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Seasonal dynamics and abundance of brown marmorated stink bug *Halyomorpha halys* (Stål) on four trap crops

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Abstract: The main purpose of the study was to examine the potential of crops, such as soybeans (*Glycine max*), sunflowers (*Helianthus annuus*), alfalfa (*Medicago sativa*), and sorghum (*Sorghum bicolor*), as trap crops for *Halyomorpha halys.* We monitored the abundance and seasonal dynamics of *H. halys* (egg clusters, larvae, and adults) on a selected number of various crops at 10-day intervals. The experiment was performed in two different regions of Slovenia (western and central) and in two different years (2021, 2022). The results varied depending on the location and the year. In the first experiment, data from the entire year showed that sorghum was the most attractive for *H. halys* adults (1.56 ± 0.12), followed by sunflowers (0.61 ± 0.05), soybeans (0.37 ± 0.03) and alfalfa (0.41 ± 0.21). In the second experiment, the abundance numbers of the pest were significantly lower compared to those of the first experiment [sorghum and soybeans (0.003 3 ± 0.002), sunflowers (0.000 3 ± 0.000 3)]. In both cases, the abundance numbers increased when all the crops entered the fruit development stage (BBCH 70+). Overall, the lower density of the *H. halys* population and the experimental design could also be some of the factors for such a low incidence of stink bugs in the central region of the country. More research will be needed to further develop effective control methods for this invasive pest.

Keywords: alfalfa; brown marmorated stink bug; sorghum; soybean; sunflower; trap crops

Due to the presence and emergence of new alien invasive pests, attempts are being made to acquire new methods to control these pests. One such pest is the brown marmorated stink bug, *Halyomorpha halys* (Stål 1855). The species originates from Asia. Its name derives from the marbled pattern that it wears on its back (shield). The bug is highly polyphagous with a high reproduction capability, a wide range of host plants and the ability to spread rapidly (Rot et al. 2018). With the aforementioned characteristics, the pest presents a serious challenge to all the existing plant protection practices and poses a serious threat to the agricultural sector, such as fruit growing. Today, in Europe, the pest is widespread, and present almost in every country (Dioli et al. 2016; Batistič 2019). The insect causes feeding damage by sucking on fruits and/or other plant organs (leaves, stems, etc.). In addition to being a harmful organism in agriculture, it also represents a nuisance pest during its search for overwintering sites in people's dwellings (Milonas & Partsinevelos 2014). Current pest control practices with insecticides are effective, but do not represent a sustainable solution to the *H. halys* problem.

One of the possible methods of an alternative approach in plant protection is the use of attractive plants or trap crops. The main purpose of such a technique is to attract a group or type of harmful organism on a pre-selected number of trap crops and try to limit the damage that they could cause on the main crop or on the main plant species (Hokkanen 1991; Bohinc & Trdan 2011;

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Batistič 2021). The method is often used in cases where there is no registered phytopharmaceutical product to control a specific harmful organism or in cases where the preparation of such a product is too expensive, or it is not allowed for use (for example, in organic production). Trap crops are also used when the main crop is not resistant to any attack or infection by harmful organisms. One of the principles of this method is based on the fact that practically all harmful insect species show a greater affinity to a specific plant species. It is important to point out that this is strongly influenced by the phenophase of the plant. By knowing the seasonal dynamics of the pest, we can also adjust the types of crops and, so to speak, 'set' the most attractive phenophase of the trap crop for the targeted pest at the time when its abundance is the greatest (Nielsen et al. 2016). With this aim, we can achieve a high abundance of the pest at a desired place/spot, i.e., on the trap crop (Hokkanen 1991). The attractiveness of trap crops can be further increased by using additional chemical compounds and attractants, such as insect pheromones, plant kairomones and additional nutritional supplements (Hokkanen 1991).

If we decide to establish a functional trap crop design, its layout depends on the type of the pest we are trying to control. We must also choose appropriate types of crops. Sowing can be undertaken in rows next to the main crop or in the way of an intercropping system, we can also try sowing the crops at the edge of the main crop or in the centre, etc. The main types of crops that are most often attacked by the brown marmorated stink bug are soybeans and corn (*Zea mays* L.). The pest has also been found on wheat (*Triticum aestivum* L.), sorghum, sunflowers and cotton (Rice et al. 2014).

The advantage of using trap crops is also that they have better environmental and economic benefits for the farmer. The trap crop method can be implemented wherever it can provide an alternative to conventional pest control methods. As a result, the overall use of pesticides is lower, trap crops are also more environmentally friendly and represent a more sustainable way of farming (Hokkanen 1991).

By monitoring the population dynamics of *H. halys* on the preselected trap crops, we tried to obtain data on the seasonal abundance and dynamics of the pest in the Central region of Slovenia (Biotechnical Faculty, Ljubljana) and in the Goriška region (western part) of Slovenia. We also assessed the potential of sorghum (*Sorghum bicolor* Moench.), soybeans (*Glycine max* L. Merr.), sunflowers (*Helianthus annuus* L.), and alfalfa (*Medicago sativa* L.) as trap crops for *H. halys* (Hokkanen 1991; Tillman 2006; Soergel et al. 2015; Nielsen et al. 2016; Mathews et al. 2017). We also compared the differences in attractiveness between the individual crops, and compared in which developmental stage of the crops was the pest most present/abundant. We also tried to explain the differences in the pest abundance in both studied regions and tried to compare both.

The aim of the research was to obtain relevant information on the effectiveness of attracting the brown marmorated stink bug to different trap crops. As part of the aforementioned information, we monitored the incidence/dynamics of the pest (egg clusters, larvae, and adults) on the studied attractant crops. The obtained data were used to compare the differences in the attractiveness between the individual crops. These results were also separately analysed according to the year and location of the two experiments. We also examined the seasonal dynamics of the pest, i.e., when and in which developmental stage the pest appeared on a certain plant species on certain census dates. Based on the obtained data, we also compared the results of 2021 from the western part of the country to the results of 2022 from the central part of the country.

Before the research, we assumed that we were going to confirm the differences in attractiveness and occurrence of the brown marmorated stink bug among the studied trap crops that were used in the experiment. These results would then be used to further determine the differences between the attractiveness and occurrence of stink bugs on all the preselected trap crops (sunflowers, soybeans, alfalfa, and sorghum).

Another hypothesis, and our assumption, was that we would find statistically significant differences in the *H. halys* abundance in the area of western Slovenia in 2021 where experiment 1 was carried out in comparison to the area of central Slovenia in 2022 where experiment 2 was carried out. In short, we will confirm the differences in the stink bug abundance according to the region of the census.

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MATERIAL AND METHODS

Research area

The experiments were carried out in 2021 and 2022 in two different areas. The first experiment was performed in the western part of Slovenia near the village of Miren (45°53'46.15"N, 13°36'25.9"E, 45 m altitude), adjacent to an old apple ('Elstar' apple variety) orchard of a local farmer. The orchard consisted of a total of seven rows of apple trees. The second experiment was performed on the Experimental Field of the Biotechnical Faculty in Ljubljana (46°02'55.2"N 14°28'24.7"E, 299 m altitude, central part of the country) which was app. 240 m away from the main cultivated fruit species (apples), as in experiment 1.

Trap crops

We used the following varieties of trap crops: sunflower 'RGT Wollf', soybean 'Atacama', sorghum 'Frisket', and alfalfa 'Soča' in both experiments.

Experimental design

Two separate experiments were performed. One in 2021 and the other in 2022. Experiment 1 was conducted in Miren in a fruit growing area. Experiment 2 was carried out the next year in Ljubljana in the Experimental Field of the Biotechnical Faculty. In the case of the first experiment, the plot was 120 m in length and 2 m in width. The plot was divided into three blocks (40 m each). In each block, we established four different types of trap crops (Figure 1). We placed them in the same sequence and in 10 m strips. First, we sowed sunflowers, then soybeans, then alfalfa and then lastly sorghum. All of the crops were sown similarly in three rows (70–75 cm of distance between the rows and 25–30 cm of inner row distance), except for alfalfa which was sown all over the established strip/part. All of the above-mentioned procedures and the sowing were carried out on April 20, 2021. The same method of sowing and division of plots was used for experiment 2 in the next growing season. This time the plot was only 78 m in length and 2.5 m in width. It was divided into three blocks (26 m each). As in the previous year, each block was then divided into four strips that represented the four growing areas for our four different types of trap crops. The order in which we sowed the crops was the same as in 2021. Firstly, we sowed sunflowers, then soybeans, then alfalfa, and lastly sorghum. The distance between the rows and the inner row spacing for every crop was the same as in experiment 1. The only major difference between experiment 1 and experiment 2 was that we sowed the seeds on different dates and the number of plants that were visually assessed in each strip (24 plants per strip/part in 2021 and 10 plants per strip/part in 2022). In experiment 2, we started sowing the alfalfa on the April 11, 2022 and then all the other crops were sown on May 5, 2022.

Figure 1. Trap cropping system near an apple orchard implemented for the monitoring and control of *Halyomorpha halys*. Miren, 2021 (Batistič 2021)

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Data acquisition and statistical analysis

To detect pests on the studied crops, we used two different detection methods: visual inspections of plants (24 plants per strip/part), for the sunflower, sorghum and soybean crops (Laznik et al. 2010), and sweep net sampling (2 r = 40 cm) for the alfalfa crop in both years (2021 and 2022). In 2021, we recorded the growth stages of each trap crop from May 5 until October 25 at 10-day intervals, and the abundance of *H. halys* individuals in the egg, larval and adult stages on the trap crops from June 25 to October 25 at 10-day intervals (Figure 2). In 2022, the recorded abundance of the pest in the form of egg clusters, larvae, and adults started on June 28 and lasted until September 5 at 10-day intervals. We also recorded the growth stages of each crop from May 17 until September 5 at 10-day intervals.

In both experiments, a general statistical analysis was performed using a multifactor analysis of variance (MANOVA), and the statistical differences within the individual factors in the experiment were calculated using a one-way analysis of variance (ANOVA). The factors in the multifactorial analysis were the date of counting, the trap crop, the developmental stage of the pest and the block. We calculated the statistical differences within the individual factors in the experiment using a one-way analysis of variance, for example, the abundance of the different developmental stages of the pest on the different trap crops. We used the Newman-Keuls test for multiple comparisons ($P \leq 0.05$) to statistically evaluate the differences in the average number of different developmental stages of the marmorated stink bug on the different trap crops and also on the primary host plant, the apple tree. For the data processing, we used the Statgraphics Centurion software (version XVII).

Figure 2. *Halyomorpha halys* attractiveness to sorghum seeds (Batistič 2021)

RESULTS

Phenophases of the crops

Tables 1 and 2 show the evaluations of the development stages of each crop in 2021 and 2022. In some cases, we selected several developmental stages (not uniform).

From both tables (Tables 1 and 2), we can see that we started recording the developmental stages when most of the plants, with the exception of alfalfa, were already past the emergence phenophase. In fact, the sorghum, soybean and sunflower plants were all in the leaf development phase from May 5, 2021 and May 17, 2022. According to our estimates, the vegetative part of the development continued until the end of June in 2021 and approximately a week later in 2022. The first pods of sunflowers began to develop approximately at the same time as the first inflorescences of soybeans began to appear (beginning of July). This developmental stage is followed by the transition to the phenophase of fruit and seed development, which was fairly uniform in all the crops. For example in 2021, most of the crops were in this developmental stage from the end of July until the first ten days of August. In 2022, however, the data between crops is less uniform. The soybeans and alfalfa were in this developmental stage earlier, around mid-July. The sunflowers and sorghum were in this phenophase slightly later. The developmental stage of fruit and seed ripening in 2021 was recorded around mid-August and it continued until the end of August. In 2022, this phenophase was quite extended, from the beginning of August until the beginning of September, with the exception of sorghum whose ripening began in the second half of August. The phenophase of senescence and plant decay can be observed from mid-September onwards in 2021. In the following year, we stopped collecting data at the beginning of September, therefore, we can add that there were no major signs of any decaying plants. In the case of sorghum in 2021, we noticed the appearance of new side shoots on the plants, which is why Table 1 lists two different phenophases. The side shoots bloomed from September 5, 2021 and

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Table 1. Evaluations of the phenophases of the crops during the period of the experiment in 2021

Date (2021)	Sunflowers	Soybean	Alfalfa	Sorghum
5. 5.	11	10	0	11
15. 5.	13–14	10	0	13
25. 5.	16–17	10	0	14–15
5. 6.	20–30	10	1	19–21
15. 6.	35–38	20–22	1–2	31
25. 6.	53–55	40–50	2–3	41
5. 7.	59–61	63–64	3	49–57
15. 7.	67	67–69	4	61–65
25. 7.	69–71	73	5–6	71–73
5. 8.	73–75	77	6–7	75–77
15. 8.	79–80	80	8	83–85
25. 8.	83	82	9	87–89
5. 9.	85–87	86	9+	92 and 61
15. 9.	89	89	9 + and (1)	99 and 69–71
25. 9.	97	91	senescence and (1)	99 and 73–75
5. 10.	97	93	senescence and (1)	99 and 75
15. 10.	97	94	senescence and (2)	99 and 77–80
25. 10.	97	96	senescence and (2–3)	99 and 83–85

BBCH – sunflowers, soybeans and sorghum; Vegetative stage index – alfalfa

increased the attractiveness of sorghum again until October 10, 2021. The same applies to alfalfa, with the exception that we did not record an increase in the attractiveness.

Table 2. Evaluations of the phenophases of the crops during the period of the experiment in 2022

Date (2022)	Sunflower	Soybean	Alfalfa	Sorghum
17. 5.	11	10–11	0	11
27. 5.	14	12	0–1	13
10. 6.	16	14	1	16
17. 6.	25–30	16	2–3	18
27. 6.	53	51–55	4–5	24
5. 7.	59	69	6	37–39
14. 7.	63	74	7	49
25. 7.	73–75	77	7–8	65–69
4. 8.	79–80	80	8	75
11. 8.	81	82–83	8	77
17. 8.	83	84	8	80
26. 8.	85	86–87	9	84
5. 9.	87	89	9	89

BBCH – sunflowers, soybeans and sorghum; Vegetative stage index – alfalfa

Abundance of *Halyomorpha halys* on the selected trap crops

General insight on the pest abundance on the crops in 2021. The abundance of *H. halys* was not significantly different between the sorghum, soybean, and sunflower plants. The abundance of *H. halys* in alfalfa was assessed with a different sampling method and cannot, therefore, be directly compared to the other trap crops.

Figure 3 shows the average number of the different developmental stages of brown marmorated stink bugs per plant (combined catch for the sunflower, soybean, and sorghum crops) from June 6, 2021 to October 25, 2021. The statistical analysis showed no differences between the blocks, therefore, we decided to present the average number of specimens detected per plant, taking all three trap crops into account (sorghum, soybeans, and sunflowers). The attractiveness of the crops was assessed uninterruptedly from the beginning of the appearance of the stink bugs on the crops until a certain period (end of October) when most crops went into senescence, and they no longer attracted any stink bugs.

First, we decided to present the results related to the adult specimens. The significantly highest aver-

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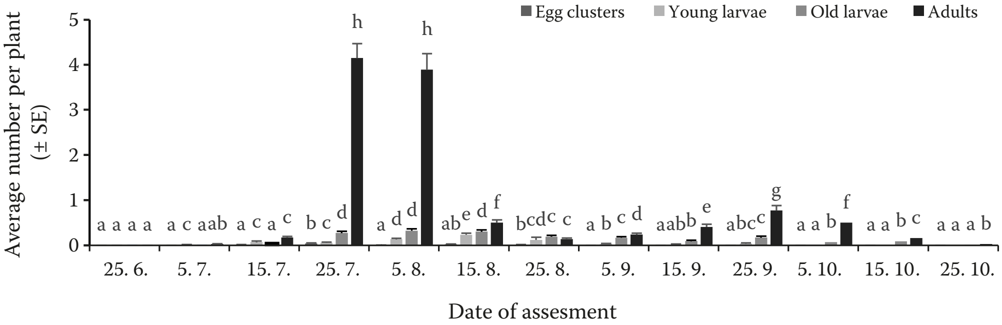

Figure 3. Average number (± SE) of the different developmental stages of *Halyomorpha halys* per plant on all the studied trap crop plants together (sorghum, soybeans and sunflowers) per the assessment date in 2021
[a–h]Lower case letters present differences between the dates and the same developmental stage of *H. halys*

age number of *H. halys* adults per plant on the trap crop was recorded on July 7, 2021 (4.15 ± 0.32) and August 5, 2021 (3.89 ± 0.36). As for the old larvae (stages L4 and L5), we can conclude that the significantly highest average number of insects per plant was recorded between July 25, 2021 (0.27 ± 0.038) and August 8, 2021 (0.30 ± 0.04). This is followed by the young larvae (stages L1, L2, and L3), whose significantly highest average number per plant on the trap crops occurred on August 15, 2021 (0.23 ± 0.04). We also found some egg clusters on the plants of the trap crops. The highest average number of egg clusters per plant was found on July 25, 2021 (0.04 ± 0.014).

From Figure 4, we can deduce that among the selected trap crops in the first studied area, sorghum (1.56 ± 0.12) was the most attractive for the *H. halys* adults followed by sunflowers (0.61 ± 0.05) and soybeans (0.37 ± 0.03). The same applies to the old larvae (Figure 4). The abundance of *H. halys* egg clusters and young larvae was the highest on the soybean plants (Figure 4). With our results, we confirmed the hypothesis in the differences of the attractiveness and stink bug occurrence among the studied crops.

On the sorghum plants, we found the significantly highest average number of *H. halys* adults and old larvae. The adults were the most abundant on July 25, 2021 (7.65 ± 0.70) and August 5, 2021 (8.01 ± 0.79), and the old larvae were the most abundant on August 5, 2021 (0.51 ± 0.10). Soybeans were the crop on which we found the largest amount of egg clusters (0.125 ± 0.04) and young larvae (0.49 ± 0.10), which were both the most abundant from the end of July until mid-August (Figure 5).

General insight on the pest abundance on the crops in 2022. The abundance of the pests was not significantly different between the sorghum, soybean, and sunflower crops. Due to the different sampling method, alfalfa was not directly included and compared with the other crops.

Figure 6 shows the average number of the different developmental stages of the brown marmorated stink bug per plant (combined catch for the sunflower, soybean and sorghum crops) from June 21, 2022 to September 5, 2022. The attractiveness of the crops was assessed uninterruptedly from the beginning of the appearance of the stink bugs on the crops until a certain period when most of the crops started decaying into senescence.

For the adult specimens of *H. halys*, the significantly highest average number of insects per

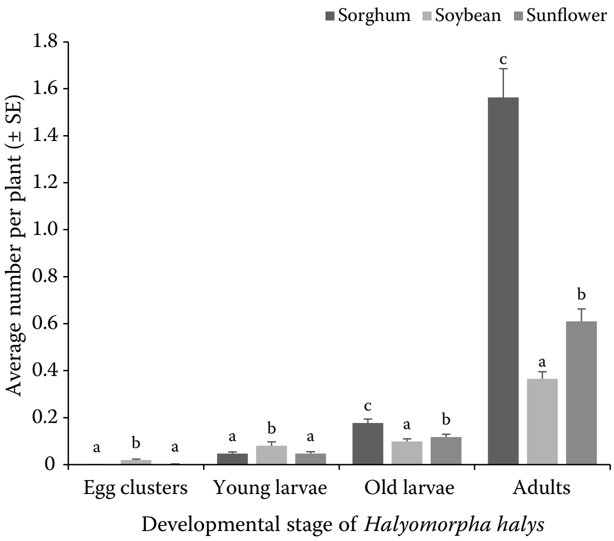

Figure 4. Average number (± SE) of *Halyomorpha halys* individuals per developmental stage on the individual sorghum, soybean and sunflower plants in 2021
[a–c]Lower case letters present differences within the same developmental stage of *H. halys* between the different trap crops

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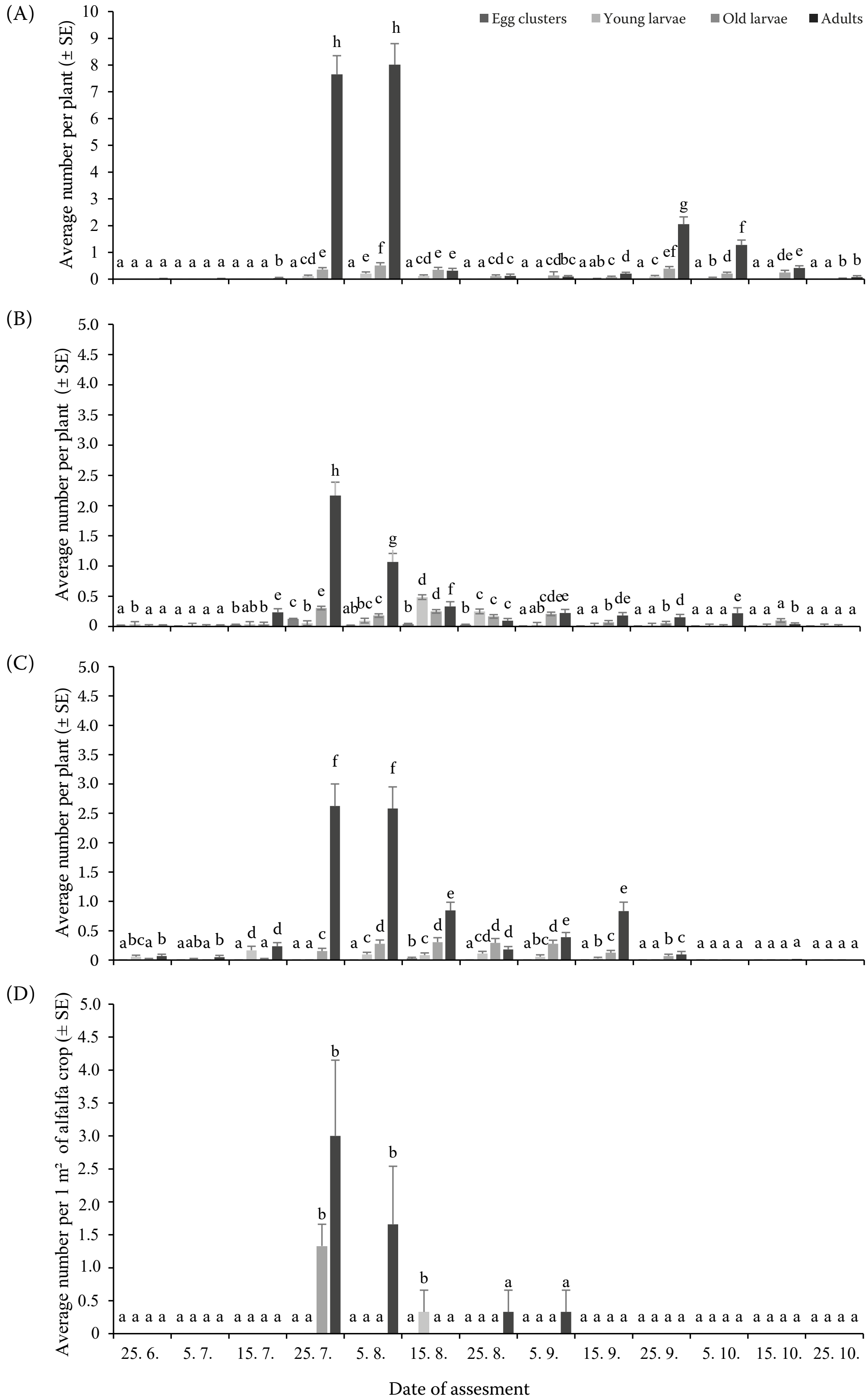

Figure 5. Average number (± SE) of the different developmental stages of *Halyomorpha halys* on the individual sorghum (A), soybean (B), sunflower (C), and alfalfa (D) plants by the date of assessment, Miren, 2021

[a–h]Lower case letters present differences between the dates and the same developmental stage of *H. halys* for each variety of trap crop

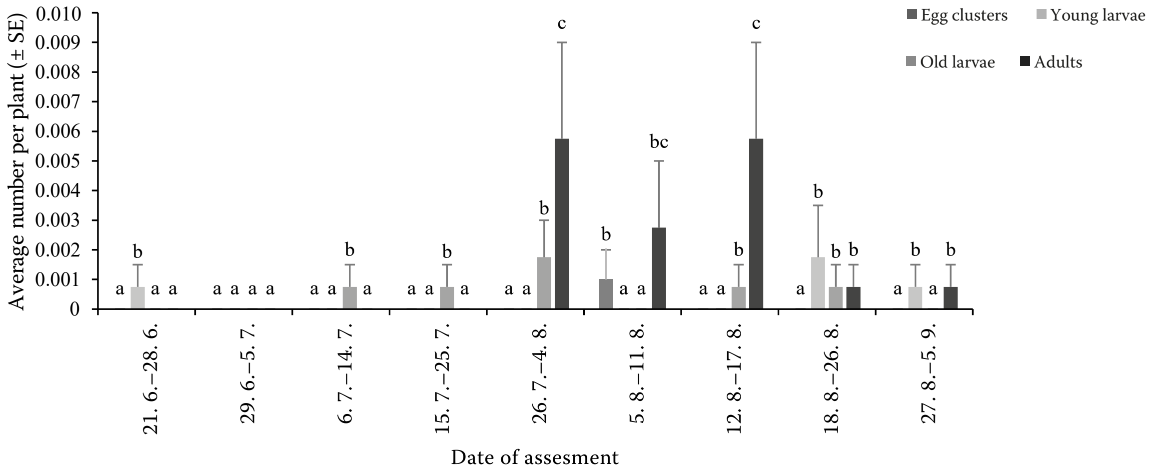

Figure 6. Average number (± SE) of the different developmental stages of *Halyomorpha halys* per plant on all the studied trap crop plants combined (sorghum, soybeans and sunflowers) per the assessment date in 2022
a–cLower case letters present differences between the dates and the same developmental stage of *H. halys*

plant of trap crop was recorded on August 4, 2022 (0.005 8 ± 0.003 25) and August 17, 2022 (0.005 8 ± 0.003 25). Continuing with the old larvae (L4 and L5), we can see from Figure 4 that the significantly highest average number is present from mid-July until the end of the data collection, the beginning of October (0.000 75 ± 0.000 75). As for the young larvae (stages L1, L2, and L3), we can conclude that the significantly highest average number of insects per plant was recorded at the end of our trial, August 26, 2022 (0.001 75 ± 0.001 75). We also found egg clusters on August 11, 2022 (0.001 ± 0.001).

From Figure 7, we can deduce that among the selected trap crops in the second year of the experiment, sorghum (0.003 3 ± 0.002) and soybeans (0.003 3 ± 0.002 2) were the most attractive for *H. halys* adults followed by sunflowers (0.000 3 ± 0.000 3). For the old larvae (L4 and L5), sorghum was also the most attractive (0.001 444 ± 0.001 222). The abundance of *H. halys* egg clusters and young larvae (L1, L2 and L3) was the highest on soybean plants (Figure 7). From the results, we can deduce that the number of caught/observed stink bugs was far smaller than in the previous year, although bearing similar results.

On the sorghum and soybean plants in August, we found the significantly highest average number of *H. halys* adults (0.02 ± 0.01). As in 2021, the soybeans were the crop on which we found the most egg clusters (0.004 ± 0.004) and young larvae (0.007 ± 0.007). The average abundance of the pest was significantly lower in 2022 than in 2021.

DISCUSSION

Both experiments were carried out with the aim of determining the effectiveness of a few selected trap crops as attracting agents for stink bugs. In short, we tested an alternative, more environmentally friendly method of attracting or repelling stink bugs from the main cultivated plant species. In terms of practical use, we sowed and cultivated four different crops with the aim of attracting brown marmorated stink bug (*H. halys*). Sunflowers, sorghum, soybeans, and alfalfa were among the crops that we classified as the potential trap crops

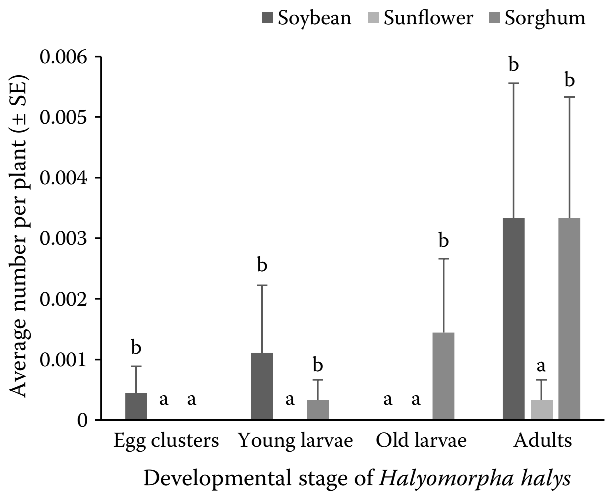

Figure 7. Average number (± SE) of *Halyomorpha halys* individuals per developmental stage on individual sorghum, soybean and sunflower plants in 2022
a–hLower case letters present differences within the same developmental stage of *H. halys* between different trap crops

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for the bug. We must add that the very design and setting of the experiment itself play a very important role in the general outcome of the experiment. The variety of crops and the associated possibility of host selection by the pest are also of great importance, as well as the phenophases of the crops which change throughout the growing season and represent a greater or lesser nutritional value for the pest in a certain specific period, therefore, the abundance of the pest on the crops is lower or higher (Hokkanen 1991; Tillman 2006; Soergel et al. 2015; Nielsen et al. 2016; Mathews et al. 2017).

As trap crops, sunflowers have been successfully used for insects from the orders Hemiptera, Lepidoptera, and Coleoptera. Soergel et al. (2015) confirmed that sunflower crops attract *H. halys*. In the research, they tried to find out if they can reduce the damage and abundance of the pest on peppers (*Capiscum annuum* L.) by using sunflowers as a trap crop. From the results of their counts, which were carried out in 2012 and 2013, we can deduce that the abundance of the pest was higher on the sunflowers than on the peppers. As many as 89 to 95% of all the stink bugs that were counted in both years appeared on the sunflowers and only 5 to 11% appeared on the peppers. However, the proportion of damage on the peppers did not decrease when compared to the control (Soergel et al. 2015).

Soybeans are a very popular host plant for *H. halys*. In East Asia, the increasing damage to this crop has been reported since the year 2000. The brown marmorated stink bug initially feeds on the young developing leaves and the stem, but also later attacks the pods and seeds (Lee et al. 2013). The usefulness of soybeans as a trap crop and its effectiveness is highlighted by Hokkanen (1991), who explains that the development cycle and seasonal dynamics of the pest are closely related to the phenology of the plant, which enables the optimal development of the pest, which consequently means that the use of soybeans as a trap crop makes a great deal of sense. This theory is additionally confirmed by the study of the seasonal dynamics and detection methods of *H. halys* on soybeans by Nielsen et al. (2011). They concluded that the abundance of the brown marmorated stink bug on soybeans coincides with the phenophase of the fruit and seed development. They also pointed out that *H. halys* has become a dominant species of stink bugs on soybeans and that the threshold of economic damage caused by this pest should be determined (Nielsen et al. 2011).

As a trap crop, alfalfa has successfully been used to reduce the abundance of various species from the family Miridae. I would like to point out the example from Australia, where alfalfa was used as a trap crop and it limited the abundance and damage of the species *Creontiades dilutus* (Stål) on cotton plants. Alfalfa was sown in an 'intercropping' system. As a result of the mentioned measure, the number of adults and nymphs of the pest on the cotton decreased by as much as 15 to 35 times, which was comparable to the results of using conventional methods of controlling the pest, i.e., using an insecticide. In the article, they also suggest that the system could be established as one of the measures in the framework of integrated pest management – IPM (Mensah & Khan 1997).

Sorghum has proven to be a successful trap crop for various species of stink bugs. When used to limit the feeding damage of *Nezara viridula* (L.) on cotton and corn, its success rate was quite high. The reduction in damage to corn cobs was estimated at 22%. Another benefit was the overall lower number of insecticide applications (Tillman 2006). In another study in which they looked at whether there is any effective attractive/trap crop against the invasive stink bug *H. halys*, they found that sorghum is most effective after July, i.e., after flowering. They also confirmed the highest abundance of the pest on sorghum, which is why this crop was ranked first in terms of the attractiveness among all the considered crops. They also found that the occurrence of the brown marmorated stink bug on sorghum and other studied crops differs. The stink bug first attacked the sunflowers and then sorghum, providing up to five weeks of effective attraction for this pest (Nielsen et al. 2016).

Starting from the data that we collected in 2021, we can say it with certainty that sorghum was the most attractive of all the studied crops for the *H. halys* adults (1.56 ± 0.12), followed by sunflowers (0.61 ± 0.05) and then soybeans (0.37 ± 0.03) (Figure 4). Older larvae were found in similar average numbers on the sorghum plants (0.18 ± 0.017) and sunflowers (0.12 ± 0.012 5), but they were the least abundant on the soybean plants (0.10 ± 0.011), (Figure 4). The average number of young larvae was similar on all three types of crops [sorghum (0.05 ± 0.008), soybeans (0.08 ± 0.02), sunflowers (0.05 ± 0.008)] (Figure 4). The egg clusters of the pest were the hardest to find and also the least present. Despite a small number of them, they were mostly found on the soybean plants

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(0.02 ± 0.004). Fewer egg clusters were found on the sunflowers (0.002 ± 0.001), but none were found on the sorghum plants. Separate graphs (Figure 5) portrait a picture of the *H. halys* abundance on all the crops separately throughout the entire growing season by dates. We can extrapolate that the adult stink bugs were the most present on the plants from July 25, 2022 until August 5, 2022, with very high average numbers that exceed the averages from any other dates. For example, on the sorghum plants, the highest abundance was (8.01 ± 0.79) adult specimens per plant, followed by sunflowers (2.63 ± 0.38), soybeans (2.17 ± 0.22) and lastly alfalfa (3.0 ± 1.15) (Figure 5). The averages for the older larvae and younger larvae were much lower (Figure 5). Also, the intensity and the occurrence of these stages was lower, which probably means that most of the crops at that time represented one of the most important sources of food for the pest and, therefore, we can observe an intensive relocation of the adult stink bugs on these crops (Figure 5). Moreover, the data also confirm it. The attractiveness of the mentioned crops increased significantly after the phenophase of the fruit development (BBCH 70) and it proceeded to decrease at the beginning of August when most of the crop seeds started to ripen (Table 1, Figure 5). Nielsen et al. (2016) also found a higher abundance of invasive stink bugs in the phenophase of the fruit/seed development. Mizell et al. (2008), who studied the effectiveness of trap crops in attracting different stink bug species throughout the growing season, also pointed out a similar finding. They recorded the phenophases of individual plants and found that the stink bugs were most present on the crops when they began to transition into the phase of fruit development. We can add that our results correlate to that finding. The authors note that it is necessary to adapt the system of trap crops to the pest and that it is necessary to choose such plant species that cover as much of the growing season as possible and, thus, attract the target organism for a longer period. A similar picture, as seen in the separate graphs (Figure 5), can be seen in Figure 3, where there is also a noticeable peak in the adult *H. halys* abundance between July 25, 2022 (4.15 ± 0.32) until August 5, 2022 (3.89 ± 0.36). The largest number of old larvae was present in the period from July 25, 2021 (0.27 ± 0.038) to August 15, 2021 (0.30 ± 0.04), and the largest number of young larvae was present on August 15, 2021 (0.23 ± 0.04). We also found a few egg clusters on the soybean and sunflower plants, specifically on July 25, 2021 (0.04 ± 0.014) and August 15, 2021 (0.023 ± 0.01). The findings of the overall general attractiveness of the crops (sunflowers, soybeans and sorghum) by date are equally interesting and similar to the data from the separate graphs.

The picture from 2022 is quite different. The results and average numbers of *H. halys* specimens per plant of trap crop are much lower in comparison to the results from 2021. For example, the highest average number of *H. halys* adults on all the combined studied crops (Figure 6) was recorded on August 4, 2022 and August 17, 2022 (0.005 8 ± 0.003 25), which is approximately 715 times less than the recorded number in 2021 (4.15 ± 0.32). The average number of other larval stages and egg clusters were also lower than the numbers from 2021, and frankly speaking, rather negligible. From Figure 7, we can see that sorghum (0.003 3 ± 0.002) and soybeans (0.003 3 ± 0.002 2) were the most attractive for the *H. halys* adults followed by sunflowers (0.000 3 ± 0.000 3). Sorghum was also the most attractive for the old larvae (0.001 444 ± 0.001 222). The young larvae and egg clusters were most present on the soybean plants. The results were similar to that from 2021 in terms of the crop attractivness classification (sorghum being the most attractive for the adults, soybeans for the young larvae and also being the best oviposition plant, etc.). However, the numbers varied widely. In 2021, the average number of adult specimens *H. halys* on one plant of sorghum (1.56 ± 0.12) was approximately 470 times higher than in 2022 (0.003 3 ± 0.002 2). Similar differences also apply to other crops and development stages. From Figure 8, we can deduce that the number of specimens found on the sunflowers and alfalfa were very low and also very scarce (found only two times). Also, the highest recorded number of specimens were the adults on the sorghum and soybeans with only (0.02 ± 0.01) specimens per plant, which is, again, an extremely lower number than that from the previous year when compared to sorghum (8.01 ± 0.79), approximately 400 times lower, and compared to soybeans (2.17 ± 0.22), approximately 11 times lower.

From the collected data, we can deduce that the average numbers of *H. halys* specimens were much more abundant in the experiment carried out in 2021 than that in 2022. This statement is based on the average catches/detections of *H. halys* bugs on the studied crops, but it is also supported by the data and average catches of *H. halys*

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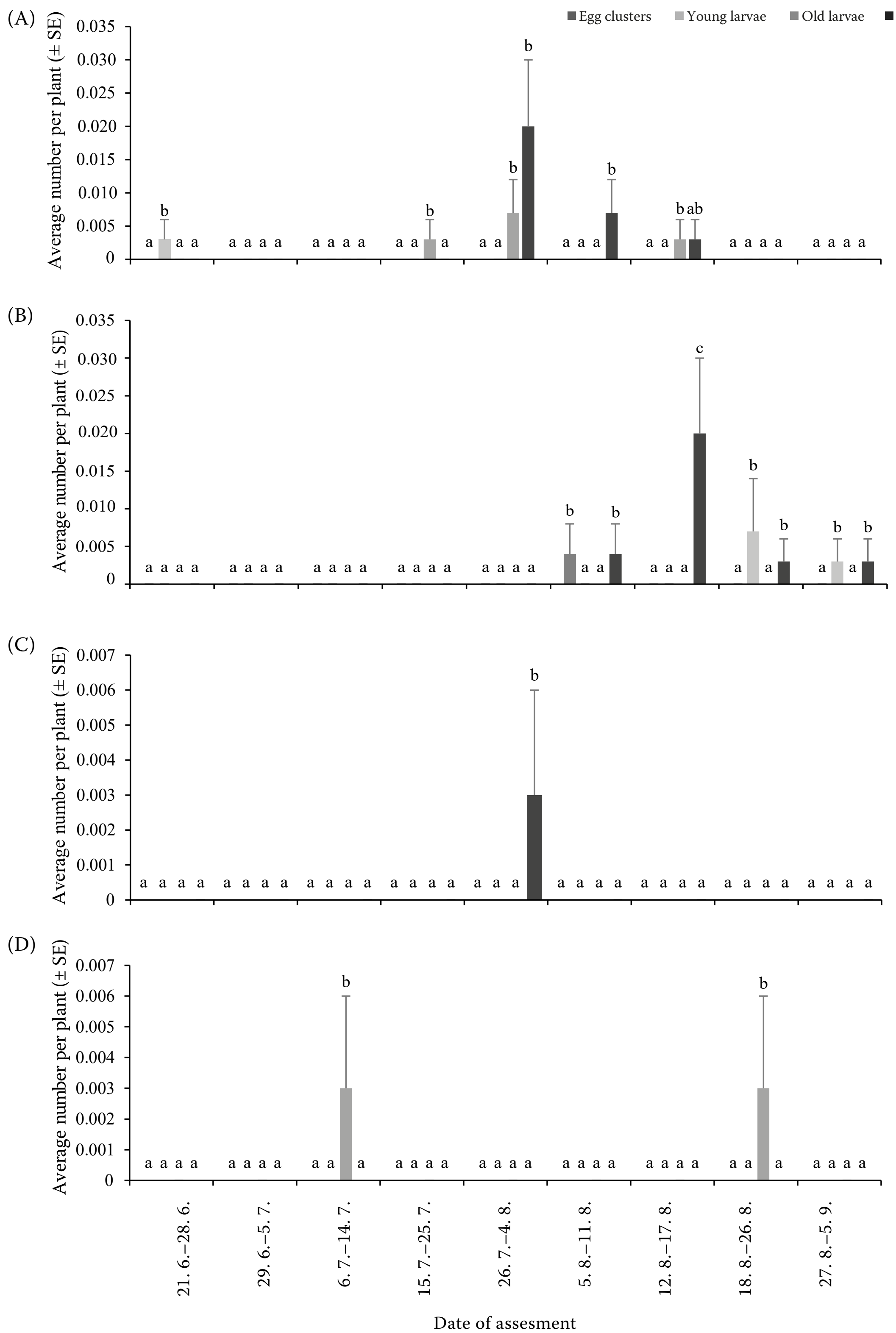

Figure 8. Average number (± SE) of the different developmental stages of *Halyomorpha halys* on the individual sorghum (A), soybean (B), sunflower (C), and alfalfa (D) plants by the date of assessmentr. Ljubljana, Biotechnical Faculty, 2022

[a–c]Lower case letters present differences between the dates and the same developmental stage of *H. halys* for each variety of trap crop

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stink bugs in pyramid traps baited with aggregation pheromones that were present on both sites. This is one of the most effective methods to use for population monitoring purposes of the invasive pest (Morrison et al. 2015). Monitoring of the pest was ongoing during the whole time when both experiments took place. According to reports of Rot et al. (2019), the incidence and overall population of brown marmorated stink bug in Slovenia is increasing yearly, and it is becoming a serious threat to fruit and vegetable growers. Per the information of Rot (2022, pers. comm.), the average catches of *H. halys* specimens near experiment 1 in the western part of Slovenia ranged from five and up to 20 specimens per day from April 1, 2021 to November 18, 2021. On the location of the Biotechnical Faculty, where experiment 2 was carried out, the catches of *H. halys* specimens ranged from one and up to nine per day from March 30, 2022 to November 30, 2022, which means that the invasive *H. halys* occurred in smaller numbers in the central part of Slovenia than in the western part of Slovenia, which supports the findings from Rot et al. (2019). Therefore, this is also one of the factors that could have influenced a lower occurrence of stink bugs on the studied crops in the central region of Slovenia. An important factor could also be the distance of the crops from the main cultivated plant species (in our case, an apple orchard) and any possible overwintering sites in the autumn. Funayama (2004) explains that apples are a satisfactory food source when more suitable foods are in short supply and also that apple fruit trees can support a full development cycle. This statement is also an important detail, as in 2021, we designed the experiment right next to the orchard of a local grower. The distance between the apple orchard and the first row of trap crops was about 3 m. The closest house to the experiment was about 145 m away. In 2022, the experiment was designed so that the closest part of the trap crops was approximately 240 m away from the apple orchard. The distance from the houses was much smaller, being only about 30 m. The mentioned characteristics and the resulting distance of the crops from the primary cultivated plant species could undoubtedly have influenced a greater or lower incidence of stink bugs on the selected trap crops.

We did not compare the number of stink bugs found on the trap crops with the number found on the primary plant culture (apple trees). However, Batistič (2021), in his study, explained that, in 2021, there was a high incidence of stink bugs on both the attractive crops and the nearby apple trees. Our study aimed to determine whether the studied plants attracted more stink bugs than the apple trees. We discovered that having a greater variety of food sources in close proximity could attract a larger number of stink bugs, as the plants developed and produced fruit/seeds in a sequence at a specific time of the year. In the second experiment, the distance between the plants and the lower overall population of stink bugs in central Slovenia were the key factors leading to fewer catches compared to the experiment carried out in the west of the country.

CONCLUSION

Based on the results which we obtained from experiment 1 in 2021, we can say it with certainty that we confirmed statistically significant differences in the abundance of *H. halys* between the sorghum, alfalfa, soybean and sunflower crops. The data from experiment 2 suggest that the result could be similar in 2022, but the incidence/abundance of the pest was significantly lower and, therefore, we cannot say it for sure.

Among the selected trap crops, sorghum was the most attractive for the brown marmorated stink bug. According to our estimates, which are supported by our results, stink bugs primarily use sorghum as a source of food and not as a crop to perform the full developmental cycle. Most adult bugs were detected on the sorghum plants in the phenophase of the fruit development (Figure 3), moreover, we did not find a large number of young larvae or egg clusters on the sorghum plants. Sorghum is followed by sunflowers in terms of the attractiveness, which proved to be a plant species that attracts stink bugs throughout the entire growing season and not only during the phenophase of the fruit development. The soybean was ranked third in terms of the attraction efficiency. Our data show that the studied pest was present on soybean plants almost throughout the entire growing season. As a result, we recorded the highest number of egg clusters and young larvae on the plant. From this, we can conclude that the pest uses soybean plants as host plants on which it feeds and can complete the entire development cycle. Alfalfa proved to be

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the least attractive to the brown marmorated stink bug among all the studied trap crops.

From the obtained data, we can also conclude that the general population of *H. halys* is less abundant in the central part of Slovenia compared to the western part. This can be supported by the catch results from the pyramid traps that were placed in both locations when the experiments took place. A lower abundance of the pest in 2022 compared to that in 2021 could also be a consequence of the placement of the experiment and the proximity to the primary host plant species, apple trees in our case. In 2021, we placed the crops next to an apple orchard and, therefore, the abundance of *H. halys* on our trap crops was much higher in comparison with the following year when the crops were a good 240 m away from the nearest apple orchard. So, we can conclude that there are many variables that play an important role in the final assessment and results in the final attractiveness of different trap crops for a targeted pest, the brown marmorated stink bug in our case.

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