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Designing and testing novel artificial shelter traps to mass-trap overwintering brown marmorated stink bugs: a proof-of-concept study in Northwestern China

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Abstract

Background *Halyomorpha halys* Stål (Hemiptera: Pentatomidae), brown marmorated stink bug (BMSB), is a highly polyphagous invasive pest worldwide. It is also known to be a nuisance pest as it enters artificial structures, including human habitats, to overwinter and releases very unpleasant odours when disturbed. Overwintering populations can be trapped and killed collectively by targeting the aggregation behaviour of BMSB adults. However, efficient traps for catching overwinter population have not been yet developed and validated. A novel and effective trapping method would be to design shelter traps in the field that entice and mass-trap overwintering BMSB as they initiate to display their typical aggregation behavior and seek shelter in the traps.

Methods In this study conducted in Northwestern China, we designed different BMSB overwintering shelter traps made of different materials (i.e., wood or corflute) and lock types (with/without lock, pyrometric or strip door lock) and tested their efficacy at two different sites and three different locations within sites. We also tested the efficacy of the traps with or without the presence of the BMSB aggregation pheromone.

Results Although trapped BMSB numbers were generally low across all traps tested, the black corflute trap was found to attract the highest average number of BMSB males and females, followed by the wooden-made trap, the bee-hive box and finally the wooden-made locked trap, which attracted the lowest numbers of BMSB. The trapping efficacy was found to not be affected by experimental sites or locations nor by the presence of the BMSB aggregation pheromone lure.

Conclusions Our results showed that traps made of black corflute with slit doors were generally preferred by overwintering BMSB. This preliminary proof-of-concept study provides valuable information for further improvement of novel overwintering traps that could be used to mass trap BMSB overwintering populations.

Keywords *Halyomorpha halys*, Overwinter population, Aggregation behavior, Artificial shelters, Trap efficacy

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Background

The brown marmorated stink bug (BMSB), *Halyomorpha halys* Stål is a polyphagous pest native to China (mainland and Taiwan), Japan and Korea that was accidentally introduced into North America in the mid-1990s and Europe in 2007, and most recently in Chile (Faúndez and Rider 2017; Leskey and Nielsen 2018). It is well established outside its native range in the USA and Europe (Haye et al. 2015; Leskey and Nielsen 2018), where it has become a severe, or potentially severe, invasive pest of many horticultural crops (Rice et al. 2014; Haye et al. 2015; Leskey and Nielsen 2018).

Adults and older nymphs (2nd–5th instars) of BMSB feed on fruits or leaves through their piercing-sucking mouthparts that remove vital plant nutrients (Zhang et al. 1993). In Northern China, BMSB has been reported to be responsible for 50–80% losses on peaches and pears (Qin 1990). Recently, BMSB was confirmed to cause serious damage on kiwifruit in the Shaan Xi province. The incidence of damaged kiwifruit increased with time during the fruit growing season, due to a cumulative effect, with the highest percentages of damaged fruit being 70% in organic orchards, and 53% in conventional orchards (Zhang J.P. personal observation). Besides the feeding damage caused by BMSB during the kiwifruit growing season, kiwifruits were also affected by this insect during the harvest and postharvest periods if the fruits were left unprotected after harvest (Chen et al. 2020). BMSB feeds mainly on economically important fruits, vegetables and field crops during the spring and summer seasons, and then adults migrate to overwinter by mid-end autumn (Rice et al. 2014). BMSB usually forms aggregations of a few to many thousand individuals at overwintering sites, which include natural and anthropogenic harbourages, such as under loose bark of fallen trees or rock piles and rocky outcroppings, human-made structures, and many other sites associated with human activity (Bergh et al. 2017).

Thus far, chemical control has been the most widely used strategy for managing BMSB in the Northeast of the USA. However, this type of control has also resulted in several adverse effects such as pesticide residues pollution to agro-environments (Leskey et al. 2012). Therefore, more environmentally, and economically sustainable management solutions, such as classical biological control (Zhang et al. 2017) and/or novel mass-trapping systems (Leskey et al. 2015; Morrison et al. 2017a; Weber et al. 2017), are urgently needed.

The recent characterization of the aggregation pheromone of BMSB offers great opportunities to develop more sustainable pest monitoring, detection, and integrated pest management strategies such as attract-and-kill, pheromone traps, and/or trap crops (Weber et al. 2017). For instance, rotating traps loaded with the BMSB aggregation pheromone were recently found to capture, on average, sevenfold more BMSB adults compared to conventional sticky panels (Suckling et al. 2019). BMSB-vibrational-based signals were also recently integrated into a trap (i.e., vibrotrap) and shown to attract male adult BMSB, and to significantly increased trap efficacy (Mazzoni et al. 2017). Traps with a combination of UV-A blue or green visible wavelengths comprised of the synthetic aggregation pheromone also provided higher BMSB attraction (up to ~ eightfold) compared to traditional sticky or small pyramidal traps (Rondoni et al. 2022).

In a variety of growing systems, BMSB seems to be a perimeter-driven pest, with greatest pest abundance and highest damage occurring on the edges of fields (Venugopal et al. 2015). In addition, some field edges are more at risk of invasion by BMSB populations, especially those surrounded by where natural BSMB populations can be found (Venugopal et al. 2014; Rice et al. 2016). Aggregation pheromone-baited traps generally capture BMSB in China from April to October, which includes the full growing season for most crops (Zhang J.P. personal observation). However, the current pheromone-based tools for BMSB have some limitations. For example, as BMSB seeks out overwintering sites around the autumnal equinox in the USA, adults cease to be responsive to their aggregation pheromone. Once settled during overwintering, BMSB do not tend to disperse to new sites unless disturbed (Toyama et al. 2011). As a result, trap captures rapidly decline. Likewise, as BMSB overwintering behavior ceases by the beginning of spring, the aggregation pheromone does not seem to be efficient at monitoring post-overwintering BMSB populations inside buildings or in the field (Morrison et al. 2017b). Thus, there is promise in the development of artificial overwintering trapping shelters for BMSB populations that enter diapause to allow mass-trapping before the start of the spring long-flights dispersal (Weber et al. 2017).

Few attempts have been made to develop optimal artificial overwintering shelters for mass-trapping of BMSB. A slit BMSB trap was used in several experiments in Japan (Watanabe et al. 1994a, b), though the slits were 3 mm wide, which might have been too small for BMSB adults based on their average size (Chambers et al. 2019). Furthermore, in a laboratory test where BMSB adults were placed in tight boxes, most BMSB settled in gaps between 4.5—5.5 mm high, but none settled in a space less than 3.5 mm (Chambers 2017). A recent study showed that a low percentage (13%) of BMSB females passed through 4-mm-high slits, while no individuals passed through 3-mm-high slits (Chambers et al. 2019). However, a 3-mm gap between adjacent inserts within wooden overwintering shelters provided overwintering harbourage for BMSB adults (Bergh et al. 2017). In addition, it seems that brown and grey coloration and woody materials could be more attractive to overwintering BMSB (Hancock et al. 2019). Thus, optimizing an overwintering shelter trap that could be deployed in the field to attract BMSB adults during their aggregation process prior to overwintering seems an obvious field of research warranting attention. Here, we report the results of a preliminary study conducted to test the efficacy of novel BMSB overwintering shelter traps made with different materials (i.e. wood or corflute) and lock types.

Materials and methods

Shelter trap design

Taking into consideration the average size of BMSB adults (Chambers et al. 2019), we designed four different types of overwintering shelter traps for BMSB, as described below:

Wooden trap

A trap with a spacing of 4 mm between the inner layers (or slits) inside the cage, which should allow BMSB adults to settle in (Fig. 1). The backside of the trap was mobile, which allowed an easy collection/counting of trapped BMSB adults during inspections.

Black corflute trap

A black corflute (corrugated plastic) rectangular box with an aluminium frame and a locking system. 60 internal corflute walls (spaced at 4 mm) were placed within the box to allow all trapped BMSB to easily settle inside (Fig. 2). Corflute is an extruded twin wall plastic-sheet material produced from high-impact polypropylene resin with a similar make-up to corrugated fibre board. The entrance of the trap followed a similar principle to that in the black pyramid traps already used for BMSB monitoring purposes (Acebes-Doria et al. 2019), i.e. an entrance that makes it easy for adult BMSB to enter but difficult to escape. Steel frame was used to make the trap strong enough to stand upright.

Wooden made locked trap

This trap was a different version of the wooden trap. This was achieved by adding an inverted pyramid as a lock system. A 12 cm diameter hole was made vertically across all layers and the inverted pyramid (8 cm high) was inserted to the hole on the top of the box surface, which prevented trapped insects from escaping (Fig. 3).

Beehive box

A box without wax and filled with wood chips to occupy one third of the internal box space (Fig. 4). A hive mat was placed on the top of the hive. This kind of trap was designed based on previous field observations that beehive boxes were able to accommodate large numbers of overwintering BMSB.

Trap deployment in the field and efficacy testing

Four replicates of each BMSB overwintering shelter trap were deployed at three locations situated in two different sites (kiwifruit orchard of Haisheng Wugong yard N34°

Fig. 1 Front (left) and rear (right) views of a wooden trap designed for brown marmorated stink bug (*Halyomorpha halys*) overwintering adults. The trap is 30×30×30 cm in size with 4 mm between the layers inside, and a total of 35 layers. The wood material is pine plank. The layer material is plywood

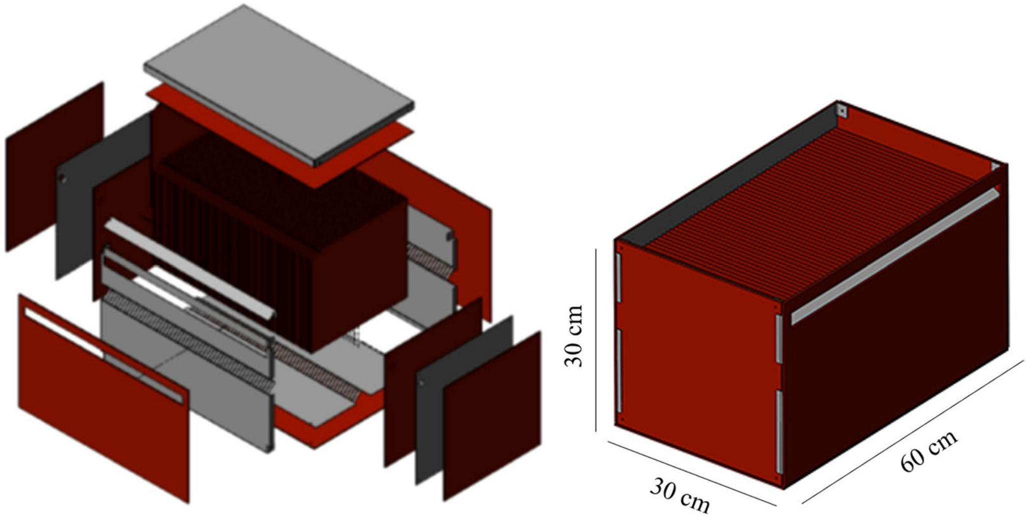

Fig. 2 Assembled view (left) and internal view (right) of the black corflute trap used in this study to trap brown marmorated stink bug (*Halyomorpha halys*) overwintering adults

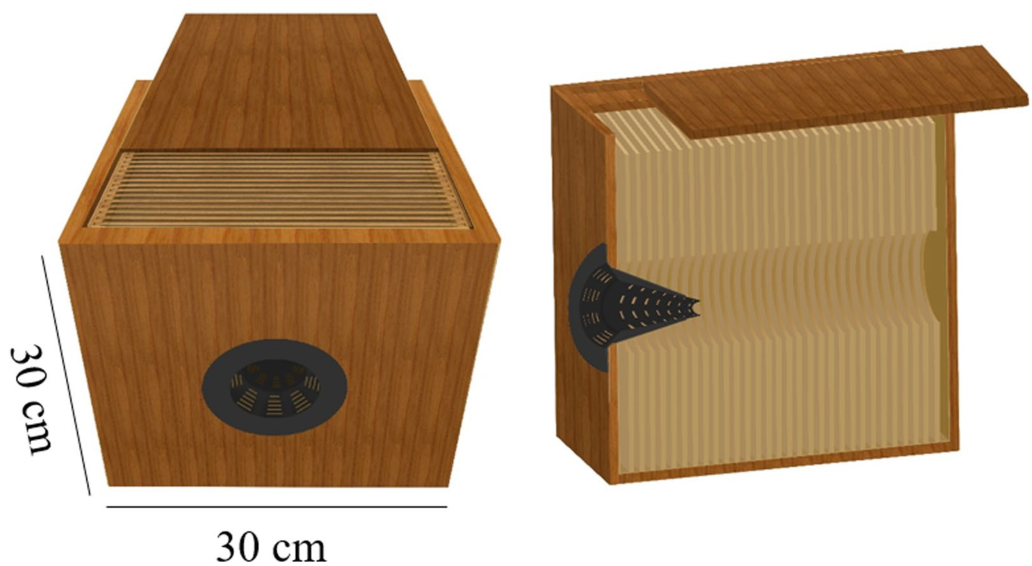

Fig. 3 Front view (left) and profile view (right) of the wooden-made locked trap used in this study to trap brown marmorated stink bug (*Halyomorpha halys*) overwintering adults

14′ 28″; E108° 10′ 2 ″ and kiwifruit station of Northwest Agricultural and Forestry University N34° 07′ 27″; E107° 59′ 31″) in Northwestern China. The two sites were 20 km apart from each other and the three different locations per site were located within 100 m distance from each other. At each location, traps were also deployed with or without the presence of the BMSB aggregation pheromone lure (PHEROCON® BMSB dual lure; Trécé, Adair, OK, USA). Thus, a total of 96 traps were tested, with the pheromone lure being provided to half of these traps. The traps deployed with BMSB aggregation pheromone lures were located at a minimum of 100 m away from each other to not to interfere with the radius of action of the BMSB pheromone (Leskey et al. 2015).

Experiments were conducted in 2019 from 15 September to 16 November since according to our personal observations, this is the time window when BMSB starts searching for overwintering sites in Northern China.

Numbers of BMSB adults captured by the traps were not checked while they were in the field, but only when

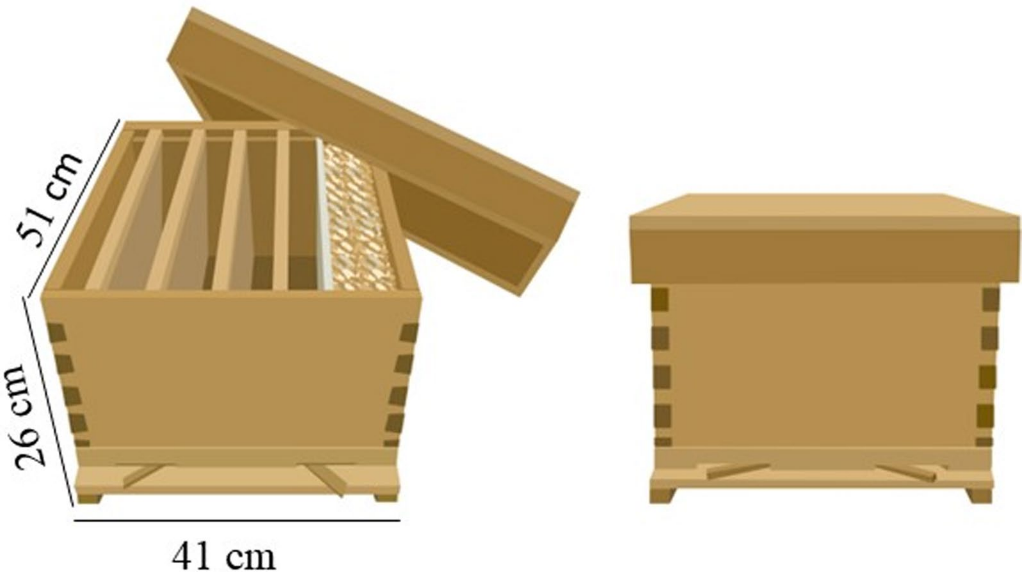

Fig. 4 Opened (right) and front (left) view of a beehive box trap used in this study to trap brown marmorated stink bug (*Halyomorpha halys*) overwintering adults

traps were retrieved. The aim was to avoid disturbing the overwintering BMBS that had found shelter in the traps causing them to leave the traps, which would have biased our final counts. At the time of trap retrieval, all BMSB adults caught in each trap were collected and taken into the laboratory, where total number of BMSB males and females captured per trap were counted and recorded.

Data analysis

The final counts of female and male BMSB trapped per trap type/site/location were analysed by using a Generalised Linear Mixed Model (GLMM) with a Poisson distribution. To assess for trap efficacy, lure presence and trap type were included as fixed effects, and site as a random (or block) effect. Pair-wise comparisons were then conducted when the effects (or their interactions) were found to be statistically significant. Raw data were log-transformed while the means and confidence intervals of the means were back transformed to linear scale. A Wald test was used to test the assumptions of the GLMM model. All tests were conducted using the *Statistics Toolbox* in MATLAB, 2017 (MATLAB 2017).

Results

All the trapping data presented here onwards was pooled and is given as average numbers (± SE) of trapped females, males or combined. BMSB preferred black corflute-made traps, which attracted the higher number of BMSB, both males (4.6 ± 0.59) and females (3.7 ± 0.53), than other type traps ($P < 0.001$), followed by the wooden-made trap (male 1.4 ± 0.81, female 1.5 ± 0.55), the bee-hive box (male 0.4 ± 0.63, female 0.5 ± 0.64), and finally the wooden made locked trap (male 0.4 ± 0.77, female 0.2 ± 0.99), which attracted the lowest numbers of BMSB (Fig. 5).

The presence of the lure did not have an effect on trapping efficacy of the BMSB ($p = 0.95$). However, the mean number of females attracted to the traps in the presence of the lure were slightly higher ($p = 0.37$), although not significantly so, compared to that of females attracted in the absence of lure, whilst male BMSB were slightly more attracted to the traps in the absence of the lure ($p = 0.34$), particularly in the wood-made and the black corflute traps (Fig. 6).

Discussion

Here, we report the results of a preliminary study conducted to test the efficacy of newly designed BMSB overwintering shelter traps containing different materials (i.e., wood or corflute) and lock types (with/without lock). We compared BMSB preference to four types of traps setat three locations in two different sites and with the presence/absence of the BMSB aggregation pheromone. Our trapping results indicated that black corflute traps attracted the highest numbers of BMSB, followed by the wooden-made traps, the bee-hive box, and the wooden-made locked trap. Trapping efficacy might be affected by the trap material, shape, and/or colour (Hancock et al. 2019). Black is a colour known to absorb the most heat (Bozsik et al. 2023), thus black coloured traps might offer a more suitable environment for overwintering BMSB traps compared to other colours. The total number of BMSB overwintering adults

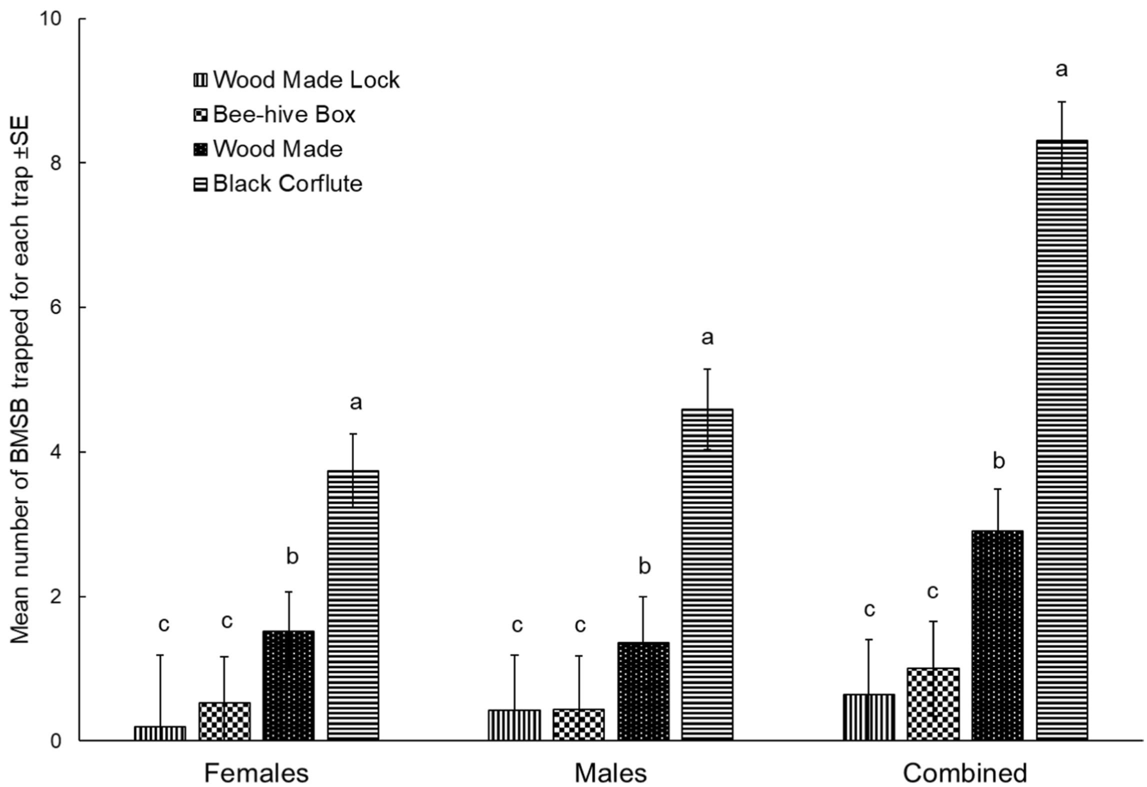

Fig. 5 Mean number ± SE of overwintering brown marmorated stink bugs (*Halyomorpha halys*) trapped by four different (wooden made, wooden made lock, bee-hive box, and black corflute) overwintering traps tested between September to November 2019. Pooled data for all experimental sites and locations is shown here. Bars with the same letter were not significantly different from each other (P < 0.05)

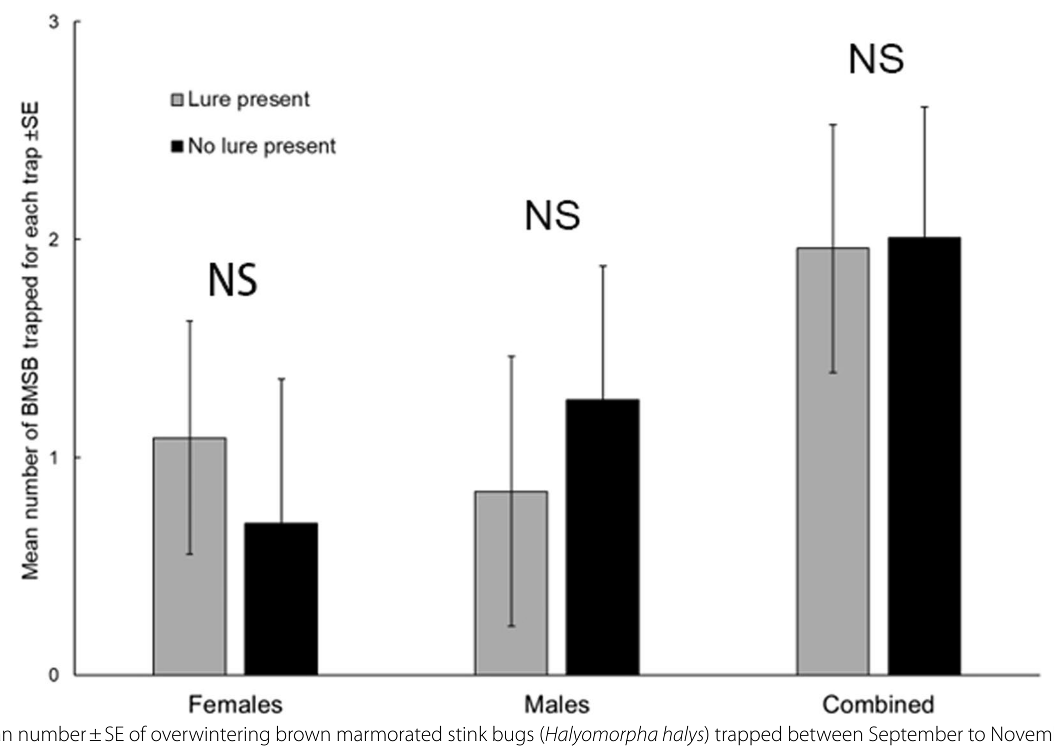

Fig. 6 Mean number ± SE of overwintering brown marmorated stink bugs (*Halyomorpha halys*) trapped between September to November 2019; in the presence or absence of a BMSB-specific aggregation pheromone lure. Data from all experimental sites and locations used was pooled

captured by all traps tested during the experimental period (15 September to 16 November 2019) was 275. Such trapping numbers are low, and therefore, the traps still require further improvements and replication over time/years to increase their efficacy. Previous studies reported that brown and grey traps and woody materials could be more attractive to overwintering BMSB (Hancock et al. 2019). However, our brown wooden-made traps did not attract a higher number of BMSB compared to the black corflute traps, which contradict Hancock's results. Other factors including geographical location, weather conditions, landscape use and local BMSB population densities during the season, among others, could explain the discrepancies between our results and those by Hancock et al. (2015). Temperature might also affect trap efficacy (Ansi et al. 2022) as well as trap height (Gianfranco Anfora, pers comm.). Therefore, future tests should aim at testing the influence of all the factors on the efficacy of the BMSB traps tested here.

Experimental location did not seem to affect the trapping efficacy of our tested traps. However, our study was conducted only once in 2019. Thus, testing the efficacy of our traps for consecutive years and across many more sites where BMSB occurs naturally will be needed in the future to ascertain this result. We also found that the presence of the BMSB lure did not significantly increase the trapping efficiency of the overwintering traps. This result is consistent with a previous study that also showed that baited traps did not capture significantly more overwintering adults compared to unbaited traps (Morrison et al. 2017b). Thus, it seems that overwintering BMSB cease to respond to their own pheromone during the overwintering period. Whether overwintering BMSB responds to other pheromones mediating their aggregation behavior remains to be tested.

In conclusion, the results of this preliminary study show that there is promise in designing overwintering traps to mass trap BMSB during their aggregation period in preparation to overwinter. However, further research is warranted to optimize the efficacy by testing these traps at many more locations/sites and seasons and by taking into account other factors important for trapping including trap size, location, and surrounding vegetation, among others.

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Author contributions
JPZ, GA, FZ, and CSM conceived and designed the experiments. JHC, QQM, LPG, and JPZ conducted experiments. JPZ, GA, AN, QQM, JHC, and XPW analyzed data. All authors contributed to writing and editing of the manuscript.

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Data availability
The data that support the findings of this study are available from the corresponding author upon reasonablerequest.

Declarations

Ethics approval and consent to participate
This article does not contain any studies with human participants or vertebrates performed by any of the authors.

Consent for publication
Informed consent was obtained from all individual participants included in the study.

Competing interests
The authors declare that they have no competing interests.

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References

Acebes-Doria AL, Agnello AM, Alston DG, Andrews H, Beers EH, Bergh JC, et al. Season-long monitoring of the brown marmorated stink bug (Hemiptera: Pentatomidae) throughout the United States using commercially available traps and lures. J Econo Entomol. 2019;113(1):159–71.

Ansi ANA, Aldryhim YN, Janobi AAA, Aldawood A. Effects of trap locations, pheromone source, and temperature on red palm weevil surveillance (Coleoptera: Dryophthoridae). Florida Entomol. 2022;105(1):58–64.

Bergh JC, Morrison WR III, Joseph SV, Leskey TC. Characterizing spring emergence of adult *Halyomorpha halys* (Hemiptera: Pentatomidae) using experimental overwintering shelters and commercial traps. Entomol Exp Appl. 2017;162:336–45.

Bozsik G, Szőcs G, Kontschán J. A new model of stink bug traps: heated trap for capturing *Halyomorpha halys* during the autumn dispersal period. Acta Zool Acad Sci Hung. 2023;69(1):39–46.

Chambers BD. Factors influencing behavior of overwintering brown marmorated stink bugs (*Halyomorpha halys*) in human dwellings. MSc thesis, Virginia Polytechnic Institute and State University, Blacksburg, Virginia. 2017.

Chambers BD, Kuhar TP, Reichard G, Leskey TC, Pearce AR. Size restrictions on the passage of overwintering *Halyomorpha halys* (Hemiptera: Pentatomidae) through openings. J Econ Entomol. 2019;112(3):1343–7. https://doi.org/10.1093/jee/toz010.

Chen JH, Avila GA, Zhang F, Lindy FG, Sandanayaka M, Mi QQ, Shi SS, Zhang JP. Field cage assessment of feeding damage by *Halyomorpha halys* on

kiwifruit orchards in China. J Pest Sci. 2020;93(3):953–63. https://doi.org/10.1007/s10340-020-01216-8.
Faúndez EI, Rider DA. The brown marmorated stink bug *Halyomorpha halys* (Stål 1885) (Heteroptera: Pentatomidae) in Chile. Arquivos Entomol. 2017;17:305–30.
Hancock TJ, Lee D-H, Bergh JC, Morrison WR, Leskey TC. Presence of the invasive brown marmorated stink bug *Halyomorpha halys* (Stål) (Hemiptera: Pentatomidae) on home exteriors during the autumn dispersal period: Results generated by citizen scientists. Agric Forest Entomol. 2019;21:99–108.
Haye T, Gariepy T, Hoelmer K, Rossi J-P, Streito J-C, Tassus X, Desneux N. Range expansion of the invasive brown marmorated stinkbug, *Halyomorpha halys*: an increasing threat to field, fruit and vegetable crops worldwide. J Pest Sci. 2015;88:665–73.
Leskey TC, Nielsen AL. Impact of the invasive brown marmorated stink bug in North America and Europe: history, biology, ecology, and management. Ann Rev Entomol. 2018;63:599–618.
Leskey TC, Short BD, Butler BR, Wright SE. Impact of the invasive brown marmorated stink bug *Halyomorpha halys*, in mid-Atlantic tree fruit orchards in United States: case studies of commercial management. Psyche. 2012. https://doi.org/10.1155/2012/535062.
Leskey TC, Agnello A, Bergh JC, Dively GP, Hamilton GC, Jentsch P, Khrimian A, Krawczyk G, Kuhar TP, Lee DH, et al. Attraction of the invasive *Halyomorpha halys* (Hemipetera: Pentatomidae) to traps baited with semiochemical stimuli across the United States. Environ Entomol. 2015;44:746–56.
MATLAB. MATLAB and statistics toolbox release. The MathWorks, Inc., Natick, Massachusetts, United States. 2017. https://au.mathworks.com/products/statistics.html. Accessed on 3 July 2023.
Mazzoni V, Polajnar J, Baldini M, Stacconi MVR, Anfora G, Guidetti R, Maistrello J. Use of substrate-borne vibrational signals to attract the Brown Marmorated Stink Bug, *Halyomorpha Halys*. J Pest Sci. 2017;90:1219–29. https://doi.org/10.1007/s10340-017-0862-z.
Morrison WR III, Milonas P, Kapantaidaki DE, Cesari M, Di Bella E, Guidetti R, Haye T, Maistrello L, Moraglio ST, Piemontese L, et al. Attraction of *Halyomorpha halys* (Hemiptera: Pentatomidae) haplotypes in North America and Europe to baited traps. Sci Rep. 2017a;7:16941.
Morrison WR III, Acebes-Doria A, Ogburn E, Kuhar TP, Walgenbach JF, Bergh JC, Nottingham L, Dimeglio A, Hipkins P, Leskey TC. Behavioral response of the brown marmorated stink bug (Hemiptera: Pentatomidae) to semiochemicals deployed inside and outside anthropogenic structures during the overwintering period. J Econ Entomol. 2017b. https://doi.org/10.1093/jee/tox097.
Qin WL. The occurance and control methods of *Halyomorpha halys*. Chin J Plant Prot. 1990;16(6):22–3.
Rice K, Bergh C, Bergmann E, Biddinger D, Dieckhoff C, Dively G, Fraser H, Gariepy T, Hamilton G, Haye T, Herbert A, Hoelmer K, Hooks C, Jones A, Krawczyk G, Kuhar T, Martinson H, Mitchell W, Nielson A, Pfeiffer D, Raupp M, Rodriguez-Saona C, Shearer P, Shrewsbury P, Venugopal P, Whalen J, Wiman N, Leskey T, Tooker J. Biology, ecology, and management of brown marmorated stink bug (Hemiptera: Pentatomidae). J Integr Pest Manag. 2014;5:1–13.
Rice KB, Troyer RR, Watrous KM, Tooker JF, Fleischer SJ. Landscape factors influencing stink bug injury in Mid-Atlantic tomato fields. J Econ Entomol. 2016;110:94–100.
Rondoni G, Chierici E, Marchetti E, Nasi S, Ferrari R, Conti E. Improved captures of the invasive brown marmorated stink bug, *Halyomorpha halys*, using a novel multimodal trap. InSects. 2022;13:527. https://doi.org/10.3390/insects13060527.
Suckling DM, Levy MC, Roselli G, Mazzoni V, Ioriatti C, Deromedi M, Cristofaro M, Anfora G. Live traps for adult brown marmorated stink bugs. InSects. 2019;10(11):376. https://doi.org/10.3390/insects10110376.
Toyama M, Ihara F, Yaginuma K. Photo-response of the brown marmorated stink bug, *Halyomorpha halys* (Stål) (Heteroptera: Pentatomidae), and its role in the hiding behavior. Appl Entomol Zool. 2011;46(1):37–40.
Venugopal PD, Coffey PL, Dively GP, Lamp WO. Adjacent habitat influence on stink bug (Hemiptera: Pentatomidae) densities and the associated damage at field corn and soybean edges. PLoS ONE. 2014;9: e109917.
Venugopal D, Martinson H, Bergmann E, Shrewsbury P, Raupp M. Edge effects influence the abundance of the invasive *Halyomorpha halys* (Hemiptera: Pentatomidae) in woody plant nurseries. Environ Entomol. 2015. https://doi.org/10.1093/ee/nvv061.
Watanabe M, Arakawa R, Shinagawa Y, Okazawa T. Fluctuation in brown marmorated stink bug's winter migrations into human dwellings. Jpn Soc Med Entomol Zool Anim Health. 1994;45(1):25–31.
Watanabe M, Arakawa R, Shinakawa Y, Okazawa T. Anti-invading methods against brown marmorated stink bug, *Halyomorpha mista*, in houses. Anim Health. 1994b;45:311–7.
Weber DC, Morrison WR, Khrimian A, Rice KB, Leskey TC, Rodriguez-Saona C, et al. Chemical ecology of *Halyomorpha halys*: discoveries and applications. J Pest Sci. 2017;90:989–1008.
Zhang CT, Li DL, Su HF, Xu GL. Research on biology of *Halyomorpha halys* and *Erthesina fullo*. For Res. 1993;6(3):271–5.
Zhang J, Zhang F, Gariepy T, Mason P, Gillespie D, Talamas E, Haye T. Seasonal parasitism and host specificity of *Trissolcus japonicus* in northern China. J Pest Sci. 2017;90:1127–41. https://doi.org/10.1007/s10340-017-0863-y.

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