

Control of *Aethina tumida* (Coleoptera: Nitidulidae) using in-hive traps

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Abstract—The small hive beetle (SHB), *Aethina tumida* Murray (Coleoptera: Nitidulidae), is a non-native pest of honey bees (*Apis mellifera* Linnaeus (Hymenoptera: Apidae)) newly introduced to Canada. The effectiveness of three in-hive traps was tested in springtime in West-Montérégie (southern Québec, Canada) and in late summer in Essex County (southern Ontario, Canada): AJ's Beetle Eater™ (AJ's Beetle Eater), Beetle Barn™ (Rossmann Apiaries), and Hood™ trap (Brushy Mountain Bee Farm). Traps were placed in the brood chamber of 12 colonies in West-Montérégie, and in 48 colonies in the top honey super in Essex County. In-hive traps were effective in reducing SHB populations without compromising the bee population or colony weight gain. In West-Montérégie, the Beetle Barn™ was the most effective trap during the first week, when SHB populations were high. It was less effective when honey bees sealed trap openings with propolis. In Essex County, the AJ's Beetle Eater™ was the most effective throughout the trial. There was no difference in efficacy between the various solutions used in the Hood™ trap (mineral oil versus mineral oil and apple cider vinegar).

Résumé—Le petit coléoptère de la ruche (CR), *Aethina tumida* Murray (Coleoptera: Nitidulidae) est un ravageur apicole (*Apis mellifera* Linnaeus (Hymenoptera: Apidae)) nouvellement arrivé au Canada. L'efficacité de trois modèles de pièges fut testée au printemps, en Montérégie-Ouest, au sud du Québec (Canada) et à la fin de l'été, dans le Comté d'Essex, au sud de l'Ontario (Canada): le AJ's Beetle Eater™ (AJ's Beetle Eater), le Beetle Barn™ (Rossmann Apiaries) et le piège Hood™ (Rocky Mountain Bee Farm). En Montérégie-Ouest, les pièges furent placés dans la chambre à couvain inférieure de 12 colonies tandis que dans le comté d'Essex, les pièges furent installés dans la hausse à miel supérieure de 48 colonies d'abeilles domestiques. Les pièges utilisés ont significativement réduit la population de CR par rapport aux colonies témoins. Ils n'ont pas eu d'effet sur la population d'abeilles immatures, ni sur la récolte en miel. En Montérégie-Ouest, le Beetle Barn™ a été le plus efficace à la première date de récolte, lorsque la densité de population de CR était élevée. Cependant, il perd de son efficacité lorsque les abeilles bouchent les ouvertures avec de la propolis. Dans le comté d'Essex, le AJ's Beetle Eater™ fut significativement plus efficace que tous les autres pièges. L'utilisation d'huile minérale ou du mélange d'huile minérale et de vinaigre de cidre de pommes dans le piège Hood™ n'a pas influencé l'efficacité de capture.

Introduction

The small hive beetle (SHB), *Aethina tumida* Murray (Coleoptera: Nitidulidae), is a pest of honey bees that originates from Africa (Lundie 1940; Schmolke 1974). It was first reported in the United States of America (Florida) in 1998 (Thomas 1998) and is now an invasive species in the United States of America, Mexico, Australia and, more recently,

Canada (Dixon and Lafrenière 2002; Somerville 2003; Neumann and Elzen 2004; Neumann and Ellis 2008; Giovenazzo and Boucher 2010; Kozak 2010). Adults enter hives or honey houses and reproduce. The larvae then inflict damages through their feces that contaminate honey and also through their associated yeast, *Kodamaea ohmeri* (Etchells and Bell) Yamada, Suzuki, Masuda, and Mikata (Fungi) (NRRL Y-30722), which induces honey

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fermentation (Torto *et al.* 2007b). The bees may also abscond if SHB infestation becomes too extensive (Ellis *et al.* 2003b).

Since the arrival of the non-native beetle in North America and Australia, various traps have been subject to testing. In-hive traps slow SHB population growth (Ellis 2005) and minimise damage to colonies by reducing the number of larvae produced. Trapping wandering larvae outside the hive may break the reproductive cycle of SHB and thus reduces damage to colonies. Efficacy of traps is variable. Modified hive entrances and screened bottom boards are inefficient (Ellis *et al.* 2003a; Hood and Miller 2005; Ellis and Delaplane 2006), while types including a coumaphos strip stapled under a cardboard, Hood™ trap (Brushy Mountain Bee Farm Inc., Moravian Falls, North Carolina, United States of America), jar-bottom board traps, and modified bottom board traps have been shown to be efficient (Elzen *et al.* 1999; Hood 2006; Torto *et al.* 2007a). Others seem to be effective but are marketed without any available scientific data (*e.g.*, AJ's Beetle Eater™ (AJ's Beetle Eater, Kundabung, New South Wales, Australia)) (Cobey 2008). Moreover, no SHB traps have been tested in Canadian honey bee colonies.

Most in-hive SHB traps follow the same principles. Because SHBs (4.7–6.3 mm long × 3.1–3.5 mm wide; Lundie 1940; Ellis *et al.* 2002; de Guzman and Frake 2007) are much smaller than honey bees (12–15 mm long), they are able to access traps through openings the bees cannot enter. Beetles also seek shelter in dark places (Lundie 1940). They then die inside the traps through contact with a pesticide or by drowning in a liquid. Coumaphos is the main pesticide used against SHB in honey bee colonies (Checkmite+™ strip, Bayer Health Care Animal Health Canada 2011). Baxter *et al.* (1999), Elzen *et al.* (1999), and Neumann and Hoffmann (2008) found mortality rates between 53% and 95% in field trials with in-hive coumaphos traps, and recommended their use for SHB control. Efficacy tests of drowning traps conducted by Hood and Miller (2003) showed that mineral oil and alcohol (95% ETOH) resulted in the highest SHB mortality (both mortality of 99%) in laboratory studies. They also showed that traps filled with apple cider vinegar caught many adult beetles in field trials, even if this liquid had a low mortality (18%) in laboratory studies, probably because vinegar acts as an attractant. Alcohol solutions evaporate quickly

and did not attract SHB in field trials. Using food grade mineral oil and apple cider vinegar has been shown to effectively attract and kill adult SHBs. Gillard (2008) recommended filling the middle compartment of the Hood™ trap with apple cider vinegar to attract the beetles, and the outer compartments with food grade mineral oil to kill them. Moreover, these natural substances can be used within an integrated pest management approach.

So far, no clear pattern of SHB congregation within bee colonies has emerged. Lundie (1940) observed that SHBs tend to congregate at the rear section of the bottom board as well as under the inner cover. Schmolke (1974) also observed SHBs on the outer frames, where honey bee density is low. Torto *et al.* (2007a) found that there were more SHBs captured in bottom board traps than in hive top traps, mostly when the number of SHBs was high. Finally, Neumann and Hoffmann (2008) recommended using traps on the bottom board to estimate the number of SHBs in a hive. Higher numbers of adult beetles were captured near the entrance of the hive. They also recommended placing more traps elsewhere in the colony (*e.g.*, side walls, outer combs, and top frames), because they only found $43 \pm 27\%$ of the total SHBs in traps located on the bottom board.

The aim of this study was to determine the effectiveness of three commercially available in-hive traps (AJ's Beetle Eater™, Beetle Barn™ (Rossmann Apiaries, Moultrie, Georgia, United States of America), and Hood™ trap) at controlling and limiting the infestation of SHB in Canadian honey bee colonies. The second objective was to test whether these traps had an effect on colony weight gain and brood population.

Materials and methods

West-Montérégie trial

The first field trial took place from 24 May to 28 June 2011, in West-Montérégie (municipality of Dundee, southern Québec, Canada). Two bee yards were used for this trial, Amhurst (45.0039, –74.4493) and Andrew (45.0007, –74.3626), located 6.7 km apart. Both sites were near the Canada/United States of America border: Amhurst at a distance of 770 m from the border and Andrew at 805 m.

Experimental colonies were hybrid Italian stock obtained from local breeders. In each bee yard, colonies consisted of one brood chamber

and one honey super separated by a queen excluder. They were placed on wooden pallets (two to four colonies per pallet), ~2 m apart in each bee yard. Colonies were checked weekly for well-being and queen cells were destroyed to avoid swarming. No supers were added or removed during the experiment. All the colonies had been naturally infested with SHBs the previous year (Giovenazzo and Boucher 2010). The colonies were destroyed a few days after the end of the experiment in order to limit SHB invasion.

On 23 May 2011, each colony was surveyed and the initial number of adult SHBs was assessed according to the methodology described by Spiewok *et al.* (2007). The lid, inner cover, bottom board, tops of frames, each side of each comb and side walls of each hive were carefully inspected.

On 23 May 2011, the number of immature bees was also estimated by measuring the brood area, as described in Giovenazzo and Dubreuil (2011). After initial colony evaluation, colonies of similar strength were divided in two groups: (1) control colonies without traps (control), and (2) colonies with all selected traps. The Amhurst site had 11 experimental colonies: three without traps (control) and eight with all the traps. The Andrew site had eight experimental colonies: four without traps (control) and four with all the traps.

In the West-Montérégie trial, selected traps and killing agents were: (1) AJ's Beetle Eater™ with mineral oil, (2) Beetle Barn™ with coumaphos 10%, and (3) Hood™ trap with mineral oil. All three traps were placed in the brood chamber and positioned to avoid interaction between them. The AJ's Beetle Eater™ and Hood™ trap were placed either on the left (L) or on the right side (R) of the brood chamber, relative to the hive entrance, but never on the same side. The Beetle Barn™ was placed either at the front (F, 20 cm behind the hive entrance) or rear (Re, 1 cm away from the back of the bottom board). This gives four placement possibilities that were randomly distributed among the group with traps.

Every week (30 May, 6 June, 13 June, 20 June, and 27 June 2011), colonies were weighed (in kg) using a scale modified for hives (Giovenazzo and Dubreuil 2011), and traps were inspected. Adult SHBs in each trap were counted and removed. When necessary, fresh mineral oil was added.

Effect of the presence/absence of traps on brood population. At the beginning (23 May 2011) and

the end (27 June 2011) of the experiment, the honey bee population was evaluated by estimating number of immature bees in each colony (Giovenazzo and Dubreuil 2011). The effect of the presence/absence of traps on brood population was evaluated by comparing the two groups (1) control, and (2) with traps, at the beginning and the end of the experiment.

Effect of the presence/absence of traps on SHB population. The effect of the presence or absence of traps on SHBs populations was evaluated by comparing initial and final populations of SHBs of the two groups (1) control, and (2) with traps. The initial number (23 May 2011) was evaluated according to Spiewok *et al.* (2007) methodology. The final number (27 June 2011) for each colony was estimated by summing the number of adult SHBs captured in each trap (30 May, 6 June, 13 June, 20 June, and 27 June 2011) and the final count of adult SHBs in colonies.

Effect of the presence/absence of traps on colony weight gain. Every week (23 May, 30 May, 6 June, 13 June, 20 June, and 27 June 2011), colonies were weighed (in kg). The effect of the presence or absence of traps on colony weight gain was evaluated by comparing the gain or loss of weight between groups.

Efficacy of in-hive traps. Every week (30 May, 6 June, 13 June, 20 June, and 27 June 2011), adult SHBs were counted and removed from each trap. The efficacy of traps was evaluated by comparing the number of captured adult SHBs in each trap of group 2 colonies.

Effect of positioning traps inside colonies. In the West-Montérégie trial, each colony had three traps placed in the brood chamber. We compared the number of SHBs captured in each trap for each trap location (L versus R for the AJ's Beetle Eater™ and the Hood™ trap, and F versus Re for the Beetle Barn™) to verify trap location effect on captured SHBs.

Essex County trial

The second field trial took place from 8 August to 5 October 2011, in Essex County, southern Ontario, Canada. For this trial, experimental colonies were located in three bee yards, Sheply (42.1208, -82.8397; 13 colonies), Garnet

(42.1146, –82.8686; 17 colonies), and Smith (42.1053, –82.9466; 18 colonies).

Colonies consisted of one brood chamber and two to four honey supers. Brood chambers and honey supers were separated by a queen excluder. Each colony was placed on a wooden base and grouped by two or four colonies. They belonged to a beekeeper in the area and were managed according to his regular practice. These colonies had been naturally infested with SHB the previous year (Kozak 2010).

Unlike the first trial in West-Montérégie, adult SHB populations were not assessed in the Essex County field trial. An attempt was made to do so, however, adult beetles were difficult to count with the Spiewok *et al.* (2007) method, partly because the honey bee colonies were too strong and contained too many honey bees and adult SHBs. However, we inspected each colony and most of the beetles we observed were on the top super at the time of observation.

In Essex County, selected traps and killing agents were: (1) AJ's Beetle Eater™ with mineral oil, (2) Beetle Barn™ and coumaphos 10%, (3) Hood™ trap with mineral oil or with mineral oil and apple cider vinegar. Each colony had three types of in-hive traps placed on top of honey super, with the same randomisation used in the West-Montérégie trial. The Beetle Barn™ was placed on top of the last honey super, underneath the lid instead of on the bottom board.

Traps were inspected every week (17 August, 24 August, 2 September, 9 September, 21 September, and 5 October 2011) and SHBs were counted and removed. The two last inspections were performed at a two-week interval. When necessary, fresh mineral oil or apple cider vinegar were added. The beekeeper repositioned the traps at their original location whenever he needed to remove or add honey supers.

Capture of adult SHBs in the Hood™ trap: mineral oil versus mineral oil and apple cider vinegar. Two types of liquid were tested in the compartments of the Hood™ trap. In 23 Hood™ traps, all the three compartments were filled with mineral oil and in the 25 other Hood™ traps, the middle compartment was filled with apple cider vinegar while the two other compartments were filled with mineral oil. The number of adult SHBs captured in those traps were counted at each inspection and compared.

Efficacy of in-hive traps. Adult SHBs were counted and removed from the in-hive traps at each inspection. The efficacy of traps was evaluated by comparing the number of captured SHBs in each trap, regardless of the type of liquid used in the Hood™ trap.

Efficacy of the Beetle Barn™. Each time, the number of sealed holes of the Beetle Barn™ was recorded. The holes were then cleaned. The number of sealed holes was then correlated to the number of adult SHBs captured in the trap to measure its efficacy.

SHB traps

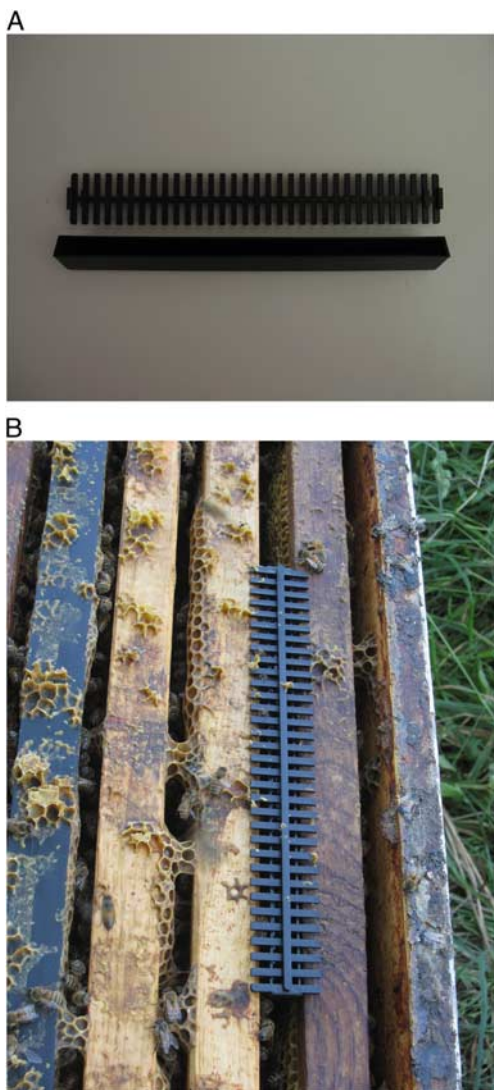
The three different in-hive traps we tested were ordered from the United States of America through F.W. Jones & Son Ltd. (Bedford, Québec, Canada). Below is a brief description of each trap.

AJ's Beetle Eater™ (AJ's Beetle Eater): This rectangular plastic trap (20.0 cm long × 1.1 cm wide × 2.0 cm deep) was designed by Tom Kennedy, an Australian beekeeper (Cobey 2008). It can hold up to 30 mL of food grade mineral oil. The comb-shaped lid has several 0.3 cm openings that allow adult SHBs to enter the trap and eventually drown in oil (Fig. 1A). This trap is placed on top of the brood chamber or honey super, in between the first and second frames (Cobey 2008) (Fig. 1B).

Beetle Barn™ (Rossmann Apiaries, www.gabees.com): This flat rectangular trap is made of black plastic (9 cm long × 7.5 cm wide × 0.7 cm deep, Fig. 2). It has small openings on each side (1.3 × 0.3 cm) that allow adult SHB to enter, but are too small for honey bees to pass through. A square piece (2 cm²) of Check Mite +™ strip (coumaphos 10% – Bayer Health Care Animal Health Canada 2011) is placed in the middle section of the trap. Adult SHB tend to hide from bees by entering the trap, and die upon contact with the insecticide strip. The Beetle Barn™ is placed on the hive bottom board or on top of frames.

Hood™ trap (Brushy Mountain Bee Farm): This trap was developed by Dr. Mike Hood at Clemson University in South Carolina (Hood 2006). It consists of a transparent plastic container (15 cm long × 2.5 cm wide × 8 cm deep, Fig. 3A) divided into three compartments (Fig. 3B) that hold up to 210 mL of food grade mineral oil or apple cider vinegar. The lid has a 12.8 × 0.3 cm opening (Fig. 3A) that allows adult SHB to enter, but no

Fig. 1. AJ's Beetle Eater trap™ (AJ's Beetle Eater). (A) Container and lid apart. (B) Trap placed in a brood chamber, on top of the first and second frames.

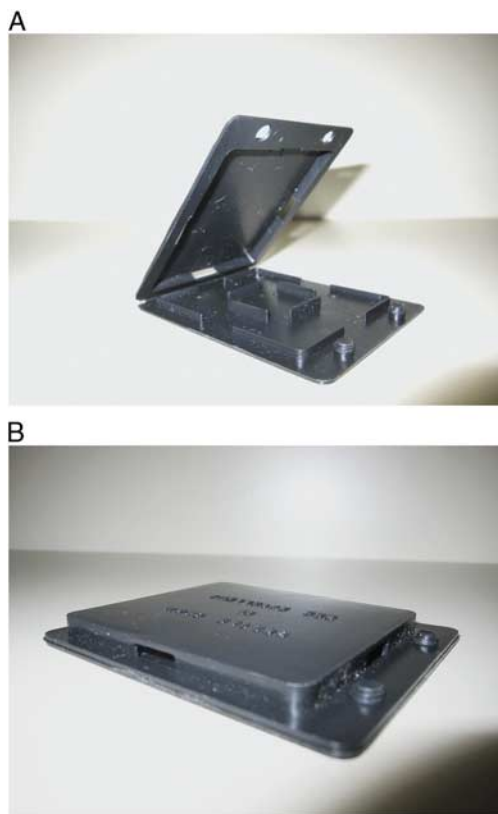


honey bees. The Hood™ trap is fixed on the bottom part of an empty wood frame (Fig. 3A) and placed next to the side wall of the brood chamber or a honey super, at frame position 1 or 10.

Statistical analysis

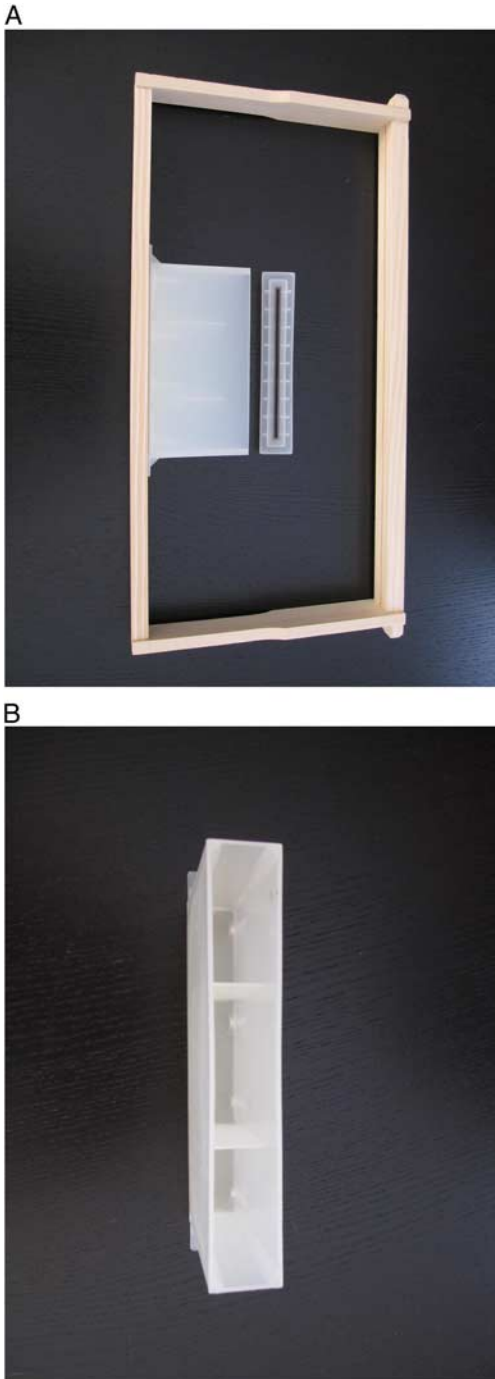
In the West-Montérégie trial, for which we have information from 19 colonies located in two sites, different analysis were done depending on the data structure. First, the 12 colonies with traps were

Fig. 2. Beetle Barn™ (Rossmann Apiaries). (A) Open. (B) Closed. Photograph credits: Martine Bernier.



compared with the other seven colonies without traps for the total brood and SHBs population. For these comparisons, generalised randomised block analysis of covariance models were used, with the random factor site (Amhurst and Andrew) as the blocking factor, and with the initial brood or SHB population as the covariate. For SHB population, the square root transformation was applied to both initial and final counts in order to meet the assumptions of the model. Colonies with traps were also compared with others without traps on the colony weight gain at the final date following the same model but without covariate. Another analysis was also applied on the 12 colonies with traps to compare the efficacy to capture SHB between three different traps (AJ's Beetle Eater™, Beetle Barn™, and Hood™ trap). All traps were present in each colony to reduce inter-colony variation and SHBs were counted over five time points, equally spaced. The comparison was done using a doubly repeated

Fig. 3. Hood™ trap (Rocky Mountain Bee Farm). (A) Trap placed in an empty frame, showing container and lid. (B) Inside the trap are three compartments. Photograph credits: Martine Bernier.



measure analysis of variance (ANOVA) model with the random effects of sites and colonies within sites. Measurements were taken across traps types and over time on each experimental unit, that is, on each colony. The covariance structure that best fit the data was the unstructured covariance for the traps and the first order autoregressive structure for the time points. Finally, the impact of the location of each trap type in the colony was evaluated. A similar model as the previous one was used with trap types and their locations combined into a global treatment factor. Contrasts were computed to compare the locations of each trap type.

In the Essex County trial, a first analysis was done to compare the number of SHBs captured in Hood™ traps filled with mineral oil those filled with a mixture of oil and apple cider vinegar. A repeated measures randomised block ANOVA model was used for this comparison, with the random factor “site” as blocking factor and treatment effect as part of the inter-colony variation. Dependence among observations taken over time on the same colony was accounted for by choosing the covariance structure that best fit the data based on the Akaike information criteria. Another analysis was done to compare efficacy of the traps inside colonies over time. For this purpose, a double repeated measures ANOVA model was used with site as random effect, and trap types and dates as repeated measures over the same experimental unit, that is, the colony. Finally, the strength of the association between captures in Beetle Barn™ and the number of sealed holes (X) over time was studied at each date using repeated measures ANOVA model with sites and colonies within site as random effects, and with X, dates and X × dates as fixed effects.

All analyses were done using the Mixed procedure of SAS (release 9.3, 2012; SAS Institute, Cary, North Carolina, United States of America) and the significance level was set to $\alpha = 5\%$. The normality assumption was verified using the Shapiro–Wilk’s statistic applied on the scaled residuals, while the homogeneity of variance was verified using the usual residual plots.

Results

West-Montérégie trial

Effect of the presence/absence of traps on brood population. There was no significant effect of

traps on the honey bee brood population ($F = 0.63$; $df = 1, 15$; $P = 0.4414$). On 27 June 2011, colonies without traps had 6082 ± 3666 immature bees (mean \pm SE) and colonies with traps had 8755 ± 3279 immature bees.

Effect of the presence/absence of traps on SHB population. Traps significantly reduced the SHB populations in honey bee colonies ($F = 17.44$; $df = 1, 15$; $P = 0.0008$) during trials. On 24 May 2011, at the start of experiment, initial average of adult SHBs for all colonies was 15.1 ± 19.3 (mean \pm SE) per colony (ranging from 0 to 88 adult SHBs per colony). On 27 June 2011, the final average number of adult SHBs was 4.4 ± 3.3 for colonies without traps and 0.7 ± 1.0 for colonies with traps. This represents a reduction of 83.3% compared with colonies without traps.

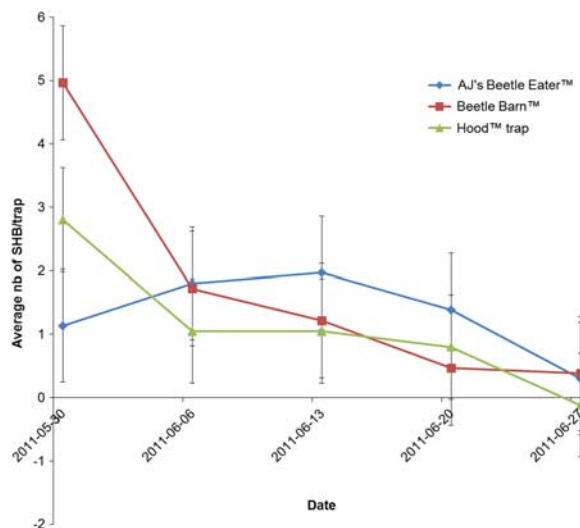
Effect of the presence/absence of traps on colony weight gain. There was no significant effect of traps on colony weight gain ($F = 1.23$; $df = 1, 15$; $P = 0.2850$). On 27 June 2011, colonies without traps gained 4.70 ± 2.88 kg (mean \pm SE) and colonies with traps gained 1.67 ± 2.60 kg.

Efficacy of in-hive traps. The interaction between traps and time was significant ($F = 2.56$; $df = 8$,

154 ; $P = 0.0121$). The greatest difference between trap efficacy was observed on 30 May 2011, at the first trap sampling. The Beetle Barn™ caught significantly more adult SHBs than the Hood™ trap and the AJ's Beetle Eater™ ($F = 8.05$; $df = 2, 154$; $P = 0.0005$) (Fig. 4). At that time, the Beetle Barn™ caught 5.0 ± 0.9 (mean \pm SE) adult SHBs while the Hood™ trap caught 2.8 ± 0.8 and the AJ's Beetle Eater™ caught 1.1 ± 0.9 adult SHB. There was no significant difference between the efficacy of traps for the following sampling dates: 6, 13, 20, and 27 June 2011.

Effect of positioning traps inside colonies. The positioning of traps in colonies, that is, left or right for the AJ's Beetle Eater™ and the Hood™ trap, and front or rear for Beetle Barn™, significantly influenced the number of adult SHBs caught in the traps ($F = 3.07$; $df = 3, 139$; $P = 0.0301$). The Hood™ trap can be placed either on the left or on the right side of the brood chamber and the Beetle Barn™ can be placed either on the front or the rear of the bottom board with equal efficacy. However, the AJ's Beetle Eater™, when placed on the left side, caught 2.0 ± 0.8 adult SHBs while it captured 0.5 ± 0.8 adult SHB when placed on the right side.

Fig. 4. Average number (\pm SE) of small hive beetle (SHB) caught in traps according to the type of trap, from 30 May 2011 to 27 June 2011, in West-Montérégie, Québec, Canada.



Essex County trial

Capture of SHBs in the Hood™ trap: mineral oil versus mineral oil and apple cider vinegar. The use of mineral oil with or without apple cider vinegar had no significant effect on number of SHBs captured in the Hood™ traps ($F = 0.001$; $df = 1, 44$; $P = 0.9452$). Traps with mineral oil captured an average of 2.7 ± 0.6 (mean \pm SE) adult SHBs per week, while an average of 2.5 ± 0.5 adult SHBs per week were captured in traps filled with mineral oil and apple cider vinegar.

Efficacy of in-hive traps. The interaction between traps and time was significant ($F = 4.81$; $df = 10, 799$; $P < 0.0001$, Fig. 5). The AJ's Beetle Eater™ captured significantly more adult SHBs than the two other traps while Beetle Barn™ captured less adult beetles than the two other traps at every sampling date.

Efficacy of the Beetle Barn™. Honey bees tend to seal the openings of Beetle Barn™ trap with propolis, which reduces its effectiveness if it is not cleaned regularly. The interaction between

the number of sealed holes and time was significant ($F = 3.79$; $df = 5, 229$; $P = 0.0025$), especially for 17 August 2011 ($P = 0.0011$) and 24 August 2011 ($P = 0.0015$). Fewer SHBs were captured in Beetle Barn™ traps when more than two holes were sealed (Fig. 6).

Discussion

This study provides a comparative evaluation of SHB traps in Ontario and Québec honey bee colonies. At the time of trap evaluations, SHBs infestation levels were higher in Ontario apiaries. We tested the effectiveness of three commercially available in-hive traps (AJ's Beetle Eater™, Beetle Barn™, and Hood™ trap) to control and limit the infestation of SHBs adults in Canadian honey bee colonies. We found that the Beetle Barn™ and the AJ's Beetle Eater™ are the most effective traps without significantly affecting colony weight gain or brood population.

In the Quebec West-Montérégie trial, from May to June, the use of in-hive traps effectively reduced beetle populations. Hood (2006) reached

Fig. 5. Average number (\pm SE) of small hive beetle (SHB) captured per trap, from 17 August 2011 to 5 October 2011, in Essex County, Ontario, Canada.

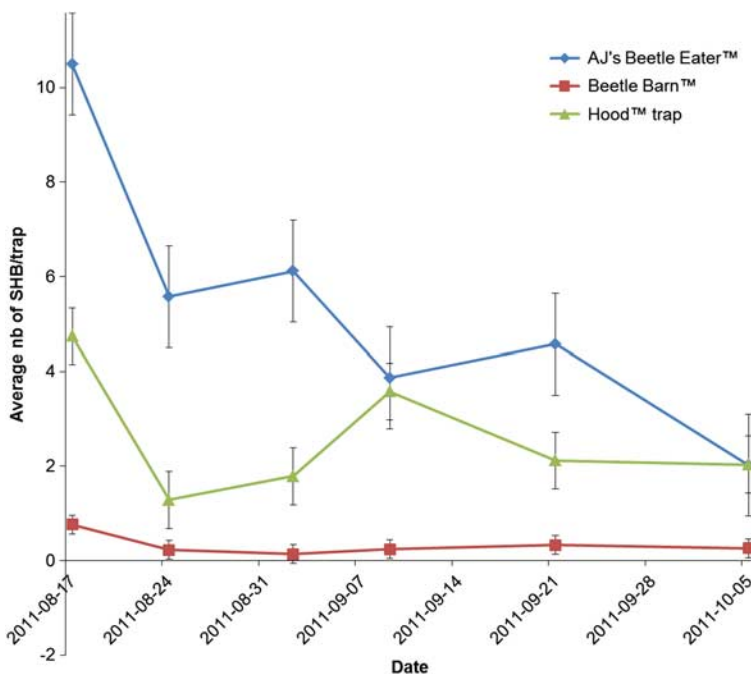
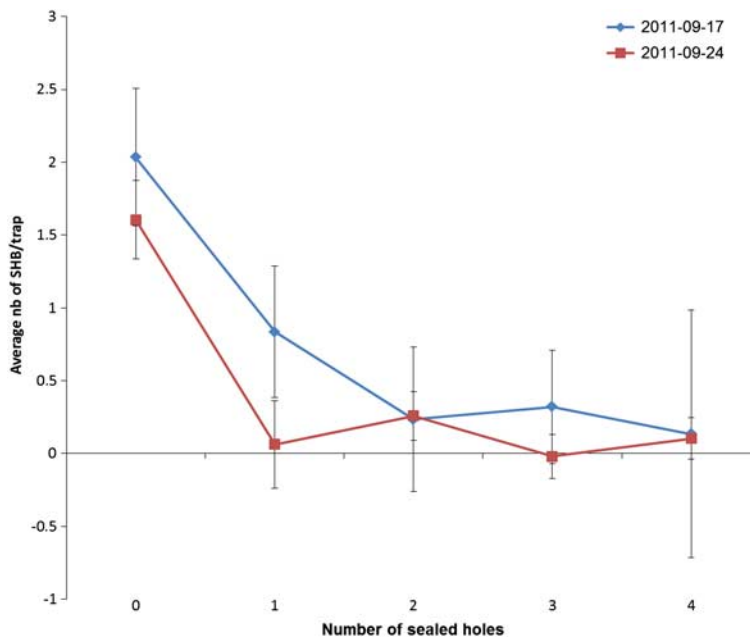


Fig. 6. Average number (\pm SE) of small hive beetle (SHB) captured by the Beetle Barn™ during week 1 and 2 in Essex County, Ontario, Canada.



the same conclusion with Hood™ traps and jar-bottom board traps. However, in colonies with no traps, the number of SHBs also declined. We speculate that this is a result of SHBs movement within colonies. Many individuals may have left a trap-free colony only to be caught in colonies that had traps. Adult SHBs are active flyers and are known to frequently move from one colony to another (Ellis 2005). Therefore, the use of in-hive traps might reduce the overall population on adult SHBs in an apiary, even if traps are not in all colonies, especially if the level of infestation is low.

In Essex County, we did not count the initial and final numbers of SHBs. SHBs are hard to find in July and August in strong colonies with two brood boxes and two honey supers. They move quickly (Schmolke 1974) and hide from light. There is therefore an important bias when trying to count them. There was also a risk of SHB reintroduction because of high infestation rates in nearby apiaries. However, every single colony that we used in this trial was infested with several individuals. At the time we examined the colonies, SHBs were visible mostly in the top honey

super. We then put the traps on top of honey super, instead of on top of the brood chamber as done in the West-Montérégie trial, in an attempt to capture them where we saw them. The seasonal dynamics of SHB have not been reported yet and might be different in Canada, where the SHB invasion is recent. Moreover, location of adult beetles in colonies has never been examined in relation to the moment of the season and the amount of food available in the colony. These parameters merit verification in the future.

In the West-Montérégie trial, traps had no effect on brood population or colony weight gain. Adult SHBs densities were low, and they may not have been high enough to cause damage to the colonies. Colonies were strong and quite aggressive, and thus seemingly able to control the beetles. No SHB larvae were observed during this trial. However, this trial lasted only for a six-week period and no honey supers were added because the colonies were doomed to be destroyed at the end of trials. The effects on bee population and colony weight gain still need to be assessed on a longer period on time, with colonies properly managed.

There are obviously both advantages and disadvantages associated with the traps we tested. All traps are easily obtained at a relatively low cost (Hood and Miller 2003; Hood 2006; Cobey 2008; Gillard 2008). They can be placed almost anywhere in the colony, except for the AJ's Beetle Eater, which must be placed on the left side of the brood chamber to be more effective. However, this significant result might have been the effect of hive orientation in the apiary. Moreover, further studies should be conducted to determine the most effective in-hive trap position in relation to the moment in the beekeeping season, because SHB position in the colony may vary during beekeeping season. Bees also tend to propolise or deposit wax in the small openings of in-hive traps (Hood 2006; Gillard 2008). For example, Hood and Miller (2003) found that 30% of trap openings were sealed with propolis, especially when there was apple cider vinegar inside. According to Cobey (2008), this limitation can be avoided with AJ's Beetle Eater™ by placing a mat over the trap. Another option is to regularly clean traps. The use of AJ's Beetle Eater™ requires opening the hive. This is time consuming, and therefore is a disadvantage of using this type of trap. The container is also small and the liquid used in the trap is subject to evaporation. We found the device difficult to manipulate because of its small size and the way the lid is clipped on the container. We found Beetle Barn™ to be the most convenient trap and the position of this trap did not have an effect on number of SHBs captured. The Beetle Barn™ can easily be inserted in the hive through the bottom board entrance with a standard hive tool. Moreover, a wire can be slipped through the two side openings of the trap to form a large loop that hangs outside the hive. The trap can be withdrawn by pulling the wire at the same time it is lifted off the floor with a hive tool. Opening of the hive is not required for inspection, which is a great time-saver. However, this trap must be cleaned frequently, because bees tend to seal openings with propolis. As shown in this study, the trap is less effective when more than two openings are sealed. The SHB could also develop resistance to coumaphos, as have varroa mites, another bee pest (Sammataro *et al.* 2005). Moreover, we do not know whether use of this trap could lead to an accumulation of coumaphos residue in honey. Kanga and Somorin (2012)

showed that chlorpyrifos ($LC_{50} = 0.53 \mu\text{g}/\text{vial}$), fenitrothion ($LC_{50} = 0.53$), and parathion ($LC_{50} = 0.68$) were more effective in killing adult SHB than coumaphos ($LC_{50} = 1.61$). However, these pesticides, like coumaphos, are organophosphates and using the same chemical family for several years in a row increase the risk of pest resistance to the chemicals. Chemical families should be used in alternation in order to avoid pest resistance (Whalon *et al.* 2008). Risks for honey bees and human consumption have yet to be assessed.

Unlike Hood and Miller (2003), we did not find differences between the use of mineral oil alone compare to mineral oil and apple cider vinegar in Hood™ traps. Beekeepers could effectively use either in their colonies. Mineral oil or apple cider vinegar must be replaced occasionally (Gillard 2008). Bees may fill the container with wax particles (Gillard 2008). A major disadvantage of the Hood™ trap is that it uses frame space. Consequently, honey bees can store less honey and pollen, which could lead to a lack of food in dearth periods and allows the beekeeper to extract less honey. Bees also tend to build drone cells in this empty frame, which can increase number of varroa mites if it is not managed properly (Hood 2006).

In conclusion, the use of in-hive traps to capture and kill SHBs in honey bee colonies is an effective way to reduce infestation levels, but further research is needed to assess trap efficacy and trap impact on colonies according to the moment of the beekeeping season, SHB populations and location of SHBs in colonies. The use of traps can also be combined with good management practices such as to keep colonies strong and healthy, as well as selection of resistant bee stock for breeding (Ellis 2005).

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