lecanicillium* are generalist entomopathogens with species- and strain-dependent differences in specificity and virulence against a range of insects (Kendrick, 1992; Lacey et al., 2001; Cuthbertson and Walters, 2005; North et al., 2006; Cuthbertson et al., 2005, 2008b). These fungi have a wide distribution and can be isolated from insects, mites, soil and a variety of other substances (Boucias and Pendland, 1998). Some strains are also commercially available. Muerrle et al. (2006) report promising results of the effects of several species of entomopathogenic fungi against SHB and recommend screening of further species to continue the development of an efficient mycoinsecticide. Entomopathgenic fungi are also being rigorously investigated as potential bio-control agents for *Varroa destructor* (Chandler et al., 2000; García-Fernández et al., 2008; Meikle et al., 2008).

Entomopathogenic nematodes (EPN) have been used

[8] Leemon D, McMahon J, 2009. Feasibility study into in-hive fungal bio-control of small hive beetle. Project report No. PRJ- 000037 for Australian Government Rural Industries Research and Development Corporation. 19pp.

successfully within control programmes for several insect species including beetles (Vega et al., 1994; Cuthbertson et al., 2003, 2007; Cabanillas, 2003; Smith et al., 2005). However, little information exists on their ability to infect SHB. Cabanillas and Elzen (2006) investigated the susceptibility of wandering larvae to commercially available EPN's. They found larvae to be susceptible to *Steinernema carpocapsae*, *S. riobrave* and *Heterorhabditis megidis* and suggest that mortality may be increased by targeting the pupal stages of the beetle, especially at times of the year when beetles spend many days in the soil before adult emergence. Recent work has demonstrated that the generalist entomopathogenic nematodes *S. riobrave, S. carpocapsae, S. kraussei* and *H. indica* have the potential to control larval stages of the SHB after a single soil application (Ellis et al., 2010; Cuthbertson et al., 2012). Ellis et al. (2010) concluded that nematodes could be used as a useful component of integrated pest management strategies aimed at reducing SHB populations below economic damage levels. Cuthbertson et al. (2012) showed that the nematodes *S. carpocapsae* and *S. kraussei* each provided total mortality of pupating larvae in sand pots and that nematodes readily emerged from dissected larvae (Fig. 5).

Additional biological agents may play a role in controlling the SHB in some areas or situations. Potential examples include parasitic wasps and flies, and predators such as ants (Hood, 1999; Torto et al., 2010). The fire ant, *Solenopsis invicta*, infests much of the current beetle-infested range in south eastern USA. Here the ant has been observed feeding on mature SHB larvae as they enter the soil to pupate (Hood, 1999). Fire ants may reduce beetle activity in some areas but little is known about this predator-prey relationship. Torto et al. (2010) observed that the ant *Pheidole megacephala* preyed on SHB larvae and significantly reduced their survival in semi-field experiments.

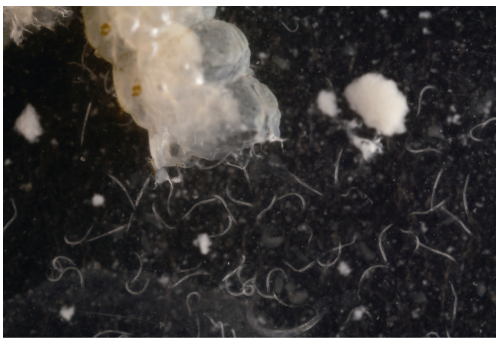

Fig. 5 Dissected *Aethina tumida* larvae releasing the entomopathogenic nematode *Steinernema carpocapsae* (UK Crown Copyright©).

The small hive beetle *Aethina tumida* offers a real potential risk to honey bees worldwide (Cuthbertson et al., 2010). The biology of the species enables it to survive a wide range of climatic conditions. The beetle has a very high reproductive rate, with population build up rapidly occurring under favourable conditions. A range of treatments including chemical and physical methods are offering various levels of control for this species. Continuing research into biological control also offers much potential.

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