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Chemical Control of Marmorated Stink Bug (*Halyomorpha halys* Stål) in Pear Orchards with Integrated Pest Management

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ABSTRACT

In the growing seasons of 2021 and 2022, two field experiments in a Williams pear and an Abate Fetel pear orchard were conducted at location Bilje near Nova Gorica. The effectiveness of two spraying programs for suppressing the marmorated stink bug (MSB) was analyzed. In program A, insecticides based on the active substances acetamprid, pyriproxyfen, spirotetramat, indoxacarb, lambda-cyhalothrin, and abamectin were used. In program B, insecticides based on the active substances acetamprid, pyriproxyfen, deltamethrin, phosmet, and abamectin were used, combined with alternative repellent preparations. In 2021, we had 23 % of fruit damaged by MSB in the Williams variety and 25% in the Abate Fetel variety, both in the untreated control plots. In 2022, the percentage of fruits damaged by MSB in the control plots was 30 % in the Williams variety and 30% in the Abate Fetel variety. The effectiveness of spraying program A in reducing the proportion of damaged fruit by MSB was 34 to 78 % in 2021 and 60 to 70 % in 2022. The effectiveness of spraying program B in reducing the proportion of damaged fruit was 34 to 78 % in 2021 and 60 to 70 % in 2022. We can not entirely prevent economically relevant crop losses with the tested spray programs.

Keywords: pear, marmorated stink bug, pest control, active substances

INTRODUCTION

The brown marmorated stink bug (MSB), *Halyomorpha halys* (Stål), Hemiptera: Pentatomidae, is an invasive, polyphagous species native to East Asia (Lee et al., 2013; Leskey and Nielsen, 2018; Fornasiero et al., 2023), which has spread to North America (Canada and USA; Hoebeke and Carter, 2003), South America (Chile), and several European countries (Maistrello et al., 2014; Maistrello and Dioli, 2014; Bariselli et al., 2016; Leskey and Nielsen, 2018; Wermelinger et al., 2008).

In 2017, the allochthonous MSB was first discovered in the region of Primorska, within the Republic of Slovenia. Many species of shield bugs are known to be highly polyphagous pests with a wide range of hosts. This is also typical for MSB. Pears are among the hosts MSB likes to attack the most (Bariselli et al., 2016; Fornasiero et al., 2023).

Managing this invasive species is particularly challenging in the first period after a mass outbreak (Green et al., 2021). The lack of basic knowledge about MSB biology and its unpredictable behavior in a new environment, scarce information on natural enemies in invaded areas, and the absence of other effective control measures, such as exclusion nets (Candian et al., 2018; Rot et al., 2023), has left farmers with few options for pest control and has created a need for immediate insecticide-based management programs (Leskey et al., 2012).

The cultivation of pears in Slovenia has shrunk to a small area because there are many problems with controlling pests and diseases. According to estimates from the literature, MSB also presents a severe pear pest in Slovenia, which currently behaves as an invasive species, the spread of which native beneficial organisms (in terms of biological pest control) cannot yet control. Until a balance between the MSB populations and its natural enemies is established, intensive chemical control will be necessary to prevent considerable damage from MSB occurrences (Kuhar & Kamminga, 2017; Lešnik et al., 2022).

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According to the data from previous research, MSB is quite resistant to many commonly used insecticides used in pear orchards (Kuhar & Kamminga, 2017; Fornasiero et al., 2023). The selection of effective active substances on the Slovenian market is small, so it is necessary to include active substances with a side effect and the ones with a deterrent effect in the spraying programs.

To evaluate the possibilities of chemical control with the available preparations in Slovenia, we conducted two field experiments, the results of which are presented below.

MATERIALS AND METHODS

Experimental location and design

The experiment was carried out in the growing seasons of 2021 and 2022 at the research station of the Biotechnical Faculty of Ljubljana in the village of Bilje, Vipava Valley (45.898448°N, 13.622511°E, WGS84). The orchard was planted with pears of the Williams Christ and Abate Fetel varieties in alternating strips, with a planting density of 0.8 x 2.80 m. The trees were 14 years old and grafted on a Quince-MA rootstock. The cultivation form was a slender spindle.

The statistical design was a field experiment in blocks with four replications. The size of one plot was at least 1000 m^2. We could not ensure complete, randomly distributed plots since we had relatively short rows and applied the preparations with a tractor-trailed sprayer. Instead of complete randomization, we oriented four blocks perpendicular to the direction of the rows of trees. The significance of differences among treatment means was determined using the Independent-Samples test and One-Way Analysis of Variance (ANOVA). Means for the percentage of damaged fruits from MSB were separated by Tukey HSD multiple comparison procedures. The means for Abbot efficacy were separated by Student's t-test at statistical significance level $p < 0.05$. A statistical evaluation of data was performed using the SPSS 25.0 program.

The determination of the spraying program's effectiveness

The FarmBeast robot is a complex device equipped with multiple sensors, including encoders for wheel odometry, the Xsens Mti 610 IMU, the Velodyne VLP16 multichannel LiDAR, and the Realsense 435if RGBD camera. However, the core of the robot's navigation system relies on the synergy between two pivotal sensors: the Velodyne VLP16 LiDAR and the Xsens Mti 610 IMU. These sensors form the backbone of the robot's sensing and navigational intelligence, enabling it to respond with unparalleled accuracy to terrain challenges and the variable demands of precision agriculture competitions.

The plots where the fruit damage was observed were divided into four groups concerning the position of the pheromonic traps:

- Group 1 (1 in Fig. 1 to Fig. 4): area untreated with insecticide active substances and near the pheromone traps (in the distance of a maximum of 10 m from the tree with trap),
- Group 2 (2 in Fig. 1 to Fig. 4): area untreated with insecticide active substances, trees were more than 10 m away from the pheromone traps,
- Group 3 (3 in Fig. 1 to Fig. 4): area sprayed with insecticide active substances (see spray programs, Table 1), near the pheromone traps (in the distance of a maximum of 10 m to the tree with trap),
- Group 4 (4 in Fig. 1 to Fig. 4): area sprayed with insecticide-active substances, the trees were positioned at least 10 m away from the pheromone traps.

Application technique and spraying program

We tested two spraying programs. The first was named (A), which, in addition to the use of available classical chemical insecticides, also contained some applications of alternative preparations, mainly with repellent action. The second program was called program (B) and mostly contained classic chemical insecticides.

The preparations were applied with the standard tractor-trailed orchard sprayer Steiner AS Q 16 (Steiner Sprayers Gmbh, Lana, Italy) at a water consumption of 1000 l/ha with built-in Albuz red nozzles. This ensured a very thorough wetting of the trees with insecticides. The insecticide active substances used and the application periods are shown in Table 1 and Table 2, respectively. All insecticides used in each season are listed, even if they do not directly affect the control of MSB. Few other pests were present in the study plots, and they did not cause damage that could otherwise be mistakenly attributed to MSB.

Table 1: Overview of applied preparations and application periods in 2021

Time period	Spraying program A		Spraying program B	
	Preparation/active substance	Dosage/ha	Preparation/active substance	Dosage/ha
25.03.	Ovitex (liquid paraffin)	20 l	Ovitex (liquid paraffin)	20 l
23.04.	Mospilan 20 SG (acetamiprid 20 %)	0.2 kg	Mospilan 20 SG (acetamiprid 20 %)	0.5 kg
06.05.	Harpun (piriproksifen 10 %)	0.5 l		
07.05.			Harpun (piriproksifen 10 %)	0.5 l
Time period	Spraying program A		Spraying program B	
	Preparation/active substance	Dosage/ha	Preparation/active substance	Dosage/ha
13.05.	Vegex Pipper (chillies extract with capsaicin) Vegex Fos Soap (plant extract soap)	2 l 1.5 l		
21.05.	Imidan 50 WG (phosmet 50 %)	1 kg	Movento SC 100 (spirotetramat 10 %)	1.9 l
28.05.	Potassium nitrate (fertiliser)	8 kg	Switch 62.5 WG (Ciprodinil 37.5 % fludioksonil 25 %) Madex max (granulovirus)	0.8 kg 0.1 l
04.06.	Mospilan 20 SG (acetamiprid 20 %)	0.5 kg	Madex max (granulovirus) Movento SC 100 (spirotetramat 10 %)	0.1 l 1.9 l
11.06.			Switch 62.5 WG (Ciprodinil 37.5 % fludioksonil 25%) Steward EC (indoksakarb)	0.8 kg 0.17 l
16.06.	Wetcit (citrus oil) Vegex Pipper Vertimec PRO (abamectin 1.8 %)	2 l 4 l 1.125 l		
20.06.			Madex max (granulovirus)	0.1 l
21.06.	Karate Zeon 5 CS (lambda-cihalotrin 5 %) Vertimec PRO (abamectin 1.8 %) Decis 100 EC (deltamethrin 10 %)	0.18 l 1.125 l 0.5 l		
29.06.	Karate Zeon 5 CS (lambda-cihalotrin 5 %) Vertimec PRO (abamectin 1.8 %)	0.18 l 1.125 l	Madex max (granulovirus) Karate Zeon 5 CS(lambda – cihalotrin 5%) Vertimec PRO (abamektin 1.8 %)	0.1 l 0.18 l 0.125 l
08.07.			Affirm (emamektin 0.95 %)	2 kg
09.07.	Vegex Beta (plant extracts) Vegex Fos Soap (plant extract soap)	2 l 1.5 l		
19.7.	Vegex Beta (plant extract) Vegex Fos Soap (plant extract soap) Kwars (silicon-based fertilizer- silicon dioxide (SiO_2) 30 %)	2 l 1.5 l 1 l	Madex max (granulovirus)	0.1 l
29.07.	S-system (sulfur fertiliser)	2.5 l	Madex max (granulovirus)	0.1 l
02.08.			Vertimec PRO (abamektin 1.8 %) Karate Zeon 5 CS (lambda – cihalotrin 5 %)	1.125 l 0.18 l

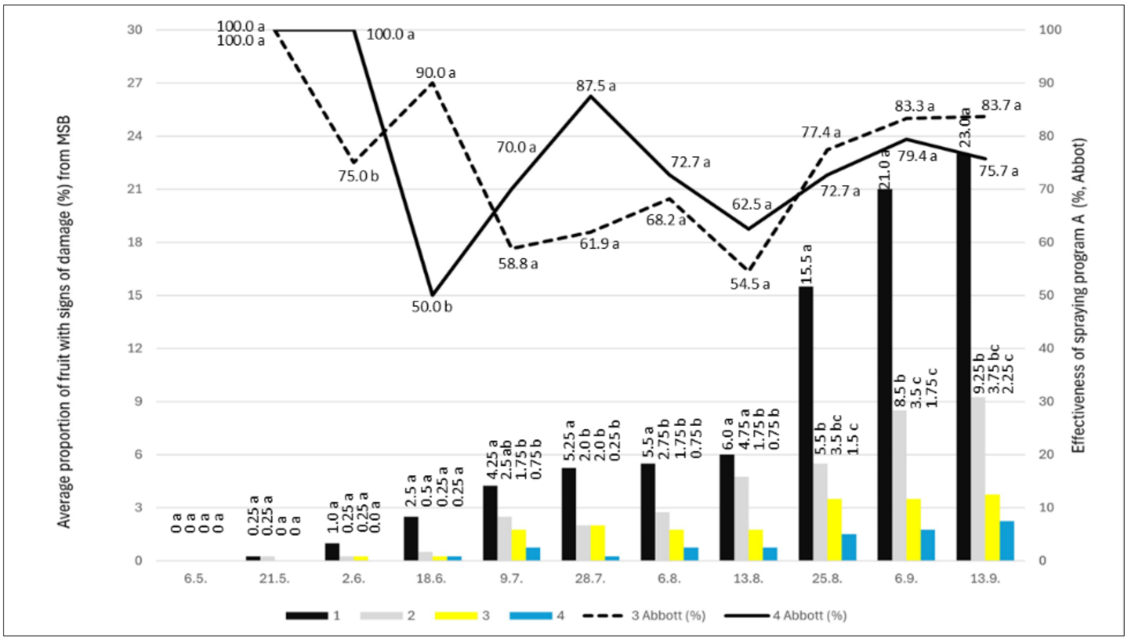
Table 2: Overview of applied preparations and application periods in 2022

Time period	Spraying program A		Spraying program B	
	Preparation/active substance	Dosage/ha	Preparation/active substance	Dosage/ha
25.03.	Ovitex (liquid paraffin)	20 l	Ovitex (liquid paraffin)	20 l
28.04.	Mospilan 20 SG (acetamiprid 20 %)	0.5 l	Mospilan 20 SG (acetamiprid 20 %)	0.5 l
05.05.	Harpun (piriproksifen 10 %)	0.5 l		
12.05.			Harpun (piriproksifen 10 %)	0.5 l
19.05.	Madex max (granulovirus) Vegex Piper Vegex Fos Soap	0.1 l 2 l 1.5 l	Madex max (granulovirus) Movento SC 100 (spirotetramat 10 %)	0.1 l 1.9 l
26.05.	Imidan 50 WG (fosmet 50 %)	1 kg	Coragen (klorantraniliprol 20 %)	0.27 l
03.06.	Madex max (granulovirus) Mospilan 20 SG (acetamiprid 20 %) Steward EC (indoksakarb)	0.1 l 0.5 l 0.25 kg	Madex max (granulovirus)) Movento SC 100 (spirotetramat 10 %)	0.1 l 1.9 l
Time period	Spraying program A		Spraying program B	
	Preparation/active substance	Dosage/ha	Preparation/active substance	Dosage/ha
10.06.	Mospilan 20 SG (acetamiprid 20 %)	0.5 l	Mospilan 20 SG (acetamiprid 20 %)	0.5 l
17.06.	Madex max (granulovirus) Siltac EC	0.1 l 0.25 l	Switch 62.5 WG (Ciprodinil 37.5 % fludioksonil 25 %) Madex max (granulovirus)	1 kg 0.1 l
27.06.	Madex max (granulovirus) Karate Zeon 5 CS (lambda – cihalotrin 5 %)	0.1 l 0.18 l	Madex max (granulovirus) Decis 100 EC (deltametrin 10 %)	0.1 l 0.5 l
07.07.	Affirm (emamektin 0.95 %) Vegex Beta Vegex Fos soap	2 kg 2 l 1.5 l	Affirm (emamektin 0.95 %)	2 kg
18.07.	Madex max (granulovirus) Vegex Beta Vegex Fos soap Siltac EC	0.1 l 2 l 1.5 l 0.25 l	Madex max (granulovirus) Vertimec PRO (abamektin 1.8 %)	0.1 l 1.125 l
29.07. Abate Fetel	S-system (sulfur fertiliser) Madex max (granulovirus)	3 l 0.1 l	Madex max (granulovirus)	0.1 l
10.08.	Madex max (granulovirus)	0.1 l	Madex max (granulovirus) Decis 100 EC (deltametrin 10 %)	0.1 l 0.5 l

RESULTS AND DISCUSSION

Spraying programs' effectiveness for the control of MSB on pears in the season of 2021

In May and June, we successfully prevented damage to the fruits. In control plot nr. 1, we had less than 3 % of fruits with visible damage from MSB (Fig. 1) at the end of June. In control plot 1, the proportion of fruits with damage exceeded 5 % by the end of June, while it was still below 3 % in control plot 2. A significant increase in the proportion of fruits with visible damage was observed at the end of August and the beginning of September (Fig. 1). Finally, when the pears were harvested, it was found that the attack in the control plots was high despite the relatively small population of MSB. The effectiveness of the spraying program utilized to reduce the proportion of fruit with damage varied between 70 and 80 % (Fig. 1).



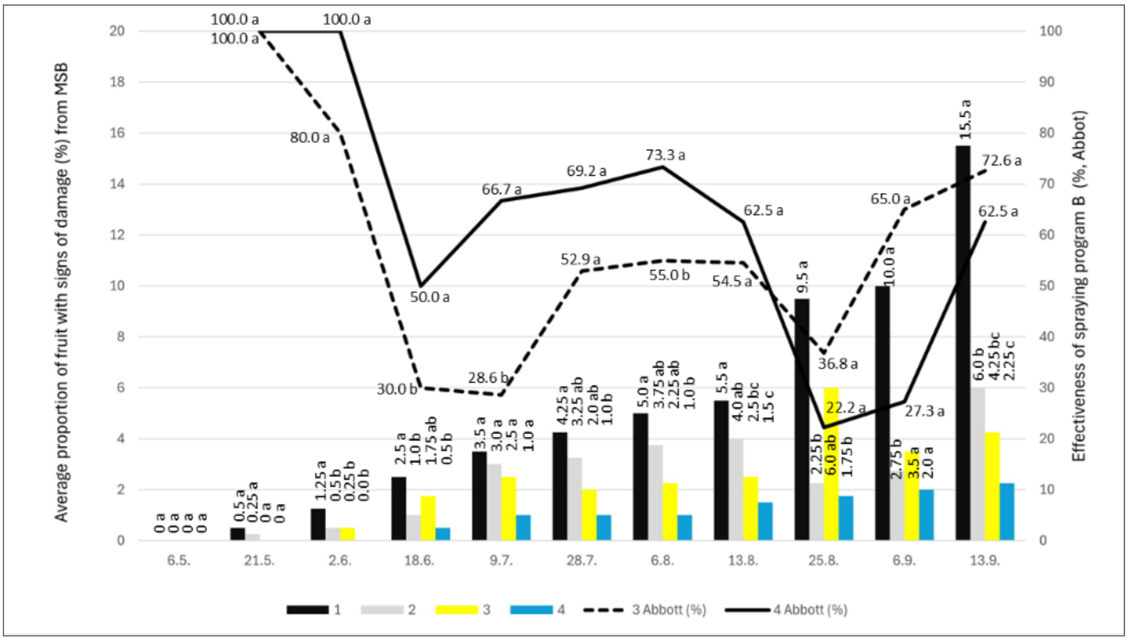
Means for the proportion of MSB-damaged fruits marked with different letters within the same assessment period are significantly different according to the Tukey HSD test ($p<0.05$), and means for the Abbot efficacy marked with different letters within the same assessment period are significantly different according to Student's t-test ($p<0.05$).

Figure 1: Average proportion of fruit with signs of damage (%) from MSB and effectiveness of spraying program A to reduce the proportion of fruit with damage (%, Abbot) in the 2021 season. 1 – the proportion of damaged fruit on an untreated plot near traps, 2 – the proportion of damaged fruit on the untreated plot at a distance from the traps, 3 – the proportion of damaged fruits on a treated plot near the traps, 4 – the proportion of damaged fruits on the treated plot at a distance from the traps

The spraying program B was slightly different from program A (Table 1) and included alternative preparations in the second part of the season.

We were most interested in the data on the proportion of fruits with visible damage during harvesting. In the untreated control plots in the experiment within the plots of spraying program A in trees with traps, 23 % of fruits had MSB-caused injuries at harvest, and in program B in the control plots, 15.5 %. The MSB pressure was similar in both experiments (Fig. 2).

At harvest, in the treated plots in trees away from pheromone traps, in spraying program A, we had 2.25 % of damaged fruits (we achieved a 75.7 % reduction efficiency; see Fig. 1), and in spraying program B, 2.25 % of fruits were damaged (we achieved 62.5 % efficiency, Fig. 2). In terms of the fruit surface damage percentage, no significant success was achieved in suppressing MSB. Regarding the percentage of fruit with damage, the treatments were still pretty successful, since the season for the appearance of MSB is long, and there was only a minimal range of available insecticides for control. Most of them do not have long residual activity.



Means for the proportion of MSB-damaged fruits marked with different letters within the same assessment period are significantly different according to the Tukey HSD test (p<0.05), and means for the Abbot efficacy marked with different letters within the same assessment period are significantly different according to Student's t-test (p<0.05).

Figure 2: Average proportion of fruit with signs of damage (%) from MSB and effectiveness of spraying program B to reduce the proportion of fruit with damage (%, Abbot) in the 2021 season. 1 – the proportion of damaged fruit on an untreated plot near traps, 2 – the proportion of damaged fruit on the untreated plot at a distance from the traps, 3 – the proportion of damaged fruits on a treated plot near the traps, 4 – the proportion of damaged fruits on the treated plot at a distance from the traps

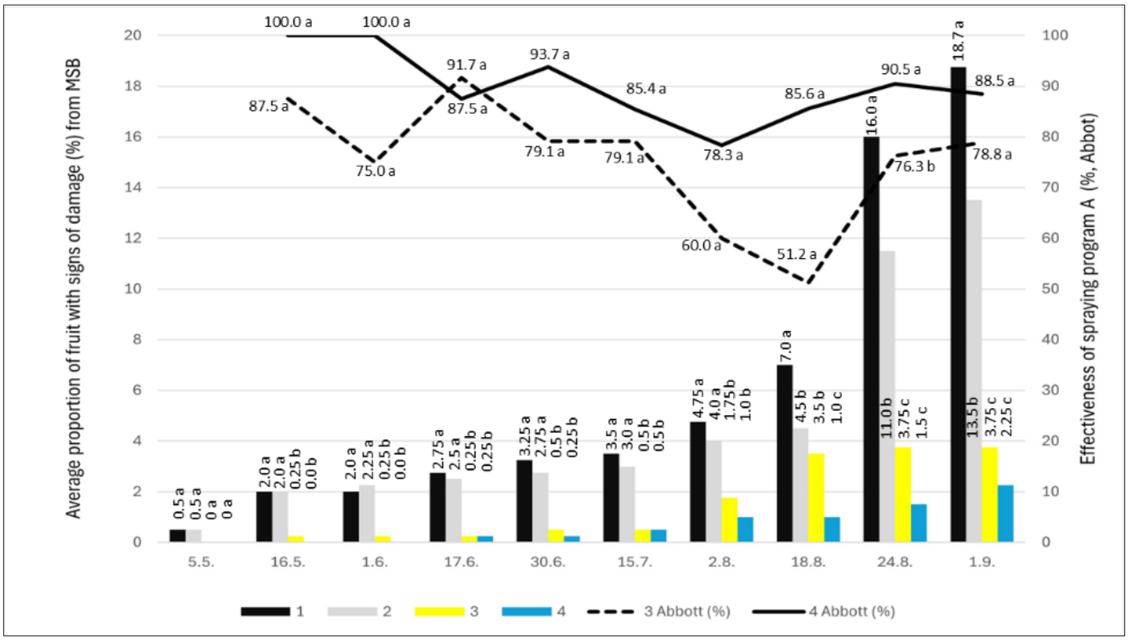
Spraying programs' effectiveness for the control of MSB on pears in the 2022 season

In the first part of the summer, very high summer temperatures caused the cyclic migrations of MSBs in other cooler ecosystems (p.e. bushes on a river bank). High temperatures may have reduced the length of the egg-laying period and could have destroyed already laid eggs.

The data on the proportion of fruits with damage caused by MSB for control treatments in the 2022 season with spraying program A show that we had a relatively small proportion of fruits with visible damage in the first part of the summer. Just before harvesting, 18.75 % of the fruits were damaged in control plots with trees in plot category 1 and 13.5 % of fruits with trees in plot category 2. This shows that MSB pressure was slightly lower than in 2021 (Fig. 3).

The spraying program reduced the extent of damage to fruits by more than 70% in plot treatment 3 and by more than 80 % in treatment 4 (Fig. 3). In the fairly intensive application program A, insecticides with some alternative active substances failed to prevent damage completely at the end of the season. It appears that the most significant increase in damage caused by MSB was in the last three weeks before harvest. The summer heat in July and the first half of August caused the eggs laid to decay and MSB to migrate to the shady shelters of the edge vegetation. There was a significant increase in the number of larvae caught at the end of August, which continued into September. Larvae migrated back to the orchard from edge vegetation.

Both larvae and young adult MSB likely contributed to the increase in damage at that time. It was estimated that the suppression was quite successful but not as successful as desired, as no improvement in results from the 2021 season was achieved.



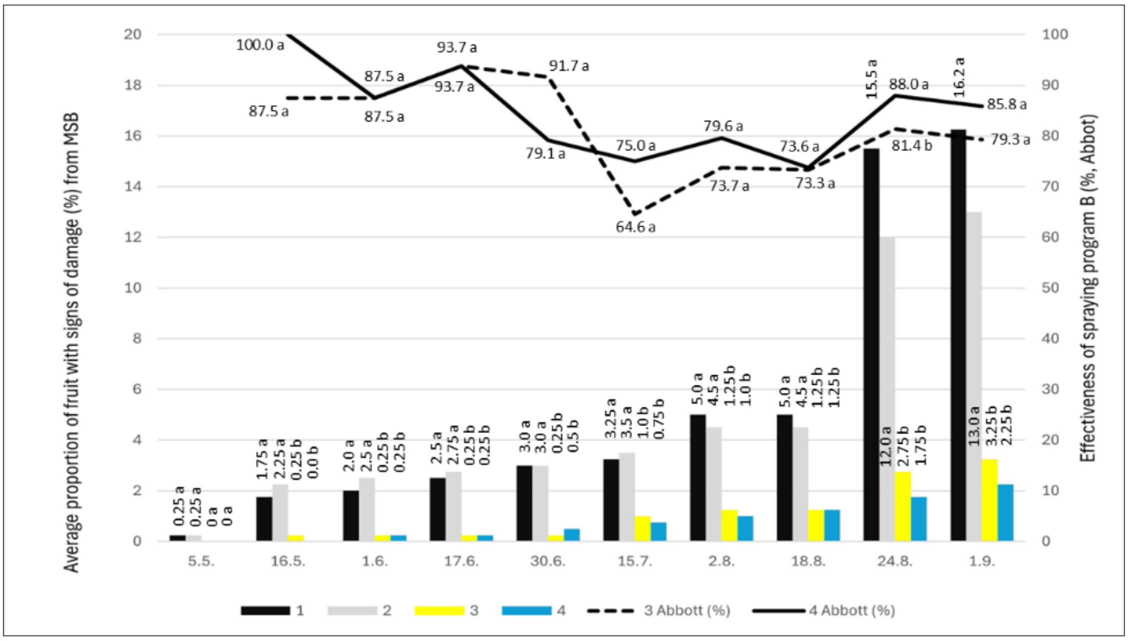
Means for the proportion of MSB-damaged fruits marked with different letters within the same assessment period are significantly different according to the Tukey HSD test (p<0.05), and means for the Abbot efficacy marked with different letters within the same assessment period are significantly different according to Student's t-test (p<0.05).

Figure 3: Average proportion of fruit with signs of damage (%) from MSB and effectiveness of spraying program A to reduce the proportion of fruit with damage (%, Abbot) in the 2022 season. 1 – the proportion of damaged fruit on an untreated plot near traps, 2 – the proportion of damaged fruit on the untreated plot at a distance from the traps, 3 – the proportion of damaged fruits on a treated plot near the traps, 4 – the proportion of damaged fruits on the treated plot at a distance from the traps

Spraying program B in the season of 2022 gave a similar result to spraying program A regarding the proportion of fruits with visible damage at harvest time. The percentage of damaged fruit in the treated plots was low, and we achieved an approximately 80 % reduction in the proportion of damaged fruit compared to the untreated control plots (Fig. 4).

If the MSB pressure had been a bit higher, such a level of efficiency would likely not have been achieved. Using insecticides was economically justified because 13 % of the fruits were damaged in the control plots without installed pheromone traps (Fig. 4).

With a yield of 30 t/ha and a pear price of one euro per kg, the loss would amount to at least 3.900 euros per ha. In this case, the value of the lost fruits is undoubtedly more significant than the cost of using insecticides. Control measures were feasible.



Means for the proportion of MSB-damaged fruits marked with different letters within the same assessment period are significantly different according to the Tukey HSD test (p<0.05), and means for the Abbot efficacy marked with different letters within the same assessment period are significantly different according to Student's t-test (p<0.05).

Figure 4: Average proportion of fruit with signs of damage (%) from MSB and effectiveness of spraying program B to reduce the proportion of fruit with damage (%, Abbot) in the 2022 season. 1 – the proportion of damaged fruit on an untreated plot near traps, 2 – the proportion of damaged fruit on the untreated plot at a distance from the traps, 3 – the proportion of damaged fruits on a treated plot near the traps, 4 – the proportion of damaged fruits on the treated plot at a distance from the traps

CONCLUSION

The results of the study show that in the untreated control plots in 2021, 23 % of the fruit was damaged by MSB in the Williams Christ variety and 25 % in the Abate Fetel variety. In 2022, the percentage of fruits damaged by MSB in the control plots was 30 % at the Williams Christ variety and 30 % at the Abate Fetel variety. The effectiveness level of spraying program A in reducing the proportion of damaged fruit by MSB was 34 to 78 % in 2021 and 60 to 70 % in 2022. The fluctuation of efficacy level throughout the summer period was moderate. The effectiveness level of spraying program B in reducing the proportion of damaged fruit was 34 to 78 % in 2021 and 60 to 70 % in 2022. Regarding the growth ratio between the percentage of fruit with damage and the rate of healthy fruits, control success was achieved, as the season of the appearance of MSB was long, and only a minimal range of preparations was available for control. The study demonstrates that with the two tested spray programs, it is possible to provide only a moderately effective control of MSB and not a complete prevention of economically relevant crop losses. Nowadays, most chemicals used for protection from MSB are broad-spectrum insecticides that are also potentially disruptive to natural enemies and pollinators. Selective insecticides that target stink bugs primarily are urgently needed to help move or return integrated agricultural pest management practices in fruit trees, vegetables, and field crops to a more sustainable system that fully utilizes integrated pest management. In the meantime, strategies that use more targeted insecticide applications, such as attract-and-kill and spraying only trees with pheromone traps in orchard border zones, have shown great promise in controlling MSB.

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Možnosti kemičnega zatiranja stenice marmorirane smrdljivke (*Halyomorpha halys* Stål) v nasadih hrušk z integriranim varstvom rastlin

IZVLEČEK

V sezoni 2021 in 2022 smo v nasadu hrušk sort Viljamovka in Abate Fetel v kraju Bilje izvedli dva poljska poskusa, v katerih smo analizirali učinkovitost dveh škropilnih programov za zatiranje stenice marmorirane smrdljivke. Pri programu A smo uporabili insekticide na podlagi aktivnih snovi acetamprid, piriproksifen, spirotetramat, indoksakarb, lambda-cihalotrin in abamektin, pri programu B pa smo uporabili insekticide na podlagi aktivnih snovi acetamprid, piriproksifen, deltametrin, fosmet, abamektin, v kombinaciji z alternativnimi repelentnimi pripravki na podlagi kaolina, silicija, žveplovega oksida in rastlinskih izvlečkov. V netretiranih kontrolnih parcelicah smo v letu 2021 ob obiranju pri sorti Viljamovka zabeležili 23 % poškodovanih plodov in pri sorti Abate Fetel 25 %. V letu 2022 je odstotek poškodovanih plodov v kontrolnih parcelicah znašal pri sorti Viljamovka 30 % in 30 % pri sorti Abate Fetel. Učinkovitost škropilnega programa A za zmanjšanje deleža poškodovanih plodov je v letu 2021 znašala od 34 do 78 % in v letu 2022 od 60 do 70 %. Učinkovitost škropilnega programa B za zmanjšanje deleža poškodovanih plodov je v letu 2021 znašala od 34 do 78 % in v letu 2022 od 60 do 70 %. S testiranimi škropilnimi programi ne moremo povsem preprečiti gospodarsko relevantne izgube pridelka.

Ključne besede: hruška, marmorirana smrdljivka, zatiranje, aktivne snovi