Efficacy of Modified Hive Entrances and a Bottom Screen Device for Controlling *Aethina tumida* (Coleoptera: Nitidulidae) Infestations in *Apis mellifera* (Hymenoptera: Apidae) Colonies

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ABSTRACT This study was designed to test whether hive entrances reduced with polyvinyl chloride pipe reduce the ingress of *Aethina tumida* Murray into *Apis mellifera* L. colonies and whether screen-mesh bottom boards alleviate side effects associated with restricted entrances. Forty-eight colonies distributed equally between two locations each received one of six experimental treatments: 1) conventional solid bottom board and open entrance, 2) ventilated bottom board and open entrance, 3) conventional bottom and 1.9-cm-i.d. pipe entrance, 4) conventional bottom and 3.8-cm pipe entrance, 5) screen bottom and 1.9-cm pipe entrance, and 6) screen bottom and 3.8-cm pipe entrance. Results were inconsistent between apiaries. In apiary 1, colonies with 3.8-cm pipe entrances had fewer *A. tumida* than colonies with open entrances, but this benefit was not apparent in apiary 2. Pipe entrances tended to reduce colony and brood production in both apiaries, and these losses were only partly mitigated with the addition of screened bottom boards. Pipe entrances had no measurable liability concerning colony thermoregulation. There were significantly fewer frames of adult *A. mellifera* in colonies with 3.8- or 1.9-cm pipe entrances compared with open entrances but more in colonies with screens. There were more frames of pollen in colonies with open or 3.8-cm pipe entrances than 1.9-cm entrances. We conclude that the efficacy of reduced hive entrances in reducing ingress of *A. tumida* remains uncertain due to observed differences between apiaries. Furthermore, there were side effects associated with restricted entrances that could be only partly mitigated with screened bottom boards.

KEY WORDS integrated pest management, *Aethina tumida*, *Apis mellifera*, screened bottom boards, modified hive entrances

Aethina tumida MURRAY (small hive beetles), native to sub-Saharan Africa (Hepburn and Radloff 1998), were discovered in the southeastern United States in 1998 (Sanford 1998, Elzen et al. 1999). In their native range, *A. tumida* cause little damage to host colonies of African *Apis mellifera* L. subspecies in which they live and feed (Lundie 1940, Schmolke 1974, Ellis et al. 2003a). In contrast, *A. tumida* infestations in colonies of European-derived *A. mellifera* subspecies can cause general colony collapse (Elzen et al. 1999, Hood 2000, Ellis et al. 2003a), resulting in significant loss of colonies to beekeepers in the United States and Australia.

Since the introduction of *A. tumida* into the United States, little progress toward developing *A. tumida* control methods has been made. In-hive applications of coumaphos-impregnated plastic strips (Check-Mite, Bayer, Cody, WY) can be used to treat *A. tumida*, but control is not consistent (Elzen et al. 1999, Hood 2000, Wenning 2001). Furthermore, coumaphos does not provide extended control because the strips are not registered to remain in colonies continuously. Treating soil around infested colonies with permethrin (GardStar 40% EC, Y-Tex, Kansas City, MO) is recommended (Hood 2000, Pettis and Shimanuki 2000) because *A. tumida* pupate in soil (Lundie 1940, Schmolke 1974). However, this treatment is not always effective (Hood 2000, Wenning 2001), killing few *A. tumida* unless application is correctly timed (Pettis and Shimanuki 2000).

Ellis et al. (2002a) described a hive entrance modification that may be useful in an integrated approach to *A. tumida* control. Standard hive entrances were replaced with polyvinyl chloride (PVC) pipes, 10.2 cm (4 inches) in length and 1.9 cm (0.75 inch) i.d., inserted 7.6–10.2 cm (3–4 inches) above the bottom board (Fig. 1). Although colonies with pipe entrances contained significantly fewer *A. tumida*, Ellis et al. (2002a) noted undesirable side effects from using pipe entrances, namely, brood reduction, debris, and water buildup. The current study was designed to test whether screened bottom boards (used for control of

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Fig. 1. A colony fitted with a 3.8-cm PVC pipe entrance and screened bottom board (screen not visible) to restrict entry of *A. tumida* while compensating for a corresponding loss of hive ventilation.

Varroa destructor Anderson & Trueman in *A. mellifera* colonies; Pettis and Shimanuki 1999, Ostiguy et al. 2000, Ellis et al. 2001) and larger diameter pipes can alleviate side effects associated with pipe entrances while rendering efficacious *A. tumida* control.

Materials and Methods

The experiment was conducted in Richmond Hills, GA, from March to May 2002. Forty-eight Langstroth honey bee colonies consisting of single deep hive bodies were created as splits from existing colonies. An effort was made to minimize the number of *A. tumida* present in the new colonies (<5 *A. tumida* per colony). All Langstroth boxes were new and previously unused at the beginning of the study. Each colony was assigned one of six treatments and given four frames of bees, three frames of brood, one frame of honey, six frames of foundation (all new frames), and a laying queen. Assigned treatments consisted of 1) a conventional solid bottom board and open entrance (control), 2) a ventilated bottom board consisting of 2-mm-wide mesh plastic screen and open entrance, 3) conventional bottom and 1.9-cm i.d. (0.75-inch) PVC entrance, 4) conventional bottom and 3.8-cm (1.5-inch) i.d. PVC pipe entrance, 5) screen bottom and 1.9-cm i.d. PVC pipe entrance, and 6) screen bottom and 3.8-cm i.d. PVC pipe entrance (Fig. 1). All pipe entrances were 10.2 cm in length and inserted through the hive body 7.6–10.2-cm above the bottom board; colonies receiving pipes had their regular entrances blocked shut so that ingress and egress of bees was limited to the pipes. Bottom screen mesh size was chosen based on *A. tumida* biometry described by Ellis et al. (2002b); the goal was to permit exit of falling *V. destructor* while denying entry to *A. tumida.* The mesh size used in this study (2 mm) was smaller than that most often used for the control of *V. destructor* (3 mm) because *A. tumida* are small enough to move through 3-mm mesh screen. Alcohol samples of ≈300 bees were taken from each colony to estimate beginning *V. destructor* populations.

Table 1. Analysis of variance testing effects of reduced hive entrances (E) and bottom screens (S) on the average number of *A. tumida* adults per colony, net colony production kilograms, and colony brood production (frames)

Variable	source	df	*F*	*P* > *F*
	Apiary 1			
A. tumida per colony	E	2	4.8	0.0228
	S	1	0.8	0.3989
	E × S	2	6.3	0.0089
Colony production	E	2	3.6	0.0501
	S	1	0.03	0.8627
	E × S	2	1.2	0.3231
Colony brood production	E	2	4.7	0.0586
	S	1	6.5	0.0440
	E × S	2	1.8	0.2478
	Apiary 2			
A. tumida per colony	E	2	15.1	0.0002
	S	1	38.3	<0.0001
	E × S	2	18.0	<0.0001
Colony production	E	2	9.5	0.0017
	S	1	0.01	0.9243
	E × S	2	6.0	0.0107
Colony brood production	E	2	11.5	0.0020
	S	1	3.2	0.1013
	E × S	2	2.4	0.1348

There were significant interactions with the main effects and location, so these variables were analyzed by location. Terms were tested against residual error.

Table 2. Effects of reduced hive entrances and bottom board design on the average number of *A. tumida* adults per colony, net colony production kilograms, and colony brood production (frames)

	A. tumida			Production			Brood		
	Solid	Screen	Entrance totals	Solid	Screen	Entrance totals	Solid	Screen	Entrance totals
					Apiary 1				
Open	27.3 ± 3.4 (4)	61 ± 10.6 (4)	44.1 ± 8.2 (8)a	3.2 ± 1.5 (4)	1.9 ± 1.1 (4)	2.5 ± 0.9 (8)a	2.7 ± 0.8 (2)	2.8 (1)	2.7 ± 0.5 (3)a
1.9	30.3 ± 4.2 (4)	28.5 ± 4.1 (4)	29.4 ± 2.7 (8)ab	0 (4)	0 (4)	0 (8)b	0.4 ± 0.1 (3)	1.6 ± 0.6 (3)	1 ± 0.4 (6)a
3.8	30.3 ± 15.6 (3)	13.8 ± 2 (4)	20.9 ± 6.9 (7)b	0 (3)	1.8 ± 1.3 (4)	1 ± 0.8 (7)ab	0 (1)	2.6 ± 0.4 (2)	1.7 ± 0.9 (3)a
Bottom board totals	29.2 ± 4.1 (11)a	34.4 ± 6.9 (12)a		1.2 ± 0.7 (11)a	1.2 ± 0.6 (12)a		1.1 ± 0.6 (6)a	2.1 ± 0.4 (6)b	
					Apiary 2				
Open	3.8 ± 2.8 (4)	3.3 ± 0.8 (4)	3.5 ± 1.3 (8)b	17.7 ± 4.9 (4)	7.9 ± 2.7 (4)	12.8 ± 3.2 (8)a	1.8 ± 0.1 (4)	1.7 ± 0.2 (4)	1.7 ± 0.1 (8)a
1.9	40 ± 7.2 (3)	1.3 ± 0.8 (4)	17.9 ± 8.3 (7)a	0 (3)	0.9 ± 0.5 (4)	0.5 ± 0.3 (7)b	0.4 ± 0.1 (2)	1.2 ± 0.05 (3)	0.9 ± 0.2 (5)b
3.8	11.5 ± 4.6 (4)	1.5 ± 0.3 (4)	6.5 ± 2.9 (8)b	0.01 ± 0.01 (4)	9.6 ± 3.6 (4)	4.8 ± 2.4 (8)b	1 ± 0.2 (2)	1.2 ± 0.6 (2)	1.1 ± 0.3 (4)b
Bottom board totals	16.5 ± 5.3 (11)a	2 ± 0.4 (12)b		6.4 ± 3.1 (11)a	6.1 ± 1.8 (12)a		1.2 ± 0.2 (8)a	1.4 ± 0.1 (9)a	

Colonies were fitted with either a conventional solid bottom board (solid) or a screened bottom consisting of 2-mm plastic mesh (screen). Additionally, colony entrances were either open conventionally (open) or reduced to a single pipe of either 1.9- or 3.8-cm diameter. There were significant interactions with main effects and location (Table 1), so these variables were analyzed by location. Values are mean ± SEM; number in parentheses = *n*. Bottom board totals and entrance totals followed by the same letter are not different at the $\alpha \leq 0.05$ level. Means were separated using Duncan's test.

All superfluous cracks or holes in the colonies were caulked and the lids taped to the hive bodies. The treatments were equally distributed between two apiaries separated by ≈10 km and containing >50 colonies, each having existing *A. tumida* populations of >50 *A. tumida* per colony (based on visual estimates). Colonies were left unmanaged and available to invading *A. tumida.* Each treatment was replicated four times in each location for a total of eight replicates per treatment (2 locations × 6 treatments × 4 replicates = 48 colonies). During both weeks 4 and 8, one new (never used), preweighed, medium-depth Illinois super was added to experimental colonies so that each colony had two supers by the end of the study. Colonies were resealed after each super addition.

The experiment was terminated on day 70. Dead colonies were removed from the study. These colonies did not succumb to *A. tumida* pressures; rather, they were unable to establish after the initial colony setup. Data collected from all colonies included weighed alcohol samples of ≈300 bees (used to determine ending *V. destructor* populations and bee weight); net weight gain (kilograms) of medium supers (for colony production estimations); ending number of *A. tumida* (determined by aspirating and counting; Ellis et al. 2002a); number of deep frames of bees, pollen, and sealed brood (with visual estimates as per Skinner et al. 2001); and presence/absence of a laying queen. Bee weight was determined by weighing the jars of alcohol before and after the addition of bees; the difference between both weights (which was the total weight of bees in the jar) was divided by the number of bees in the jar to give individual bee weight. Unlike in our first study (Ellis et al. 2002a), there was no water accumulation in the colonies so this variable was not analyzed in the current study.

After data collection, all experimental colonies were moved to Oconee County, GA, and put in one location of maximum sunlight. Three days later, the temperature of the interior brood nest was determined with a hand-held digital thermometer.

Statistical Analysis. The data were analyzed in a randomized design analysis of variance (ANOVA) recognizing entrance type (open, 1.9-cm pipe, 3.8-cm pipe) and bottom screen (present or absent) as main effects and apiary location as block (except for colony temperature for which there was no location effect). There were interactions between the main effects and location for *A. tumida* per colony, net gain of honey supers, and colony brood production. As a result, the data for these variables could not be pooled and were therefore analyzed by apiary (Table 1). The test error term was residual error. Means were separated with Duncan's test and differences accepted at $\alpha \leq 0.05$. All analyses were conducted using the software package SAS (SAS Institute 1992).

Results and Discussion

In apiary 1, there were significantly more *A. tumida* in colonies with open entrances than in colonies with 3.8-cm pipe entrances (Tables 1 and 2). Colonies with

Table 3. Analysis of variance testing effects of reduced hive entrances (E) and bottom screens (S) on average weight per bee milligrams, average internal colony temperature (°C), percentage of *A. tumida* female, amount of adult bees (frames), amount of stored pollen (frames), and change in the number of *V. destructor* per adult bee

Variable	Source	df	*F*	*P* > *F*
bee wt	L	1	0.1	0.7392
	E	2	0.4	0.6675
	S	1	10.5	0.0029
	E × S	2	2.5	0.1026
	L × E × S	5	0.9	0.4923
Colony temp.	E	2	0.5	0.6380
	S	1	1.3	0.2584
	E × S	2	0.9	0.4034
% *A. tumida* females	L	1	4.7	0.0374
	E	2	1.0	0.3989
	S	1	1.5	0.2340
	E × S	2	0.2	0.8566
	L × E × S	5	0.6	0.70
Amount of adult bees	L	1	2.7	0.110
	E	2	13.0	<0.0001
	S	1	7.3	0.0106
	E × S	2	7.3	0.0023
	L × E × S	5	0.8	0.5736
Amount of stored pollen	L	1	0.04	0.8496
	E	2	8.4	0.0011
	S	1	0.01	0.9425
	E × S	2	4.7	0.0159
	L × E × S	5	0.9	0.5121
Change in no. of *V. destructor*	L	1	0.01	0.9430
	E	2	1.3	0.2866
	S	1	0.22	0.6443
	E × S	2	1.12	0.3379
	L × E × S	5	0.94	0.4674

The experiment was blocked on two apiary locations (L), except for colony temperature. The interaction L × E × S was never significant, so all terms were tested against residual error.

1.9-cm pipe entrances were not different from colonies with the other two entrance types. In apiary 2, *A. tumida* numbers were also affected by entrance, but the trend was different; there were significantly more *A. tumida* in colonies with 1.9-cm entrances than either 3.8-cm pipe entrances or open. The contrasting results for apiaries one and two suggest that other factors (such as apiary location and nectar flow) may be crucial in finally establishing the efficacy of reduced entrance devices in controlling *A. tumida.* Indeed, factors such as nectar flow may influence colony buildup and colony strength, which would directly contribute to the efficacy of pipe entrances in slowing beetle ingress because stronger colonies would likely guard the reduced entrances better. The success of reduced entrances in limiting *A. tumida* ingress reported in our previous work (Ellis et al. 2002a) may have been an artifact of particular season, larger numbers of invading *A. tumida*, and overall colony health.

An effect of screen on *A. tumida* numbers was apparent only in apiary 2 where there were more *A. tumida* in colonies without screens than in those with screens (Table 2). We cannot posit an explanation for this effect, especially because the trend was reversed in apiary 1. We do, however, believe the screen mesh used in this study did not allow increased *A. tumida* ingress because the mesh size was smaller than published data on *A. tumida* biometry (Ellis et al. 2002b). If one were to use a smaller mesh size, the potential attributes of such screens toward *V. destructor* control might be compromised. We noted that *A. tumida* often congregated outside the colony under the screen mesh. Presumably this is in response to colony odors dissipating through the screen below the hive. It is possible that future *A. tumida* control methods, in the form of below-hive trapping devices, could take advantage of this behavior.

In both apiaries, the net gain of honey supers was affected by entrance type (Table 1). In apiary 1, net gain was higher in open entrances than with 1.9-cm pipe entrances (Table 2). The 3.8-cm entrance group was not different from the other two. In apiary 2, net gain was higher with open entrances than either 3.8- or 1.9-cm entrances (Table 2). Thus, in some conditions the proposed IPM strategy may involve a cost to colony productivity. However the 3.8-cm entrance is clearly preferable over the 1.9-cm entrance and in one apiary it did not significantly reduce yield. Nevertheless, it seems prudent to limit use of the candidate integrated pest management (IPM) strategy to nonproduction seasons.

Concerning brood production, there was a significant effect of entrance in apiary two (Table 1); colonies with open entrances had more frames of sealed brood than colonies with either 3.8- or 1.9-cm pipe entrances (Table 2). Although not significant, the trend was the same in apiary 1. Thus, we conclude that there is a cost to brood production with this candidate IPM strategy, as suggested by Ellis et al. (2002a). There was a significant effect of screen in apiary one in which colonies with screens had significantly more frames of brood than colonies without. Although not significant, the trend was the same in apiary 2. Mean values in Table 2 show that brood production in colonies with reduced entrances was increased with the addition of a bottom screen. Thus, bottom screens may partially offset the negative effect of reduced entrances on brood. A positive effect of screens on brood has been reported in previous work (Pettis and Shimanuki 1999, Ellis et al. 2001).

Absence of interactions between main effects and apiary location permitted us to pool apiary data for bee weight, percentage *A. tumida* female, frames of adult bees, frames of pollen, and change in the number of *V. destructor* per adult bee; colony temperature was analyzed without location effects (Table 3). There was a significant effect of screen on bee weight, with heavier bees in colonies with screens than without (Table 4). There was no effect of screen or entrance on colony temperature. It is noteworthy that the candidate IPM strategy of restricted entrances had no measurable liability concerning thermoregulation by bees. The percentage of *A. tumida* female was affected only by apiary location, with significantly more female *A. tumida* in apiary two (71.4 ± 7.2%) than apiary one (53.2 ± 2.9). In both apiaries there were greater numbers of female *A. tumida* than males. Female-biased *A. tumida* sex ratios have been reported by others (Schmolke 1974; Neumann et al. 2001; Ellis et al.

Table 4. Effects of reduced hive entrances and bottom board design on average weight per bee (milligrams), average internal colony temperature (°C), percentage of *A. tumida* female, amount of adult bees (frames), amount of stored pollen (frames), and change in number *V. destructor* per adult bee

	Bee wt			Temp.		
	Solid	Screen	Entrance totals	Solid	Screen	Entrance totals
Open	133.9 ± 5.6 (8)	135.5 ± 4.2 (6)	134.6 ± 3.6 (14)a	34.1 ± 0.4 (8)	34.3 ± 0.4 (8)	34.2 ± 0.3 (16)a
1.9	121.1 ± 4.8 (7)	141.1 ± 4.5 (7)	131.1 ± 4.2 (14)a	35 ± 0.2 (4)	34.4 ± 0.6 (8)	34.6 ± 0.4 (12)a
3.8	117.2 ± 5.1 (7)	141.6 ± 7.5 (8)	130.2 ± 5.5 (15)a	35.1 ± 1 (5)	33.8 ± 0.5 (8)	34.3 ± 0.5 (13)a
Bottom board totals	124.5 ± 3.3 (22)a	139.7 ± 3.3 (21)b		34.6 ± 0.4 (17)a	34.2 ± 0.3 (24)a	
	% Female			Bees		
	Solid	Screen	Entrance totals	Solid	Screen	Entrance totals
Open	53.9 ± 11.5 (7)	60.7 ± 11.6 (8)	57.5 ± 8 (15)a	6.7 ± 1 (8)	5.1 ± 0.7 (8)	5.9 ± 0.6 (16)a
1.9	50 ± 3 (7)	64 ± 7.7 (6)	56.5 ± 4.2 (13)a	0.6 ± 0.2 (7)	3.7 ± 0.5 (8)	2.3 ± 0.5 (15)b
3.8	68.6 ± 10.1 (7)	71.7 ± 9.7 (8)	70.3 ± 6.8 (15)a	2.4 ± 0.8 (7)	5.6 ± 0.9 (8)	4.1 ± 0.7 (15)c
Bottom board totals	57.5 ± 5.2 (21)a	65.6 ± 5.7 (22)a		3.4 ± 0.7 (22)a	4.8 ± 0.4 (24)b	4.8 ± 0.4 (24)b
	Pollen			Change in no. of *V. destructor*		
	Solid	Screen	Entrance totals	Solid	Screen	Entrance totals
Open	0.9 ± 0.2 (8)	0.5 ± 0.1 (8)	0.7 ± 0.1 (16)a	0.04 ± 0.04 (7)	0.006 ± 0.003 (8)	0.02 ± 0.02 (15)a
1.9	0.1 ± 0.1 (7)	0.3 ± 0.1 (8)	0.2 ± 0.05 (15)b	−0.001 ± 0.0006 (7)	0.03 ± 0.03 (8)	0.01 ± 0.01 (15)a
3.8	0.4 ± 0.1 (7)	0.6 ± 0.1 (8)	0.5 ± 0.07 (15)a	−0.02 ± 0.01 (7)	−0.0003 ± 0.0003 (8)	−0.01 ± 0.006 (15)a
Bottom board totals	0.5 ± 0.09 (22)a	0.5 ± 0.06 (24)a		0.005 ± 0.01 (21)a	0.01 ± 0.01 (24)a	

Colonies were fitted with either a conventional solid bottom board (solid) or a screened bottom consisting of 2-mm plastic mesh (screen). Additionally, colony entrances were either open conventionally (open) or reduced to a single pipe of either 1.9- or 3.8-cm diameter. Values are mean ± SEM; number in parentheses = *n*. Bottom board totals and entrance totals followed by the same letter are not different at the $\alpha \leq 0.05$ level. Means were separated using Duncan's test.

2002b, c). Because the percentage of females was not affected by bottom type, there is no reason to believe that female beetles (which are bigger than males and perhaps unable to cross the screen as well as males) were excluded from hives with screens more than males.

Frames of adult bees were affected by screen and entrance, with more bees in colonies with screens and significantly fewer bees in colonies with 3.8-cm pipe entrances or 1.9-cm entrances compared with open entrances (Table 4). There was also a significant interaction for this variable between screen and entrance, apparent in Table 4. In colonies without bottom screens there was a more pronounced decline in bee population with the addition of a reduced entrance, and the compensation afforded by the larger of the two entrances (3.8 cm) was modest. In colonies with screens, however, the addition of a reduced entrance reduced bee population only with the smaller 1.9-cm entrances; population with 3.8-cm entrances was actually higher than in the open entrances (Table 4). Thus, although there is an overall cost to adult bee population with reducing colony entrances, this cost can be offset in 3.8-cm pipe entrances if the beekeeper simultaneously uses a screened bottom board.

Frames of pollen were affected by entrance, with significantly more pollen in colonies with open entrances or 3.8-cm pipe entrances than 1.9-cm entrances (Table 4). Thus, there seems to be a cost to pollen storage with entrances reduced below 3.8 cm. Furthermore, there was a significant interaction between main effects, apparent in Table 4. In colonies without a screen bottom there was an overall sharper drop in pollen with the addition of a reduced entrance. With screened colonies the cost to pollen storage of a reduced pipe entrance was moderated, with pollen in fact higher in 3.8-cm pipe entrances than the open group. As we found for adult bee populations, there is a cost to stored pollen with reducing colony entrances, but this cost is offset in 3.8-cm pipe entrances with a screened bottom board.

Because bottom screens are used in *V. destructor* IPM protocols (Pettis and Shimanuki 1999, Ostiguy et al. 2000, Ellis et al. 2001), we examined changes in number of *V. destructor* per adult bee. We found no effects of entrance or screen on this variable (Table 3), probably due to the low number of *V. destructor* present in the study. It remains inconclusive whether the screen mesh size used in this study, which is smaller than that conventionally used for the control of *V. destructor*, inhibits *A. tumida* ingress while permitting the exit of falling *V. destructor*.

We conclude that more studies must be done on reduced hive entrances to determine their efficacy in impeding *A. tumida* ingress. Our data suggest that reduced hive entrances may slow *A. tumida* ingress in some instances but that their success is limited by other factors internal or external to the colony. Furthermore, reduced entrances cause harmful secondary effects on brood and bees that are only partly mitigated by screened bottom boards.

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