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EVALUATION OF THE EFFECTIVENESS OF DIFFERENT TRAP TYPES AND PHEROMONES AGAINST *Halyomorpha halys* (HEMIPTERA: PENTATOMIDAE)

Mansur ULUCA[1]*, Kibar AK[1]

[1]*Black Sea Agricultural Research Institute, Department of Plant Healthy, 55300, Samsun, Türkiye*

Abstract: Brown Marmorated Stink bug (BMSB) (*Halyomorpha halys*, Hemiptera: Pentatomidae) was first detected in Türkiye in 2017 and is an important invasive insect species worldwide. About 300 hosts have been identified for this pest until recently. Among the hosts of the pest in the Black Sea region, mainly hazelnuts, fruits and vegetables are included. This study was carried out to evaluate the effectiveness of different traps in 2020 and 2021 in a mandarin garden in the Kemalpaşa district of Artvin, one of the places where the pest was first transmitted to Türkiye. Small Funnel Trap (SFT), McPhail Funnel Trap (MPT), Multi-Funnel Trap (MFT), and Big Funnel Trap (BFT) and two different pheromones SMC and TRC were tested against *H. halys*. Each trap was tested with two different pheromones, and the trapping performances of different trap types were followed from the beginning of July to the end of October. The adults were counted every week in the traps. In the traps, it was determined that the most insect-attractive pheromone and trap type combination was TRC+BFT and that the least effective insect trapping type was the SMC+MPT combination. In general, it was determined that TRC, which is the most effective pheromone, also works effectively with BFT and MPT. It was determined that SMC pheromone formed a more effective combination with SFT. In addition, it is predicted that larger-scale designs of MPT will be more effective together with TRC, and SFT with SMC. In this study, it was determined that the performances of different types of traps and pheromones that can be used in the control and monitoring of BMSB vary up to 29 times, and the importance of the combination of pheromone and trap was revealed.

Keywords: Attract-kill, Brown marmorated stink bug, Monitoring, Pheromone trap

***Corresponding author:** Black Sea Agricultural Research Institute, Department of Plant Healthy, 55300, Samsun, Türkiye
E mail: mansur.uluca@tarimorman.gov.tr (M. ULUCA)
Mansur ULUCA https://orcid.org/0000-0001-9805-6464
Kibar AK https://orcid.org/0000-0002-8004-2686

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1. Introduction

Brown Marmorated Stink Bug (BMSB), *H. halys* is an invasive pest that continues to spread and damage in ecological areas suitable for its biology, as in all countries where it spreads. BMSB was first identified outside of its homeland in 1996 in the USA (Hoebeke and Carter, 2003). First report of this pest was in Türkiye in 2017 and it has since spread to many countries in North America, South America, Europe, and Africa (Çerçi and Koçak, 2017; Ak et al., 2019a; Ak et al., 2023; Anonymous, 2023).

The large host range of BMSB includes many cultivated plants such as peach, apple, pear, hazelnut, almond, soybean, corn, pepper, tomato, as well as ornamental and forest plants (Nielsen and Hamilton, 2009b; Haye et al., 2015; Bariselli et al., 2016; Musolin et al., 2017; Hamilton et al., 2018; Leskey and Nielsen, 2018; Ak et al., 2019b; Dumbadze et al., 2019).

The nymphs and adults of the pest cause damage by feeding on the parts such as fruits, bud and leaves of the plants they host (Haye and Weber, 2017). For example; late season feeding by adults induced the highest proportion of injured apples and early season adult feeding resulted in the highest percentage of wounded peaches. As a consequence, various necroses that deepen from the fruit's outer surface to the inside cause significant economic losses (Acebes-Doria et al., 2016).

Since the beginning of the epidemic in many countries, it has been determined that this pest has caused significant economic damage to these plants. (Nielsen and Hamilton, 2009a; Hedstrom et al., 2014; Bariselli and 2016; Bosco et al., 2018; Dumbadze et al., 2019). The population monitoring and control of the BMSB gains importance as it spreads to the level of damaging agricultural areas in a short time.

Because of its high flight capacity of up to 117 km in season, this invasive pest needs to be monitored dynamically, and the time of whatever control must be correctly predicted (Lee and Leskey, 2015). As the population of this insect, which has a high reproductive and spreading force, increases and the damage intensifies, studies on the correct detection and monitoring of the population of the pest in agricultural areas have increased. In this respect, the aggregation pheromones of the pest, which play a very important role in the intraspecific communication of the pest in determining the annual population change, are combined with different types of traps and used for different purposes in the USA, Europe, Georgia, and Türkiye (Joseph et al., 2013; Aigner and Kuhar 2014; Sargent et al., 2014; Murvanidze et al., 2018; Rice et al., 2018; Ak et al., 2019b). In previous research on the subject, the most important attractants were the two component aggregation pheromones (3S,6S,7R,10S)-10,11-epoxy-1-bisabolen-3-ol and (3R,6S,7R,10S)-10,11-epoxy-1-bisabolen-3-ol (Khrimian et al., 2014). Furthermore, with this combination's synergist, methyl (2E, 4E, 6Z)-decatrienoate (MDT), the impact of the attractant is increased (Weber et al., 2014).

Using these pheromones, it is killed by insecticide nets or collected in funnel traps and destroyed by mechanical means, which can be evaluated within the scope of the attract-kill method (Kuhar et al., 2017; Ak et al., 2019a). However, the common use of pheromone traps against this insect is by using sticky trays, pyramid traps, McPhail traps, and funnel traps for population monitoring throughout the season (Hamilton et al., 2018). Besides these, when the pheromone traps of BMSB are evaluated with population monitoring, meteorological data of the region, and biological information of the pest, the spreading parameters of the pest can also be explained (Wallner et al. 2014; Nielsen et al., 2013). Using black pyramid traps, researchers have followed the seasonal abundance and phenology of BMSB populations across the United States, while in Türkiye they use sticky pheromone traps for monitoring (Leskey et al. 2015a; Hadden et al., 2022; Ak et al., 2023). The catching BMSB data were compared to the pyramid and sticky traps, which revealed equivalent population fluctuations for a lot of areas. As a result, throughout the season, the number of *H. halys* adults and nymphs trapped in pyramid traps was much higher compared to sticky traps. However, both may be trusted to monitor this pest in different regions (Acebes-Doria et al, 2020).

In this research, aggregation pheromones of BMSB were used in four different trap types and their performance was compared. Because it was unclear whether this different trap type would function effectively in the Eastern Black Sea Region's ecological conditions. The possibility of using aggregation pheromones, which are an effective component in population monitoring, with these traps for various reasons has been investigated.

2. Materials and Methods

2.1. Materials

We compared trap performances with *H. halys* adults and nymphs, four different trap types, and two distinct aggregation pheromones. These pheromones are TRC (Pherocon®, Trécé Inc., Adair, OK, USA) containing 5 mg aggregation pheromone+50 mg MDT synergist and SMC® [100 mg murgantiol/dispenser and 80 mg methyl (E,E,Z)-2,4,6-decatrienoate (MDT)]. In the research, the following traps were used:

a) Small-funnel Trap (SFT): It includes of an umbrella-type funnel cover at the top and a pheromone holder, a yellow funnel, a transparent bucket (3 l) at the bottom, and a hanging wire (Figure 1 a).
b) McPhail Trap (MPT): There is a transparent plastic cover and a pheromone holder with a diameter of 15 cm at the top and a length of 20 cm, and an inverted yellow funnel base with a 3 cm inlet hole at the bottom. Insects attracted by the pheromone fixed at the top inside the transparent cover enter the trap through the funnel mouth and gather in the chamber (Figure 1 b).
c) Multi-funnel Trap (MFT): This trap consists of a chamber (1 liter) at the bottom, 3 black plastic funnels (diameter 18 cm, height 10 cm), and a funnel cover. Insects that enter the funnel entrance with the pheromone placed under the cover are caught by falling into the chamber (Figure 1 c).
d) Big-funnel Trap (BFT): Funnel traps are made by cutting the top 15 cm of a 19 lt plastic carboy (bottom diameter: 28 cm, height: 58 cm, mouth diameter: 5 cm) and mounting it on the rest of the carboy. By hanging the pheromone at the entrance of the trap's open part, insects are attracted from this point and collected in the lower chamber (6 liter) (Figure 1 d).

Figure 1. Different traps types: (a) Small funnel trap; (b) McPhail trap; (c) Multi funnel trap; (d) Big funnel trap.

2.2. Method

Traps placed in the mandarin orchard in Kemalpaşa (Artvin) between July and October were checked for 21 weeks in 2020 and 19 weeks in 2021, and the captured adults were recorded. In each trap type, 2 different pheromones were tested with 3 replications. The traps were hung at a height of 1–1.5 m on the mandarin trees at the yield age at 10 m intervals. The performances of the traps were determined according to the trap types, pheromones, and months with the insects caught.

3. Results

3.1. Efficacy of Pheromones

Adults of BMSB was captured in small numbers by both pheromones in July and August, and it was determined that the number of insects caught increased starting in September. As a result, the temporal attraction frequency of the two pheromones during the season is equivalent (Figure 2). The pheromones caught significantly more adults at a rate of 94.1%–1.9%; that is, a total of 1225 adults and 62 nymphs (Table 1). In this respect, the overall trap performance of all traps is represented by total adults and nymphs. A one-way ANOVA was used to compare total weekly adult and nymph trap captures from July to September 2020 and 2021.

BMSB captures in SMC pheromone was correlated with all trap types. SMC+SFT was demonstrated to be 2.6 times more effective than TRC+SFT, and the performance of TRC in the other 3 traps was higher. In this study, most insects were caught in the TRC+BFT combination, and the TRC+MPT combination captured significantly more BMSB compared with all SMC+trap types. Although the TRC pheromone has the highest total capture percentage, catching frequencies are similar for both pheromones in July and October (Table 2). Accordingly, capture rates of SMC and TRC pheromones in July and August are very low; levels of insects peak in September and decrease in October.

3.2. Efficacy of Traps

The average weekly performance of the SFT and BFT with SMC pheromone is 1.3 and 1 insect per trap in 2020 and 2021, respectively. Therefore, the performances of these traps are equivalent in SMC pheromone. The two-year seasonal performance of the traps is shown in Figures 3 and 4.

In the time-dependent performance of traps, an increasing number of insects were caught from the end of August, until overwintering. Using this temporal definition as a baseline, captures of BMSB were considerably higher in SMC+SFT, TRC+BFT, and TRC+MPT combinations than in other traps at the relative population density in September. Furthermore, these pheromone-trap combinations caught BMSB almost constantly during the experiment.

The highest capture is detected in the BFT trap in TRC, which performs up to 10 times better compared to other traps. The number of insects caught in the MPT trap was determined to be between 2-4 times, resulting in the closest performance to the BFT (Figure 5 and 6).

In general, SMC and TRC pheromones were determined more effective at catching insects in September. In addition, BMSB abundance peaked in the BFT trap, which is the most effective trap, in September, as indicated by peak captures (Table 2).

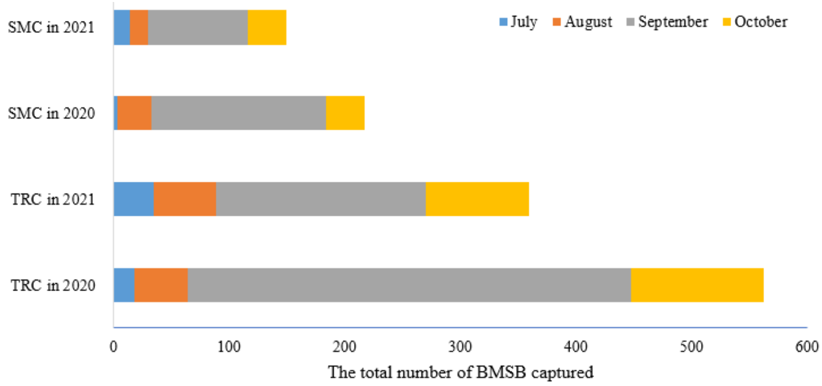

Figure 2. Performance of SMC and TRC pheromones by month in 2020 and 2021.

Table 1. Capture of BMSB adults and nymphs with four different traps and two pheromones in 2020 and 2021

		Adult Mean ± SE	Nymph Mean ± SE
SMC	SFT	68.00±8.00 b	4.00±3.00 a
	MPT	10.50±3.50 a	0.50±0.50 a
	MFT	29.00±5.00 a	1.00±0.00 a
	BFT	69.50±14.50 b	0.50±0.50 a
TRC	SFT	25.00±8.00 a	3.00±2.00 a
	MPT	76.00±4.00 a	14.5±10.50 a
	MFT	45.00±4.00 a	2.00±1.00 a
	BFT	289.50±92.50 b	5.50±1.50 a

Significant changes are indicated by rows with different letters (Duncan's HSD, α = 0.05).

Table 2. Capture of BMSB in four trap types and TRC and SMC pheromones in 2020 and 2021

Traps	Mounts	SMC		TRC	
		2020	2021	2020	2021
		Mean ± SE	Mean ± SE	Mean ± SE	Mean ± SE
SFT	July	0.00±0.00 a	0.40±0.19 a	0.11±0.11 a	0.20±0.14 a
		0.00±0.00 A	0.40±0.19 A	0.13±0.13 A	0.20±0.14 A
	August	1.00±0.26 b	0.46±0.19 b	0.50±0.17 a	0.27±0.15 a
		1.00±0.26 B	1.11±0.32 AB	0.5±0.17 AB	0.39±0.14 A
	September	3.44±0.54 b	2.73±0.47 b	1.05±0.27 a	0.73±0.25 a
		3.44±0.54 C	1.89±1.96 C	1.05±0.27 C	0.61±0.22 A
	October	0.17±0.12 a	0.47±0.24 a	0.22±0.13 a	0.27±0.12 a
		0.20±0.14 AB	0.17±0.40 A	0.27±0.15 A	0.17±0.17 A
MPT	July	0.11±0.76 a	0.13±0.09 a	0.83±0.26 b	0.73±0.21 a
		0.07±0.07 A	0.13±0.35 A	0.67±0.27 A	0.73±0.21 AB
	August	0.11±0.76 a	0.00±0.00 a	1.28±0.31 b	0.80±0.30 ab
		0.17±0.9 A	0.22±0.17 A	1.56±0.29 AB	1.78±0.46 BC
	September	0.61±0.18 a	0.33±0.21 a	2.39±0.43 a	3.4±0.61 b
		0.61±0.18 B	0.06±0.06 A	2.39±0.43 C	2.28±0.54 C
	October	0.00±0.00 a	0.00±0.00 a	0.89±0.32 a	0.67±0.27 a
		0.00±0.00 A	0.00±0.00 A	1.07±0.37 A	0.00±0.00 A
MFT	July	0.56±0.56 a	0.27±0.15 a	0.56±0.56 a	0.87±0.29 a
		0.00±0.00 A	0.27±0.15 AB	0.00±0.00 A	0.87±0.30 AB
	August	0.33±0.14 a	0.47±0.22 b	0.39±0.12 a	1.60±0.55 b
		0.39±0.14 A	0.67±0.21 C	0.44±0.12 A	1.83 ±0.47 B
	September	1.22±0.30 a	0.67±0.21 a	1.61±0.40 a	0.93±0.32 a
		1.22±0.30 B	0.50±0.17 AB	1.61±0.40 B	0.33±0.14 A
	October	0.33±0.14 a	0.27±0.15 a	0.28±0.14 a	0.67±0.67 a
		0.40±0.16 A	0.00±0.00 A	0.33±0.16 A	0.00±0.00 A
BFT	July	0.00±0.00 a	0.13±0.09 a	0.00±0.00 a	0.53±0.22 a
		0.00±0.00 A	1.33±0.09 A	0.00±0.00 A	0.53±0.22 A
	August	0.22±0.13 a	0.13±0.09 ab	0.39±0.20 a	0.93±0.36 ab
		0.22±0.13 A	1.22±0.43 AB	0.39±0.20 A	3.00 ±0.93 A
	September	3.11±0.42 b	2.00±0.48 b	16.22±1.87 b	7.00±1.32 c
		3.11±0.42 C	1.50±0.33 C	16.22±1.87 C	6.94±1.05 B
	October	1.33±0.46 b	1.47±0.32 b	5.00±1.24 b	4.93±0.96 b
		1.60±0.53 B	0.83±0.30 AB	6.00±1.35 B	2.33±1.11 A

"A-B-C" characters are used for grouping by months and "a-b-c" characters are used for grouping by performance traps. Significant changes are indicated by rows with different letters (Duncan's HSD, α = 0.05).

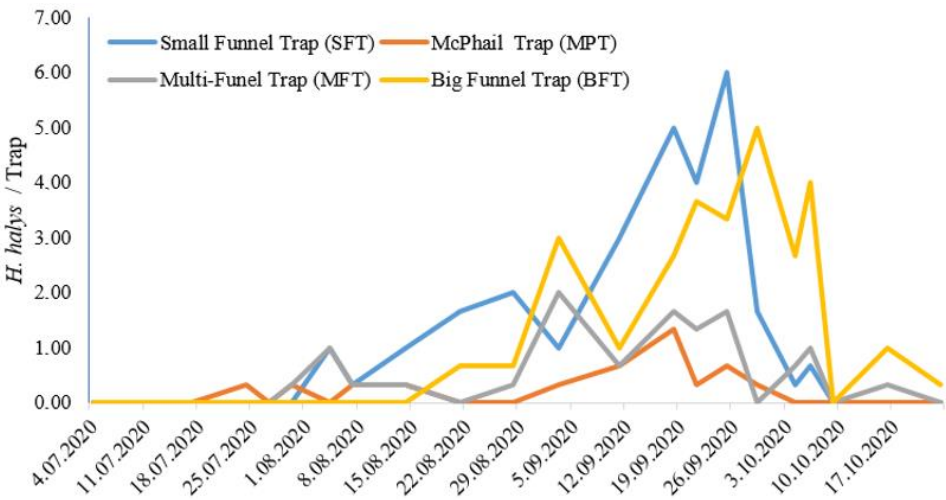

Figure 3. Performance of all traps in SMC pheromone in 2020.

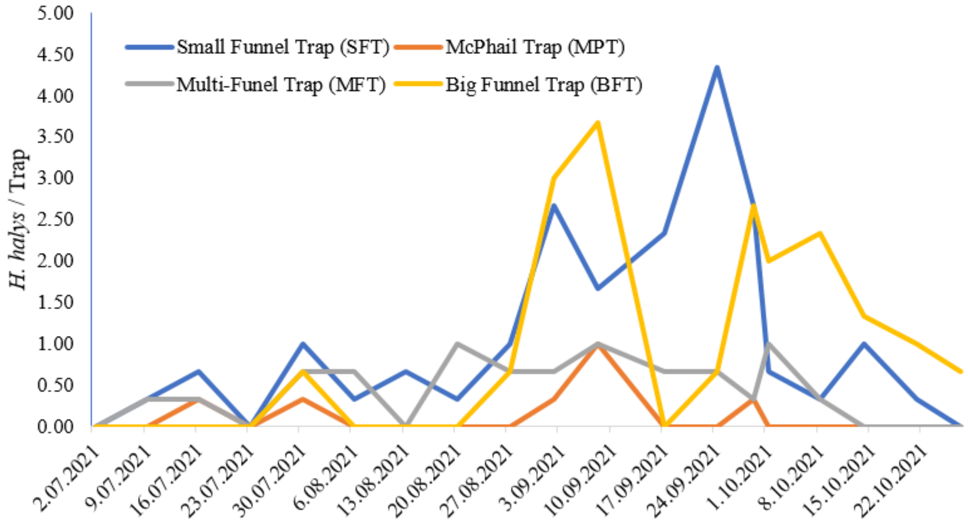

Figure 4. Performance of all traps in SMC pheromone in 2021.

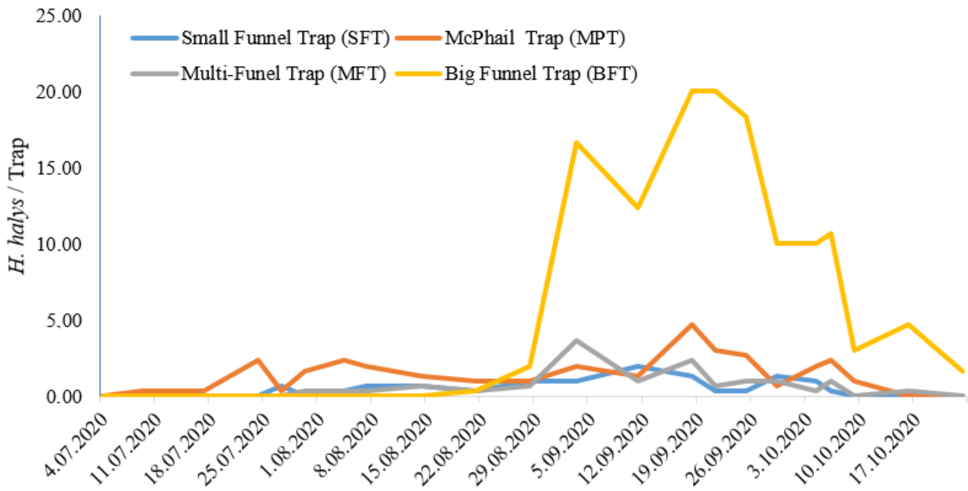

Figure 5. Performance of all traps in TRC pheromone in 2020.

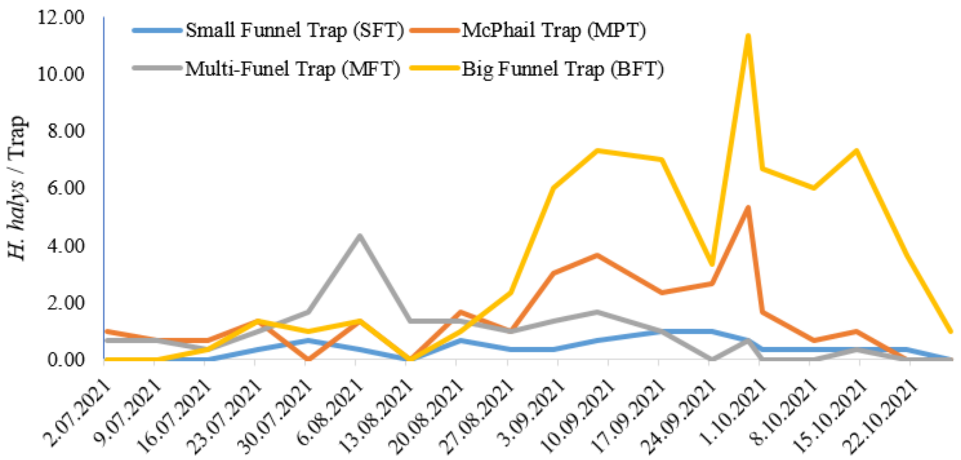

Figure 6. Performance of all traps in TRC pheromone in 2021.

4. Discussion and Conclusion

According to the results of many studies, the use of various traps utilized to control BMSB aims at monitoring, attract-kill, and live capture (Sargent et al., 2014; Leskey et al., 2015b; Rice et al., 2018; Suckling et al., 2019). These traps are generally used together with aggregation pheromones as an attractant and methyl (E,E,Z)-2,4,6-decatrienoate (MDT) lure as a synergist (Weber et al., 2014; Rice et al., 2017; Chase et al.,2018; Ak et al., 2019b; Acebes-Doria et al., 2020).

In this study, TRC, the most effective pheromone, was determined to combine successfully with BFT and MPT, whereas the SMC pheromone combined more effectively with SFT. As the study was evaluated in general, the TRC+BFT combination was determined to have 2-29 times more performance than other traps. In this case, using the BFT trap only for attract-kill in terms of its size, cost, and time-dependent performance is more appropriate. Especially the 6-liter capacity chamber of the trap, which is very effective at capturing a large number of insects. Moreover, the catching rate increases rapidly in September and October, while a small number of insects are caught in BFT until the end of August. This type of trap captured 23 times more BMSB than the sticky trap (Pherecon®) used for monitoring with the same pheromone, and these sticky traps are also used for monitoring purposes in the same region (Ak et al., 2019a; Ak et al., 2019b). As a result, while it's important to capture many insects in a brief period of time with attract-kill traps, it is critical for the monitoring traps to catch insects for a long time.

The attract-kill method should be not preferred for agricultural parcels of small sizes because may cause a bad effect. For example, damage from using attract-kill traps to catch BMSB in *Solanum lycopersicum* small gardens is greater than damage without traps (Sargent et al., 2014). Monitoring traps may provide longer-term data on relative population densities, whereas attract-kill traps provide data on high populations in a short period of time. Against a large number of BMSB adults and nymphs, insecticide applications were made to the killing blocks, and the use of attract-kill blocks resulted in 2–7 times less damage compared with standard areas. Overall, attract-kill proved successful in controlling low to moderate *H. halys* populations in agricultural lands (Morrison et al., 2018). The killing blocks edges of orchards may be good assist-solution in the fight against BMSB throughout the season (Rice et al., 2018). For growers with organic agriculture and beekeeping in the Eastern Black Sea Region, the attract-kill method may not be feasible because of the pesticide residue.

In this context, synthetic pheromones and LED combined with one trap can be evaluated as alternative methods. (Rondoni et al., 2022). The Aluminum Foil Pan Trap type can catch up to 144 insects per week over the overwintering period (Aigner and Kuhar 2014). In addition, the combined use of synthetic pheromone and LED at the same pyramid trap showed a synergistic effect on *H. halys* positive phototaxis. This multiple trap combination attracted up to 8 times more BMSB, increasing performance (Rondoni et al., 2022). However, more research should be conducted to accurately characterize BMSB behavior utilizing light-based attractants alone or in combination with specific pheromone monitoring methods (Leskey et al., 2015b).

In order to improve the design of BMSB traps, efforts were initially focused on identifying disadvantages and increasing efficiency. For example, although large pyramid traps are effective, they are unsuitable for agricultural use because they are expensive, cumbersome, and difficult to establish (Rice et al., 2018). In our study, the accumulation of rainwater in the reservoir of the BFT was a drawback. Because insect cadavers block the base drainage holes during rain, the reservoir may fill with water from time to time. Furthermore, during periodic controls, thin plastic material deforms quickly, which may cause insects to escape. Horizontal funnel traps designed to capture BMSB live provide an alternative to these drawbacks (Suckling et. al., 2019). In addition, trap designs should be cheaper, lightweight, durable, and uncomplicated (Morrison et al., 2015). In another study, modified pyramid traps were more successful than standard pyramid traps and small pyramid traps, and different designs of the same trap type also affected performance considerably. The researchers determined that adults were caught more frequently in modified pyramid traps, and more nymphs were caught in all other traps (Rice et al., 2018). However, considering that the rate of catching adults is higher in all traps in our study, it is clear that the trap type is very effective on the adult-nymph ratio. Consequently, lower nymphal captures may indicate relative populations, although in a smaller overall than adults.

Transparent sticky traps combined with BMSB pheromone and synergist are stated to be basic and simple to use for monitoring purposes (Acebes-Doria et al., 2018). SMC+SFT and TRC+MPT can be used because of their small size and durable materials for long-term monitoring programs in early July–early October. Interestingly, using the SMC pheromone, the seasonal peak of BMSB captures in the SFT trap paralleled those captured by BFT that most efficacy combination. Although the reservoir of SFT was quite small compared to that of BFT. In this research, SMC+BFT has been deemed to be the best trap with regard to performance and usability. Additional studies must be conducted to examine alternative trap designs with additional trap types in varying populations in order to shift to simpler designs. Therefore, the evaluation criteria of BMSB traps vary according to the intended use and performance of the traps. At this point, it is important to make the right choice. The application of insecticides, in apple orchards has decreased by 40% due to the use of pheromone traps in making decisions about insecticide treatments (Short et al., 2016). Using pheromonal monitoring can help determine susceptible crops to invasion and make proactive applications.

Recently, using semiochemicals and semi-physical attractants together as synergists (viotraps) and technological applications (BugMap, image analysis system, sensor, smart trap) have been researched for more sustainable IPM strategies and sophisticated approaches (Malek et al., 2019; Čirjak et al., 2022; Zapponi et al., 2023).

In general, the availability of various types of traps and attractants that can be used against BMSB expands research possibilities. This study showed that trap design and pheromone composition may influence trap effectiveness significantly. According to the results of the study, the potential of using the four traps tested in our study for the indirect and direct control of BMSB should be evaluated with new research.

Author Contributions

The percentage of the author(s) contributions is presented below. All authors reviewed and approved the final version of the manuscript.

	M.U.	K.A.
C	80	20
D	50	50
S	60	40
DCP	50	50
DAI	60	40
L	70	30
W	60	40
CR	50	50
SR	70	30
PM	20	80
FA		100

C=Concept, D= design, S= supervision, DCP= data collection and/or processing, DAI= data analysis and/or interpretation, L= literature search, W= writing, CR= critical review, SR= submission and revision, PM= project management, FA= funding acquisition.

Conflict of Interest

The authors declared that there is no conflict of interest.

Ethical Consideration

Ethics committee approval was not required for this study because there was no study on animals or humans.

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