Effect Of Height and Color on the Efficiency of Pole Traps for *Aethina tumida* (Coleoptera: Nitidulidae)

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ABSTRACT Olfactory cues released by adult bees, brood, pollen, and honey from a honey bee, *Apis mellifera* L., colony are the primary stimuli that guide the beetle *Aethina tumida* Murray (Coleoptera: Nitidulidae) to host colonies. To investigate the response of adult *A. tumida* to visual stimuli, we tested the influence of color and height on trap efficiency. Two pole trap colors (black and white) were evaluated at three heights (46 cm, 1 m, and 3 m) from October 2008 to December 2009. *A. tumida* were trapped in the greatest numbers between 17 April and 15 May 2009. The lowest numbers were captured during the winter and fall. The trapping results showed that both color and trap height significantly influenced capture. The average catch in the white traps (mean ± SE, 2.47 ± 0.30) was significantly higher than that of the black traps (1.53 ± 0.29) probably because white is more reflective than black. Among the heights evaluated, there were more beetles caught when traps were positioned at 46 cm (the same height as the entrance of the hives) with 3.07 ± 0.51 beetles compared with beetles captured at 1 m (1.88 ± 0.30) or 3 m (1.06 ± 0.18) high. Male and female beetles exhibited similar responses to trap color and height. The relationship between the numbers of beetles in colonies and capture rates in traps was very poor and did not provide a basis to evaluate trap efficiency. In addition, because capture rates seemed generally low in relationship to the number of beetles in the apiary, substantial improvements to the trap may be necessary.

KEY WORDS *Aethina tumida*, out-hive traps, in-hive traps, white trap, polyvinyl chloride trap

The beetle *Aethina tumida* Murray (Coleoptera: Nitidulidae) can cause serious problems for beekeepers in the southeastern United States when large numbers are present in honey bee, *Apis mellifera* L., colonies (Elzen et al. 1999). This abundance of *A. tumida* in the south is due to their increased reproduction and accelerated development during hot summers (de Guzman and Frake 2007). As a result, more generations of *A. tumida* per year are expected and produce populations large enough to reach damaging levels. Colonies taken over by *A. tumida* can produce hundreds to thousands of *A. tumida* larvae, the most damaging developmental stage. After successful pupation in the soil, they emerge as adults and reinfest active bee colonies. Hives are invaded through the fall and winter and become the springtime inhabitants of the colonies (de Guzman et al. 2010).

There are two recommended control measures for *A. tumida:* coumaphos strips (CheckMite$^+$, Mann Lake Ltd., MN) stapled to corrugated board for use inside the colonies and GardStar (Y-TEX Corporation, Cody, WY) to drench soil in front of colonies. However, chemical control can lead to resistant populations and toxicity to bees and pesticides in honey are always a concern. The use of chemicals always has negative consequences. At present, trapping is potentially the most useful tool in controlling adult *A. tumida* in honey bee colonies and apiaries. These trapped adults are the potential mates and egg layers. Thus, effective trapping reduces reproduction and minimizes damage to colonies. Different designs of *A. tumida* traps are now commercially available. These traps are specifically designed for in-hive trapping and some require baits containing insecticides that are toxic to honey bees. *A. tumida* adults and worker bees exchange food (trophallaxis) (Ellis et al. 2002). Thus, killing agents used with in-hive traps are potentially spread to honey bees by *A. tumida* adults. Also, in-hive traps require manipulation of colonies every time traps are serviced. In contrast, baited traps for use outside the hives are more advantageous because honey bees are not exposed to the negative effects of killing agents and chemical contamination of hives, including honey and other hive by-products is minimized. In addition, out-hive traps are less labor-intensive because no colony manipulation is involved. At present, there is only one successful out-hive trap for adult *A. tumida* with experimental support. This is the pole trap made of black polyvinyl chloride (PVC) pipe containing fermented pollen dough bait and hung at a height of 1 m (Arbogast et al. 2007).

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Table 1. Numbers of *A. tumida* adults counted inside colonies and collected from traps through time

Apiary	Date	No. colonies	Mean *A. tumida* per colony	Total adult *A. tumida* in the apiary	Date range	Mean *A. tumida* per trap	Total *A. tumida* from traps
1	10/10/2008	32	29.6 ± 3.4	946			
	2/13/2009	28	10.8 ± 2.0	303	10/31/2008–2/6/2009	0.03 ± 0.01	8
	7/30/2009	16	165.0 ± 34.8	2,640[a]	2/20/2009–7/10/2009	1.34 ± 0.28	443
	11/6/2009	29	86.1 ± 18.5	2,498[a]	8/7/2009–11/2/2009	1.08 ± 0.14	226[a]
	1/22/2010	22	47.3 ± 17.0	1,041[a,b]	11/13/2009–12/7/2009	0.17 ± 0.05	10[a]
2	10/29/2008	27	174.4 ± 23.0	4,709			
	4/2/2009	17	34.9 ± 10.2	594	11/7/2008–3/20/2009	0.15 ± 0.04	48
	7/20/2009	44	21.3 ± 3.0	939	4/3/2009–7/10/2009	5.39 ± 0.87	1,294
	10/19/2009	42	60.3 ± 5.1	2,534	7/24/2009–10/16/2009	2.10 ± 0.43	441
	1/21/2010	13	16.4 ± 2.4	213[b]	11/2/2009–12/7/2009	0.12 ± 0.04	11

[a] Total number of *A. tumida* in the apiary or total trapped *A. tumida* for new location.
[b] Final *A. tumida* count in the colonies; no final count was obtained from colonies at the initial site 1.

Numerous insect traps have been developed by examining the response of target insects to colors. Improvement of those traps was then made by determining the height of traps that provides optimum catch. Therefore, this study was conducted to determine the influence of color and height on the catch efficiency of the PVC pole traps.

Materials and Methods

Trap Setup. Trap configuration and components were as described by Arbogast et al. (2007). The effect of color was tested by constructing traps with either white or black PVC pipe (7.62 cm in diameter). In brief, each trap consisted of a pollen dough bait (one-fourth cup placed in a mesh bag) inoculated with the yeast *Kodamaea ohmeri* (Teal et al. 2006), one Vaportape II (Hercon Environmental, Emigsville, PA) to kill any trapped *A. tumida*, and two vials with water (≈16 ml each) and wick to maintain moisture of the bait. Traps were hung on white PVC poles. Each main pole held six traps on three pairs of wooden side-arms (≈15.24 cm out on each side of the pole): one black trap and one white trap hung at 46 cm above ground level (approximately the same height as the entrance of the hives within the apiaries), a black and white pair of traps at 1 m (height used for the first evaluation of this pole trap) and a pair at 3 m. Five poles (30 traps, 15 black and 15 white) were used in each of two apiaries.

The order of trap color on each pole was initially assigned randomly, but the positions of black and white traps at every height were reversed every time the traps were examined. Traps were installed on 25 October 2008 for apiary 1 and on 31 October 2008 for apiary 2. Examination of traps was done every 2 wk until 21 December 2009. At each examination, trapped *A. tumida* were collected, traps were cleaned and vials with water were either replaced or refilled. Baits were changed when baits showed signs of drying. Because other species of beetles also were trapped, all captured beetles (*A. tumida* and other beetles that had similar size as *A. tumida* adults) were counted and examined under a microscope for accurate identification. The sex of the adult *A. tumida* also was determined by gently pressing the abdomen of live or freshly dead beetles. However, dried specimens were dissected under a microscope to determine their sex.

Apiary and Colony Setup. The two apiaries used in this study had established colonies headed by Russian, Italian, or supersedure queens. For both locations, the numbers of adult *A. tumida* in the colonies were determined by examining every frame, hive cover, hive walls, and bottom board of each colony for the presence of *A. tumida* (de Guzman et al. 2006). For each apiary, five observations of adult beetles in hives were made between October 2008 (before traps were positioned) and January 2010 (after the traps were removed) (Table 1). For all apiaries, the increase in the number of colonies was due to the addition of new colonies, and the decrease in colony numbers was due to either removal or death of colonies. On 23 April 2009, 44 colony divisions were obtained from apiary 2 colonies and moved to a holding site leaving only eight colonies. After 47 d, the 44 colonies were returned to the same apiary. The eight colonies were removed from the apiary before the arrival of the new groups of colonies thereby leaving no colony at apiary 2 for 1 wk. In July 2009, problems with raccoons (*Procyon lotor* L.) that destroyed traps and consumed the pollen dough bait and water became serious in apiary 1, necessitating the relocation of the traps to a different apiary. Hence, no data were obtained for one collection date in July for apiary 1. The new location had fewer colonies but with higher numbers of *A. tumida*s at the time of transfer. Continuous rainfall flooded this new location in 21 December 2009 and led to the termination of the experiment. The last observations for both apiaries were not included in the analyses because of the possible effects of flood waters.

Data Analyses. All data were standardized by date, apiary and pole to determine color and height effects. Because there were no *A. tumida* captured from October 2008 to early February 2009, these observation periods were excluded from the analyses. Analysis of variance (ANOVA) using Proc Mixed was used with color and height modeled as fixed effects. A color by height interaction was detected, so the data were analyzed separately by color and height by using the slice tests within Proc Mixed (SAS Institute 2008). Date, color and height were modeled as fixed effects to determine the trends of catches over time. Al-

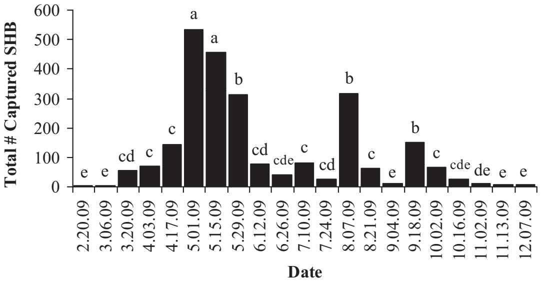

Fig. 1. Total numbers of small hive beetles caught in biweekly trappings from February 2009 through December 2009. Bars with different letters are significantly different ($P < 0.05$); statistical tests were conducted on mean differences and not total differences. Traps were installed in October 2008, but no *A. tumida* (SHB) were caught until February 2009.

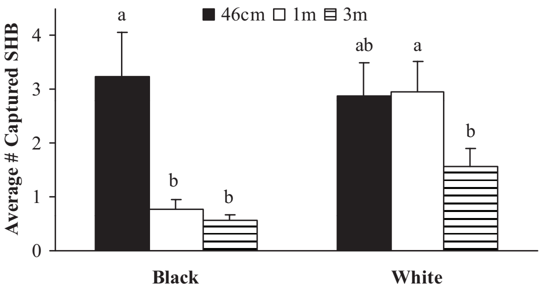

Fig. 2. Average number of *A. tumida* (SHB) caught per trap as influenced by trap color and height. Statistical tests were conducted separately by trap color; bars with different letters are significantly different ($P < 0.05$).

though there was no three-way interaction detected, two-way interactions (date by color and height by color) were observed, so the data were analyzed separately by color. To observe apiary trends through time, date, color, and height were modeled as fixed effects and analyzed by apiary. There were two-way interactions with color, so the data were analyzed separately by color by using the slice test in Proc Mixed. For these analyses, the data were transformed using the square-root transformation to normalize them (SAS Institute 2008).

Results

Seasonal Numbers of Trapped *A. tumida*. In total, 2,481 adult *A. tumida* were captured between mid-February 2009 and December 2009 (Fig. 1). Although the traps were established in October 2008, we did not trap any *A. tumida* until February 2009 and even then in very low numbers. As temperatures warmed in spring, the numbers of trapped *A. tumida* gradually increased reaching peak numbers in May. The numbers of trapped beetles declined significantly ($P < 0.0001$) in June and July and peaked again in early August, with a lesser peak in mid-September. Thereafter, catch numbers remained low until the end of the experiment on 7 December 2009, which was much like the period from February through March.

Effects of Trap Color and Trap Height. ANOVA revealed a significant interaction between color and height of traps ($F = 12.29$, $P < 0.0001$) (Fig. 2). Black traps caught 3.25 ± 0.82 (mean ± SE) at 46 cm, 0.78 ± 0.17 at 1 m, and 0.56 ± 0.11 beetles at 3 m. The average numbers caught by the 46-cm-high traps were significantly greater than the numbers caught by black traps at either of the other two heights. In contrast, white traps caught 2.88 ± 0.61 at 46 cm, 2.97 ± 0.56 at 1 m, and 1.56 ± 0.35 beetles at 3 m. The average numbers caught by the white traps at 1 m were significantly greater than the numbers caught by the white traps at 3 m. The average numbers caught by the white traps at 46 cm were intermediate and did not differ significantly from the number of beetles caught in white traps at either 1 or 3 m high.

Overall, higher captures were recorded from white (2.47 ± 0.30) than black (1.53 ± 0.29) traps ($F = 23.89$; $P < 0.0001$) and from 46-cm-high (3.07 ± 0.51) than 1- (1.88 ± 0.30) or 3-m-high (1.06 ± 0.18) traps ($F = 8.67$; $P = 0.0002$).

Effects of Trap Color and Trap Height on Captures of Males and Females. Very similar numbers of males (1,106) and females (1,341) were trapped. Generally, the average numbers of males and females trapped followed similar patterns of interaction between trap height and trap color when analyzed separately (Fig. 3).

Number of Beetles in the Apiaries and Colonies. The number of *A. tumida* adults inside colonies varied through time and between apiaries (Table 1). At the beginning of the experiment, apiary 2 had more *A. tumida* adults than apiary 1. The initial count at apiary 2 was never reached again despite the increase in the number of beetles observed in October 2009. At the end of the experiment, apiary 1 still had ≈1,041 *A. tumidas* (47.3 ± 17 *A. tumida* per colony), a reduction of 1,457 *A. tumidas* from the preceding count. A similar trend was observed in apiary 2 with a reduction of 2,321 *A. tumida* adults.

Other Species of Nitidulid Beetles Captured. Of all the nontarget insect species trapped, we only further

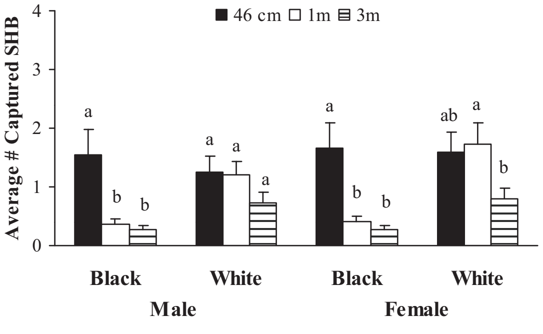

Fig. 3. Average number of female and male *A. tumida* (SHB) caught per trap as influenced by trap color and height. Statistical tests were conducted separately by trap color; bars with different letters are significantly different ($P < 0.05$).

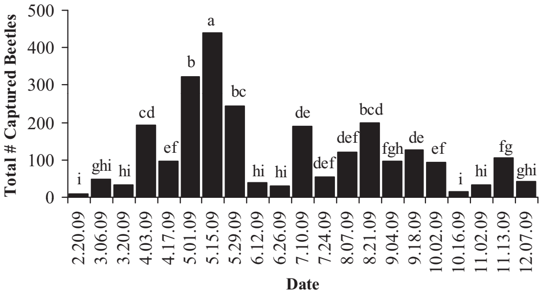

Fig. 4. Total numbers of other species of nitidulid beetles caught in biweekly trappings from February 2009 through December 2009. Bars with different letters are significantly different ($P < 0.05$).

examined the four species of nitidulid beetles that are similar in size to *A. tumida.* In total, 2,533 non-*A. tumida* nitidulids were caught between mid February and early December 2009. These species and the number of each caught were as follows: *Cryptarcha ampla* Erichson, 916; *Colopterus maculatus* Erichson, 838; *Lobiopa* sp., 553; and *Amphicrossus ciliatus* Olivier, 229.

The average number of other nitidulid species captured also varied significantly with color and height of traps ($F = 6.89$, $P = 0.001$). When pooled across species, the numbers of captures showed a peak capture in spring similar to *A. tumida* (Fig. 4). White traps were also more attractive than black traps ($F = 69.54$, $P < 0.0001$), with means of 2.84 ± 0.21 and 1.28 ± 0.11 beetles, respectively (Fig. 5).

Discussion

Several studies suggest that the *A. tumida* uses olfactory stimuli to locate hosts. These attractive stimuli include odors released by adult bees, brood, pollen, and honey (Elzen et al. 1999, Suazo et al. 2003, Torto et al. 2005), as well as volatiles produced by fermentation when symbiotic yeast carried by the beetle contaminates pollen and honey (Torto et al. 2007). In this study, we found that adult *A. tumida* also may use visual stimuli to locate hosts because white traps captured significantly more beetles than black traps. This difference in visual attraction to black and white may

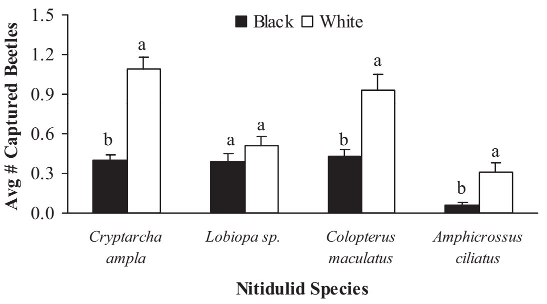

Fig. 5. Average number of other nitidulid beetles caught per trap as influenced by trap color. For each species, bars with different letters are significantly different ($P < 0.05$).

be due to the difference in reflectance. White reflects all wavelengths, whereas black absorbs them. Strom and Goyer (2001) reported that light colored (white and yellow) traps, grouped as "high peak reflectance," caught significantly fewer southern pine beetles, *Dendroctonus frontalis* Zimmermann, than the dark-colored (black, blue, brown, gray, green, red) or "low peak reflectance" traps. Our observations do not agree with their results. If we use Strom and Goyer's (2001) groupings however, our results corroborate the findings of Falach and Shani (2000) who showed that yellow traps (with a high reflectance similar to white traps) caught twice as many scarabid beetles (*Maladera matrida* Argaman) as did the black traps (low peak reflectance). In addition, the attraction of adult *A. tumidas* to the white traps may have been influenced by the use of white poles. Nevertheless, the wooden side-arms of the pole where the traps were actually suspended may have masked that cryptic effect.

The discrepancies between the results of Strom and Goyer (2001) and those of Falach and Shani (2000), as well as those of this study may be explained by physiological and behavioral differences between the various species studied. Nocturnal insects have evolved substantially different eyes than insects that are active in daylight (Saifullah and Tomioka 2003). The southern pine beetle is more active during the day (Coster et al. 1977), whereas the scarab beetle is nocturnal, being active for ≈2.5 h after sunset (Gol'berg et al. 1989). Observations regarding the effects of trap color on capture frequencies suggest that daytime flyers are more attracted to colors that have low peak reflectance, whereas nocturnal flyers are attracted to colors with high peak reflectance. The flight pattern of *A. tumida* has not been studied. Although we have seen adult *A. tumida* flying during daytime, they seem to be more active at dusk (L.I.G., unpublished data). This could explain the greater attraction of *A. tumida* to white traps.

Placing traps at the proper height will improve trap efficiency for various insects, including sap beetles (Peng and Williams 1991). Overall, our results showed that the lowest trap (46 cm), the same height as the entrance of the hives, captured the most beetles. In several dispersal studies, catches of pheromone traps decreased as a function of distance from the release point (Byers 1999). Arbogast et al. (2007), when studying the same traps with the same baits, concluded that the traps were effective in capturing adult *A. tumida* when they were hung at a height of 1 m. In the current study, the highest traps caught the least number of beetles. It may be that the kairomone emitted by the pollen dough bait used in this study had only short-range attractancy. Hence, the lowest trap would catch more beetles if the beetles were mostly just emerging from the soil where they pupate. Also, the placement of baits in the trap may have influenced the rate at which the attractants from the baits were released (Lindgren 1983). The pollen dough baits were placed at the bottom of the trap, which may have limited the release of attractant odors despite the presence of five small holes drilled through the bottom cap for drainage.

Our results also showed that the number of *A. tumida* captured varied through time. None, or very few beetles, were trapped in the fall and winter months when *A. tumida* activity is slowest. According to de Guzman et al. (2010), high numbers of *A. tumida* adults are usually observed inside the colonies during late summer and fall as adults prepare to overwinter. Although the *A. tumida* overwinters within the honey bee cluster (Pettis and Shimanuki 2000), the low number of trapped beetles in winter may suggest that cold temperatures greatly reduce flight activities but most importantly reproduction and the emergence of new adults.

The decline of *A. tumida* populations in the colonies over time in relation to the beetles captured by the traps was intended to provide an indirect measure of trap effectiveness. However, there seems to be no relationship between total numbers of beetles in the apiary and the numbers of beetles captured in the traps. It may be that the beetles that have found their way into colonies are no longer good candidates for out-hive trapping. During periods when beetles were lost from colonies, the capture of beetles in traps did not indicate that the loss was the result of trapping. Perhaps the beetles in the colonies died or left the apiary. Also, the traps generally did not catch large numbers of beetles although the numbers were sufficient to detect differences between trap colors and heights. Perhaps further improvements to the traps will result in a better relationship between numbers of beetles caught and the numbers of beetles in colonies.

The fact that other nitidulid species also were trapped suggests that the trap and bait may be useful in trapping other species of nitidulids. It is possible that the feeding or presence of one species of nitidulid beetle inside the trap may have produced enough kairomone to attract other species of sap beetles, including the *A. tumida.* Nevertheless, we did not see any of these four beetle species inside the colonies.

Our results suggest that out-hive traps are most effective during seasons when *A. tumida* are active. However, due to the multivoltine (more than one generation per year) nature of *A. tumida*s continuous trapping may impact dispersing populations even when only a few *A. tumida*s are captured. In this case, the combined use of in-hive traps in late summer through the fall when beetles are inside the hives (de Guzman et al. 2010), and out-hive traps in spring when *A. tumida*s are actively dispersing may substantially reduce *A. tumida* populations. Although these pole traps did not catch high numbers of beetles, the trends that we observed in this study provide us with a relative measure of *A. tumida* migration. Likewise, this new information on the response of *A. tumida*s to colors and the influence of height on *A. tumida* catches will facilitate the improvement of existing management strategies for the *A. tumida* or the development of new strategies.

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