Harmonia axyridis (Coleoptera: Coccinellidae) in Buildings: Relationship Between Body Height and Crevice Size Allowing Entry

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ABSTRACT Although the introduced lady beetle *Harmonia axyridis* (Pallas) (Coleoptera: Coccinellidae) is an important predator of aphids in a variety of crop systems during the growing season, it is often a pest in fall and winter when it enters buildings seeking overwintering sites. One of the primary recommendations for managing this annual influx is to prevent beetle entry by caulking or otherwise filling potential entry points in buildings. The goal of this study was to determine how small a gap the beetles are able to enter in choice and no-choice studies by experimentally exploiting their behavioral tendency to seek dark shelters at cool temperatures. Within the size range of adults collected in central North Carolina in 2003 (1.99–3.29 mm body height), no beetles entered a 2-mm access during no-choice experiments. Most (83%) entered a 3-mm gap; those failing to cross the 3-mm threshold were significantly larger than those that traversed it. In choice experiments, 98.2% of beetles entered shelters. As in the previous study, no beetles entered shelters with 2-mm gaps. Significantly fewer were found in shelters with 3-mm entrances than in those with 4- or 5-mm access; beetles that entered 3-mm gaps were significantly smaller than the remainder of the test population. Although no *H. axyridis* crossed a 2-mm threshold in either experiment, a gap of this size may nonetheless allow admission if it has flexible borders (e.g., foam weather stripping); beetles were observed attempting forced entry into too-small crevices.

KEY WORDS multicolored Asian lady beetle, management, aggregation behavior, negative phototaxis, urban pest

The introduced lady beetle *Harmonia axyridis* (Pallas) (Coleoptera: Coccinellidae) successfully suppresses aphids in a variety of agroecosystems in the United States (e.g., Brown 2004, Costamagna and Landis 2006), but it is notorious for being a pest in autumn, when large numbers take flight, alight on structures, and then move into interior spaces looking for dark, protected sites to settle for the winter. Vast numbers may enter buildings (Kidd et al. 1995, Huelsman and Kovach 2004) where they intrude on human activities. They stain textiles, stink, and sometimes bite; contaminate manufacturing, medical, and food processing facilities; and trigger allergic reactions, including rhinoconjunctivitis, wheezing, facial edema, and urticaria (Yarbrough et al. 1999, Albright et al. 2006, Davis et al. 2006, Sharma et al. 2006).

Recommendations for managing these invasions include daily vacuuming and indoor blacklight traps that capture some beetles active in living/working spaces. Spraying or fogging rooms with insecticides is rarely effective, because the main pool of insects is typically located in inaccessible parts of the building (e.g., behind insulation). Sensitive environments, such as hospitals, schools, and nursing homes may have policies limiting the use of insecticides. The preferred approach is to block initial entry when beetles alight on structures at the conclusion of their autumn flight (Waldvogel et al. 2005). After landing on the exterior of a building, the insects begin a walking local search for access points, such as the cracks and crevices found around window and door casings, utility pipes, eaves, and siding (Nalepa et al. 2004, 2005). Caulking or otherwise sealing these gaps may block beetle invasion of interior spaces, but, tightly sealed buildings can lead to the accumulation of contaminants implicated in a variety of maladies broadly designated as "sick building syndrome" (http://www.epa.gov/iaq/pubs/sbs.html).

The objective of the current study was to determine the gap size that successfully blocks passage of *H. axyridis*, to aid in management decisions regarding the sealing of potential entry points. Although the rigid, convex elytra may preclude their traversing openings smaller than body height, it is also possible that beetles may make behavioral adjustments (e.g., spreading the elytra) that permit access via smaller gaps.

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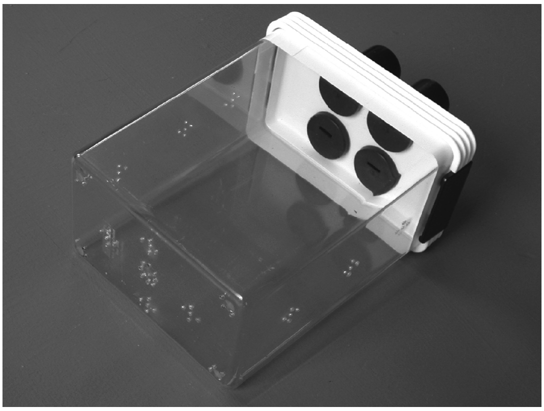

Fig. 1. Experimental chamber used in crevice size experiments; chambers were oriented with their largest dimension on the substrate, as pictured. Beetles released into the body of the container enter black plastic film canisters in response to lowered temperature. Slits cut into lids of the film canisters were used to determine gap sizes that allow beetle entry.

Materials and Methods

Adult *H. axyridis* were collected during their autumn flight on 30–31 October and 3 November 2003; the insects were hand-picked as they landed on a brick barn on the grounds of the North Carolina Department of Agriculture & Consumer Services Beneficial Insects Laboratory in Cary, NC (35.79° N, 78.73° W, 146-m elevation). Until they were used in experiments, beetles were held in 3.8-liter glass jars in a sheltered outdoor location; each jar contained crumpled paper towels and a small square of wet sponge as a water source. Each insect was used just once in experiments.

Experimental chambers were clear, 2.4-liter polycarbonate food storage containers (ClickClack, Christchurch, New Zealand) with small holes drilled into the sides and bottom for air circulation. The containers had opaque white lids into which four, 3.2-cm-diameter holes in a 2 by 2 arrangement were cut. A standard black plastic photographic film canister was inserted into each of the holes, with the lid facing the interior of the experimental chamber (Fig. 1). Slits 2 cm in length and of different experimental height were cut into the lids of the film canisters, and a small, loose roll of corrugated cardboard was placed inside for thigmotactic stimulation. The exact height of slits in the canister tops was regulated using two methods: by sliding metric Allen wrenches into the gaps and by visual measurement with the ocular micrometer of a dissecting microscope. Entry slits had to pass both criteria before they were used in experiments. Preliminary measurements of 97 beetles narrowed the range of entry sizes used in experimental treatments. Chambers were cleaned in hot, soapy water between experiments; film canisters and corrugated cardboard were used just once.

Preliminary experiments conducted in autumn 2002 established that *H. axyridis* enter these film canister shelters in a fully lit room in response to decreasing temperatures. During the winter aggregation period coccinellids are generally photonegative at lower temperatures and photopositive at higher temperatures (Park 1930, Copp 1983). The contrast of the black canister lids with the white lid of the chamber also facilitated beetle orientation to the canisters as aggregation sites (Nalepa et al. 2004, 2005). Experiments were conducted in an environmentally controlled room (9 m^2, 2.13 m in height) in the Southeastern Plant Environment Laboratory (Phytotron) at North Carolina State University. Beetles were induced to enter an experimental canister via a stepped lowering of room temperature. Lighting was provided by high-output cool-white fluorescent bulbs at an intensity of 330 μmol (spectral distribution available at http://www.ncsu.edu/phytotron/manual.pdf). Humidity was held constant at 12%. Experiments were initiated at 1100 hours by releasing beetles into experimental chambers. Initial room temperature was 21°C. Starting at 1300 hours and hourly thereafter until 1700 hours, the room temperature was decreased by $\approx$2.8°C. Minimum temperature was 7°C at 1700 hours; this temperature was maintained until the experiment was terminated at 1800 hours. At the end of experiments, each film canister with enclosed beetles was removed, labeled, and the experimental cap replaced with a solid cap. Beetles remaining in the main arena of the experimental chamber were counted and collected. All beetles were frozen until their body size was determined. The height of each beetle was measured with a Mitutoyo Digimatic Caliper to the nearest 0.01 mm at the thickest point of the body: between the metasternum and the top of the elytra. Each beetle was measured three times, and the mean of these three measurements was used in statistical analysis.

Experiment 1: No-Choice Tests. The first experiment was designed to test entry size limits by offering a group of beetles aggregation sites (canisters) accessible via a fixed entrance size. In each of four chambers 30 adult *H. axyridis* were offered a choice of four canisters, each of which had the same size entry slit: either 2, 3, 4, or 5 mm in height (n = 120 beetles per trial). The experiment was repeated over 3 days: 7, 9, and 11 November 2003 (total of 360 beetles). Chambers were arranged radially, and their compass positions randomized between trials. Chambers were visually isolated from each other by placing each in a white, open top, cardboard box.

Experiment 2: Choice Tests. The second experiment was designed to test choice preferences of beetles given a range of entry sizes. In each chamber 30 adult *H. axyridis* were offered the choice of four sizes of entry slit: 2, 3, 4, and 5 mm. Five replicates were run during each trial (total of 150 beetles), repeated over 3 days: 6, 8, and 10 November 2003 (total of 450 beetles). The position of canisters within chambers, and the position of the radially arranged chambers within the room were randomized between trials. Chambers were visually isolated as described above. In both studies, the number of beetles used in a cham-

Table 1. No-choice experiments: number and size of beetles entering shelters with access of a given height

Entry ht	Beetles that entered shelter			Beetles that did not enter shelter		
	No. beetles (%)	Mean size[a] (± SEM)	Min. size/max size	No. beetles (%)	Mean size[a] (± SEM)	Min. size/max size
2 mm	0 (0.0)			89 (100.0)	2.8 (0.02)	2.20/3.15
3 mm	74 (83.1)	2.68 (0.03)	1.99/3.15	15 (16.9)	3.08 (0.03)	2.76/3.29
4 mm	89 (98.9)	2.80 (0.02)	2.29/3.16	1 (1.1)	2.65	
5 mm	88 (96.7)	2.76 (0.03)	2.01/3.27	3 (3.3)	2.66 (0.21)	2.38/3.06

[a] Height of beetle at the thickest part of the body (in millimeters).

ber sometimes varied by an insect or two, due to the difficulty of isolating and counting active beetles.

Statistics. Data were analyzed using PROC GLM in SAS, version 9.1 (SAS Institute 2004). In experiment 1 (no-choice), body sizes of the test insects in the experiments were analyzed by treating crevice size as a fixed effect; trial, chamber position, and canister position were included as random effects. A chi-square test was used to determine the significance of canister position in influencing choice. To compare body sizes of the beetles that entered 3-mm shelters versus those remaining in the outer chamber, trial and canister position were treated as random effects, and type III MS for trial × canister position used as the error term in contrasts. In experiment 2 (choice), the proportion of beetles passing through each crevice size was analyzed by treating crevice size as a repeated measures factor and assuming an unstructured error covariance (using the REPEATED statement in PROC GLM).

Results

Beetles were very active at 21°C when first introduced into chambers; flight attempts were common. Movement was rare and sluggish at 7°C when the experiments were terminated. In experiment 1 (no-choice), none of the beetles given a 2-mm access entered canister shelters (Table 1). The size of beetles offered 2-mm entry access was not significantly different from the remainder of the test population ($F = 0.18$; df = 1, 32; $P = 0.67$); the smallest beetle in this experimental group was 2.2 mm in height. Most (83%) beetles given 3-mm access entered a shelter. Of this group, the body height of those that remained in the outer chamber at the conclusion of the experiment was significantly larger than the body height of those that entered canister shelters (mean of 3.08 and 2.68 mm, respectively) ($F = 22.97$, df = 1, $P = 0.001$). Nearly all *H. axyridis* offered entry sizes of 4 and 5 mm entered shelter (98.9 and 96.7%, respectively). Beetles that entered shelters during this experiment significantly chose one canister shelter over others of the same size in two of the three trials ($P < 0.01$, $P < 0.02$, and $P = 0.08$, respectively; chi-square test). However, the position of the preferred canister varied, indicating that the preferences were related not to experimental design, but to the social tendencies of the insects. In two experiments, large beetles were observed repeatedly attempting to force entry through 3-mm slits, without success. At no point did they spread their wings to facilitate entry.

In experiment 2 (choice), 98.2% of beetles entered canister shelters. As in experiment 1, no beetles entered canisters with 2-mm crevices. Significantly fewer beetles entered canisters with 3-mm access than entered canisters with either 4- or 5-mm access; those that did enter the 3-mm canisters were significantly smaller than the remainder of the test population (Table 2). Overall, experimental beetles ranged from 1.99 to 3.29 mm in body height ($n = 807$).

Discussion

Within the size range of *H. axyridis* collected in autumn of 2003 in central North Carolina, a 2-mm gap excluded all test insects, but a gap of 3 mm allowed most to enter. Thus, the height of a beetle with closed elytra is a reasonable estimation of the size of a void through which it can pass. However, the experiments reported here are based on gaps bordered by rigid material. Because beetles vigorously attempted to force entry into too small crevices, it is possible that large beetles may muscle their way through small gaps bordered by physically yielding materials such as foam or soft rubber weather stripping. Geographic variation in the body size of beetles also should be a consideration in management decisions. Beetles collected in the mountains of North Carolina, for example, are significantly larger than those collected at lower elevations (Nalepa et al. 1996), and measurements of 100 *H. axyridis* collected during autumn flight in Columbus, OH (C.A.N., unpublished data), were larger than the beetles used in this study (range, 2.44–3.52 and 1.99–3.29 mm in height, respectively).

Excluding *H. axyridis* from a structure that these beetles consider an attractive overwintering site re-

Table 2. Choice experiments: number and size of beetles entering shelters of four alternative access heights

Entry ht	No. beetles (%)[a]	Mean size of beetles[a,b] (± SEM)	Min. size/max size of beetles
2 mm	0		
3 mm	95 (21.2)a	2.70 (0.02)a	2.22/3.06
4 mm	183 (40.8)b	2.80 (0.02)b	2.18/3.28
5 mm	162 (36.2)b	2.79 (0.02)b	2.13/3.16
No-choice[c]	8 (1.8)	2.85 (0.06)	2.49/3.04

[a] Values within a column followed by the same letter are not significantly different.

[b] Height of beetle at the thickest part of the body (in millimeters).

[c] No-choice in this context refers to beetles that were in the main experimental arena at the conclusion of the experiment.

mains a daunting task. Decreasing contrasting elements (Nalepa et al. 2005) and sealing obvious entry points seems a reasonable first step, particularly on the building face that receives afternoon sun (south, southwest, or west-facing), where beetles first alight (Kidd et al. 1995). Nonetheless, caulking visible gaps has a poor record of success, particularly in older houses (Huelsman and Kovach 2004). In general, buildings are not designed to obstruct determined insects. They typically possess numerous small openings that enhance performance of the wall assembly but also serve as breaches suitable for insect entry. The mesh size of screening on gable vents, soffit vents, and the like are generally intended to stop larger intruders such as swifts, squirrels, and opossums. Vents and service line penetrations through foundation walls are not always well sealed, and they may provide access to basements and crawl spaces. Although beetles that invade cavity walls via weeps and vents can enter living spaces only if the seals on the underlying substrate are breached, shrinkage and deterioration of these seals as the building ages are common (Brock 2005).

Attention to the quality of workmanship and choice of materials during new construction may play some role in alleviating later problems in areas prone to beetle intrusion. Misalignments of fittings and errors of workmanship in field-applied joint sealants can provide entry points, and such sealants must be maintained every few years. The mesh size of screens covering chimneys, attic vents, foundation vents, and exhaust vents should be ≤2 mm. The dimensions of weeps in storm windows, skylights, and sliding glass doors vary with the manufacturer, and should be confirmed as ≤2 mm before purchase. The timing of new construction also should be a consideration. *H. axyridis* has been known to get into walls during autumn construction, and although these insects may be unable to later invade living quarters, beetle corpses in interstitial spaces can lead to secondary pests such as dermestids.

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