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A NEW MODEL OF STINK BUG TRAPS: HEATED TRAP FOR CAPTURING *HALYOMORPHA HALYS* DURING THE AUTUMN DISPERSAL PERIOD

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Invasive stink bug species, such as *Halyomorpha halys* (Stål, 1855) (Hemiptera: Heteroptera: Pentatomidae), are serious agricultural pests worldwide. During autumn dispersal, adults aggregate in large numbers in human-made structures, homes and on walls of buildings. Preferred overwintering sites are sun-warmed, well-protected shelters. Exploiting a new concept, we developed a new collection method for monitoring and controlling them in their pre-overwintering period. Our trap design exploits the heat preference of stink bugs seeking overwintering sites. As a result, significantly greater numbers of *H. halys* adults moved into our black box traps, equipped with a heating apparatus, than into unheated ones. Experiments were performed in October during the pre-overwintering autumn dispersal period. Traps were placed next to a building that served as an overwintering site, where stink bugs usually aggregate in large numbers. Heated traps were operated on sunny afternoon hours when stink bugs were found to be active by visual observations. Our results represent the first example of an effective collection method based on artificially heated traps placed in natural conditions.

Key words: brown marmorated stink bug, invasive species, overwintering, trapping.

INTRODUCTION

Invasive stink bug species have widely spread across Europe in the last few decades, causing significant agricultural losses. One of the most destructive species in Europe is the brown marmorated stink bug, *Halyomorpha halys* (Stål, 1855) (Hemiptera: Heteroptera: Pentatomidae), native to East Asia. Other widespread, economically important invasive species are the southern green stink bug, *Nezara viridula* (Linnaeus, 1758) (Hemiptera: Heteroptera: Pentatomidae), native to East Africa and western conifer seed bug, *Leptoglossus occidentalis* Heidemann, 1910 (Hemiptera: Heteroptera: Coreidae), native to North America. Expansion of their distribution area and worldwide spread are likely caused by either climate change or the transportation of goods (Panizzi 2008, Wermelinger *et al.* 2008, Vétek *et al.* 2014, Valentin *et al.* 2017, Lesieur *et al.* 2019).

The severity of their agricultural impact is derived from their polyphagous pest status, ability to adapt to new environments, fecundity, and lack of potential natural enemies (Lesieur *et al.* 2014, Panizzi 2015, Portilla *et al.* 2015). Beyond their economic impact, they invade homes and other human structures during their pre-overwintering period, causing nuisance and potential allergic reactions (Mertz *et al.* 2012, Leskey & Nielsen 2018).

Change of photoperiod is a key factor that induces overwintering behaviour. Seeking for overwintering sites occurs when the day length is shortened (Musolin & Numata 2003, Niva & Takeda 2003). The authors revealed that *H. halys* and *N. viridula* choose well-protected overwintering sites to survive the winter. In natural landscapes, they overwinter under the bark of dead trees or leaf litter (Khalafallah *et al.* 2005, Lee *et al.* 2014). Homes and other human-made structures ensure protected and heated overwintering sites for stink bugs; thus, during the pre-overwintering periods, they aggregate in great numbers on walls and inside of buildings (Inkley 2012, Hancock *et al.* 2019). While pheromone traps are effective methods to capture *H. halys* adults in high numbers during their breeding season (Akotsen-Mensah *et al.* 2018, Ak *et al.* 2019), however in the autumn, during the pre-overwintering period (which is, according to our observations, typically in October, under the climate of Hungary), adult captures are less numerous (Tillman *et al.* 2017). *Halyomorpha halys* does not respond to its aggregation pheromone during the overwintering period (Morrison *et al.* 2017). Here, we report on an alternative method that can be effective for attracting and trapping stink bugs seeking for overwintering sites.

MATERIAL AND METHODS

Experimental site – The experiment was carried out in a city park composed of diverse tree species in the town of Martonvásár (Central Transdanubia, Fejér county, Hungary). Several buildings are situated on the southern and western edge of the park, where large numbers of stink bugs seeking for shelter had been constantly found during their pre-overwintering period in previous investigations.

Trap design – The trap body was a 350 × 250 × 140 mm (9 L) black plastic box. Two sides of the box were opened by 15 × 260 mm slots, while two 20 × 135 mm slots were opened on the top side of the box (Figs 1 & 2).

Heated traps were equipped with a 250 × 500 mm size heating foil (D3025 type, 220 W/m^2, Dimat Fűtéstechnika Kft., Pécs, Hungary). Heating foils were placed tightly to the inner surface of the boxes. They were equipped with a digital thermostat (XH-W3001 type, 220V, 1500 W, Caxtool Kft., Szeged, Hungary) for continuously heating the traps. The thermostat was set to keep the temperature of the heating foil between 36–37 °C. During the experiments, the traps' inner space temperature was also regulated to 36–37 °C. The temperature on the surface of the top of the box was set to 32–34 °C.

Control traps consisted of the same trap body as heated ones, without heating apparatus. The temperature inside the control traps was the same as the outside temperature or slightly above it (maximum recorded temperature was 23 °C) when direct solar radiation hit the surface of the traps.

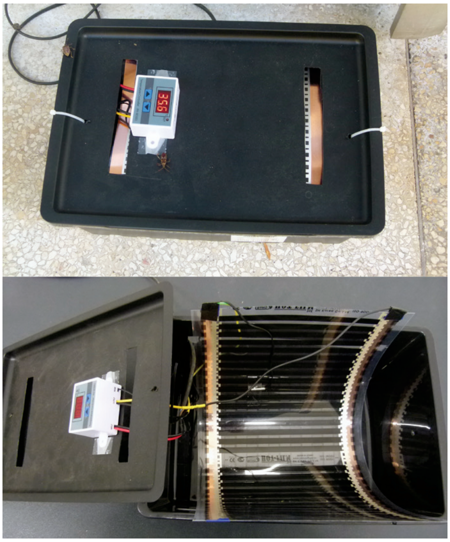

Fig. 1. Photo of trap design and operation on field

Field observations – During the test days, numbers of stink bug species were recorded on the surface of the 40 m long section of a north-western side wall of a building, up to 4 m height, situated right at the site where the traps were set up. Visual observations were made every hour between 11 am and 16 pm.

Field trapping test – The traps were placed along a 40 m long wall of a glass steel building at its north-western side, placed on the ground ca. 15–20 cm from the wall. Heated and control traps were placed in pairs along the trapping site (Fig. 2). Three trap pairs were installed at ca. 10 meters from each other. In a trap pair, the distance between heated and unheated traps was ca. 50 cm.

Trapping tests were conducted in October 2022, when stink bugs searched for overwintering shelters. Traps were operated in sunny hours from 11:30 am to 16:30 pm. The air temperature when the traps were operated ranged between 18–21 °C.

Six recordings were made during the trapping period. At the end of the experiment of each day, i.e., after the five-hour operation time, stink bugs were removed from traps, and the number of the catch was recorded. The sex and species identity of stink bugs in traps were identified based on their external morphology (Kóbor 2017). In total, 18–18 catches of heated and control traps were evaluated.

Statistical analyses – To compare the mean numbers of stink bugs seeking overwintering shelters on the section of a wall where traps were set up, repeated measure ANOVA was performed, followed by Durbin-Conover pairwise comparison test (alpha was set to 5%).

To compare the catches of heated and unheated traps, data were analyzed by Welch's t-test (alpha was set to 5%). A Saphiro-Wilk test was used to assess whether samples likely originate from the normal distribution. The evaluated value of $P < 0.0001$ suggests a violation of the assumption of normality. Homogeneity of variance was analysed by Levene's test, revealing a violation of the assumption of equal variances ($P = 0.03$).

The statistical program of *jamovi* was used to analyze the dataset (The jamovi project, 2021), *jamovi* (Version 2.2) [MAC OS], retrieved from https://www.jamovi.org).

Fig. 2. Arrangement of the traps. The edges of slots were marked with white lines on the photo, because of the better visualization

RESULTS

Field observations – In the observation site, three invasive stink bug species were found: *H. halys*, *N. viridula* and *L. occidentalis*. Field observation prior to the trapping revealed that the majority of stink bugs searching for overwintering shelters was active in the sunny afternoon hours at the trapping site. When comparing the hourly mean numbers of *H. halys* during the daily observation period, it turned out that they did not significantly differ from each other (repeated measure ANOVA, P = 0.55, df = 5); nevertheless, adults were recorded in the highest number between 13 h and 15 h. The mean number of *L. occidentalis* adults was significantly greater from 13 h to 14 h than outside this period (repeated measure ANOVA, P = 0.013, df = 5). The number of *N. viridula* was relatively low at every recording without significant difference (Fig. 3).

Visual observations also revealed that moving activity occurred in the sunny afternoon hours (13–16 h). Adult stink bugs moved in the traps during this period. During periods of no direct sunshine, stink bugs were inactive.

Field trapping test – The total number of captured stink bugs in heated traps was 122, while in unheated traps, it was only 23. The dominant species was *H. halys*, accounting for 95.8% of the total captures. The total number of captured *H. halys* specimens in heated traps was 117 (making 94% of the total catch), while the same species made up 99% of the sample in unheated/control traps (number of adults: 22). Other species in traps were *N. viridula* and *L. occidentalis*.

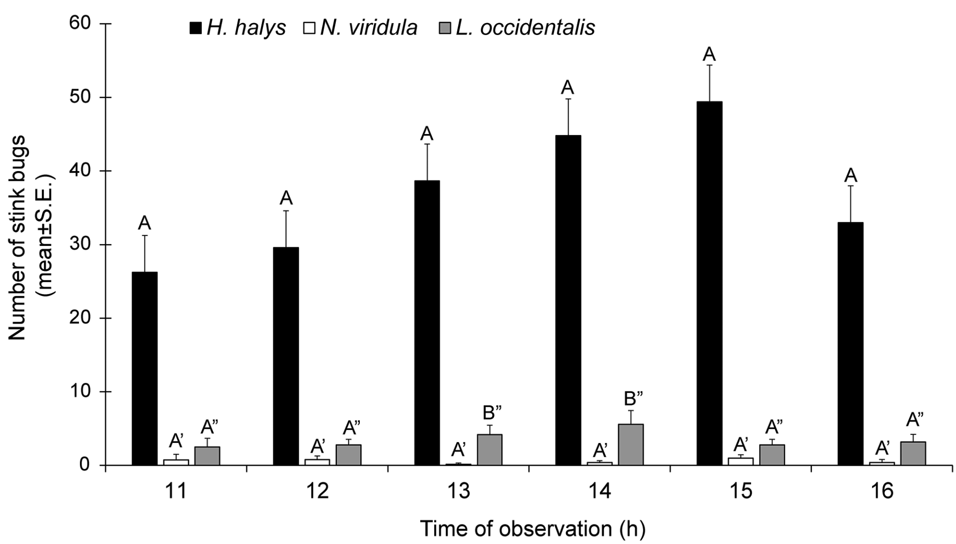

Fig. 3. Mean number of stink bugs observed in the trapping site (statistics: repeated measure ANOVA, Durbin-Conover pairwise comparison test, P ≤ 0.05)

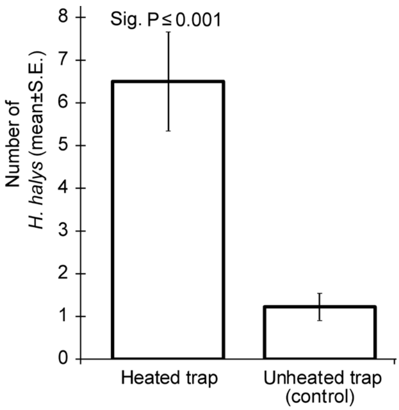

Fig. 4. Mean number of *H. halys* captured by traps (Welch's t-test, P ≤ 0.05)

The total *N. viridula* catches in heated traps were two female adults, while unheated ones did not catch any. Three females of *L. occidentalis* were captured by heated traps, while only one was by unheated ones.

Heated traps captured significantly greater numbers of *H. halys* adults than unheated control traps (Welch's t-test, P ≤ 0.001, df = 19.5). The mean number of *H. halys* in heated traps was 6.5±1.16 specimens/trap/recording, whilst in control traps, it was 1.22±0.32 (Fig. 4). The sex ratio was 1:1 in heated traps, while the female-male ratio was 2:1 in control.

DISCUSSION

Our artificially heated trap design proved to be effective in capturing *H. halys* in a significantly greater number than unheated traps during their pre-overwintering period. There was no sex bias in captures. Females and males moved into heated traps in equal ratios. The dominant species in both types of traps was *H. halys.* Although *N. viridula* and *L. occidentalis* were present in the trapping site, their relatively low number was also reflected in captures. The highest mean number of observed *H. halys* specimens around the trapping site was 49.4±12.35 specimens/recordings, while only 1±0.44 and 5.6±1.86 mean specimens of *N. viridula* and *L. occidentalis* were found there, respectively. The number of specimens by species observed in the trapping site correlated with their total number in the traps, with somewhat higher captures in the heated traps. Consequently, we cannot exclude that heated traps were also effectively capturing *N. viridula* and *L. occidentalis*. Our previous, preliminary study reflected that both *H. halys* and *N. viridula* preferred heated shelters against unheated ones (Bozsik *et al*. 2021). That examination was made under semi-natural conditions, with isolated specimens, using a laboratory heating element and cardboard box shelters. That method was unsuitable for field studies. In contrast, our present trap design is suitable for repeatable field studies because of its relatively low cost, easy accessibility of its fixtures, reliable operation mode and construction, which fit well to outside, natural conditions.

Our chosen black trap colour was based on the work of Hancock *et al.* (2019), where authors described that *H. halys* were found in greater numbers on darker-coloured homes during their autumn dispersal period. Our black control box traps (without heating apparatus) captured only a relatively low number of adults compared to heated traps; thus, the dark colour seemed to have a low effect in our experiment.

We observed that invasive stink bugs were mostly active in the sunny afternoon hours on the surface of the north-western side wall where trapping was carried out. This is in accordance with studies in which the temperature was found to be the most significant factor influencing the flight activity of stink bugs during their search for overwintering sites (Inkley 2012, Lee & Leskey 2015). The preference for heat during the pre-overwintering period was shown in numerous studies, which revealed that heated and warmed spaces are preferred overwintering sites of stink bugs (Kobayashi & Kimura 1969, Watanabe *et al.* 1994, Lee *at al.* 2014, Chambers 2017). Our findings about daily activity were used as supporting information for trapping, the exploration of the diurnal activity was not the aim of our study. Determining the diurnal activity pattern of stink bugs in the trapping site could help to determine better the most effective hours for operating the heated traps. Our preliminary observation showed that the optimal time range for trapping, when stink bugs move into the traps, are those hours when the ambient temperature and sunshine are favourable for the moving activity of stink bugs. This typically occurs in the early afternoon hours. In the days of our preliminary observations, this felt between 13–16 h.

Earlier studies reported the use of overwintering traps with limited success, but those were shelter traps without heating apparatus (Bergh *et al*. 2017, Chambers 2017). According to the results of Bedoya *et al.* (2020) *H. halys* use vibration signals in the autumn dispersal period. These cues are used only by males and triggered when adults colonize their overwintering sites and not in their active, shelter seeking-period. The authors did not find any significant movement regulator effect by these signals.

Our results are the first to prove the efficiency of overwintering traps equipped with heating apparatus to capture stink bugs. To further improve the effectiveness of heated traps, more experiments are planned in the near future.

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