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Performance evaluation of spirodiclofen, spirotetramat and carboxymethyl cellulose-B for management of *Cacopsylla pyri*

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Abstract: The pear psyllid [*Cacopsylla pyri* (L.), (Hemiptera: Psyllidae)] represents one of the most economically significant pests of pear in Serbia and worldwide. It causes direct damage throughout feeding on young stems and leaves, but also creates favourable conditions for the development of plant diseases. In this article susceptibility of *C. pyri* to spirodiclofen, spirotetramat, and their combinations with foliar fertilizer (carboxymethyl cellulose-boron, CMC-B) was investigated in order to assess their efficacy. Experiments were conducted in accordance with standard OEPP/EPPO methods, in field trials on two localities in the Republic of Serbia (Kula, Vrbas), during 2020/21. Results of the field trials indicate good efficacy for all variants in pear psyllid control in pear orchards. The high efficacy of spirodiclofen (87.4–95.4%), spirotetramat (82.5–91.8%), spirodiclofen + CMC-B (90.3–99.8%), spirotetramat + CMC-B (89.5–96.8%) was achieved at both localities seven days after treatment during 2020/21 field trials. Also, it can be concluded for examinations 14 days after treatment, where the efficacy of spirodiclofen (84.9–92.0%), spirotetramat (81.2–91.7%), spirodiclofen + CMC-B (88.9–97.5%), and spirotetramat + CMC-B (82.3–92.5%) was high at both of investigated localities. Based on the obtained results it can be concluded that the high efficacy of the researched insecticides is a good indicator of *C. pyri* susceptibility in pear orchards.

Keywords: pear psyllid; *Pyrus communis*; pesticide; CMC; efficacy

The pear psyllid (*Cacopsylla pyri*) represents the most economically significant pest of pear in Serbia and worldwide. It is regularly found in pear orchards. The larvae cause direct damage throughout feeding (sap-sucking) on young stems and leaves, which reduces plant photosynthetic capacity but also creates favourable conditions for the development of diseases. Pear psyllid is also a vector of phytoplasma on pear (pear decline). If infected, trees could wilt, scorch, and decay in a few weeks, causing significant economic losses. The basic strategy of *C. pyri* suppression deeply relies on the use of chemical insecticides with different mechanisms of action, but with a large number of generations, it makes this pest very difficult to control. It should be taken into account that pear psyllid very easily develops resistance to insecticides, so it must be properly and timely applied (Pasqualini et al. 2002). Also, insecticides used in its control need to be highly selective in order to safeguard its natural predators (fam. Anthocoridae, Chrysopidae, Coccinelidae and Miridae). Spirotetramate is an active substance from a group of insecticides called ketoenols. This active substance has the unique characteristic of two-way systemicity. Applied through the leaves, spirotetramat enters the vascular system of the plant (xylem,

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phloem) from where is transmitted both upward to the young leaves and down to the root. Insects that feed by sucking plant juices bring insecticide into their body and in this way many developmental processes are being disrupted. Spirotetramat produces growth inhibition of younger insects, reduces the ability of insects to reproduce, resulting in mortality. It acts to inhibit the biosynthesis of lipids and represents a new alternative for the control of problematic sucking insects such as psyllids (Salazar-Lopez et al. 2016). Spirodiclofen represents a novel insecticide that also acts by inhibiting lipid biosynthesis. It belongs to a chemical group of tetronic acids. The mechanism of action provides effective protection without fear of cross-resistance with existing insecticides. It is characterized by slow initial action. The results are manifested in the form of a reduction in the entire population and it affects all developmental stages of harmful insects. Spirodiclofen shows an insecticidal activity against the pear psylla, scale insects and it could be used as an alternative to broad-spectrum insecticides for suppressing pear psylla infestations. (Elbert et al. 2002; Saour et al. 2010). CMC-B is registered in Serbia like foliar fertilizer but it also has an insecticide effect on *C. pyri*, *Nezara viridula*, *Halyomorpha halys*, etc., by mechanical mode of action, which is reflected in blocking the external openings of the respiratory system (spiracles) of the insect and eventually causing its death by suffocation (Injac and Jeličić 2020). Also, it cleanses the vegetation from honeydew and improves plant growth and development. The main goal of this research was to evaluate the efficacy of two selective and bio-rational insecticides (spirodiclofen, spirotetramat) and their combinations with carboxymethyl cellulose-boron (CMC-B) on the *C. pyri* susceptibility in pear orchards, in order to avoid or minimize the negative consequences of the insecticide application to the non-target organisms, all with the aim of achieving high efficacy and economy in pear fruit protection.

MATERIAL AND METHODS

In order to determine the efficacy of spirodiclofen, spirotetramat and their combination with CMC-B in the management and control of pear psyllid (*C. pyri*) in pear orchards, the experiments were set up at two similar sites in the Republic of Serbia, both located in Vojvodina province: Kula (45°38'27.8''N; 19°30'35.7''E) and Vrbas (45°33'15.6''N; 19°37'26.8''E). The orchards were raised during 2009, with the represented pear cultivar variety „Williams“ and planting distance of 4 × 2.5 m. Field trials were conducted for two years in a period from 2020 to 2021. For the biological efficacy, experimental design and data analysis standard OEPP/EPPO methods [(PP 1/44(2), 2004); (PP 1/152(4), 2012)] were used. Foliar treatments were performed using a back sprayer with a water consumption of 1 000 L/ha. The preparations based on the active substance spirodiclofen (Envidor 240 SC, a.i. 240 g/L; Bayer CropScience AG, Germany) and spirotetramat (Movento 100 SC, a.i. 100 g/L; Bayer CropScience AG, Germany) were applied in a concentration of 0.06% and 0.15%, respectively. Also, in combinations with foliar fertilizer (CMC-B, 2% of water-soluble boron, 70% plant extracts), 2.5 L/ha of CMC-B was added. Preparations were applied before flowering (phases 56–60 BBCH-scale), at the time of emergence of L1 grade larvae. The number of larvae aged L1–L3 and L4–L5 was observed visually using the magnifying glass on 10 marked shoots 20–25 cm long, on the outside of the tree, exposed to the sun and at a height of 1–2 m, slightly before treatment in order to review the abundance of *C. pyri* larvae and determine timely treatment. Treatments were conducted at the same time on both localities on March 18, 2020 and March 30, 2021. During the experiment, three observations were performed (slightly before treatment, seven and 14 days after treatment). Field trial results were presented as the absolute and mean values for the number of larvae, standard deviation from the average values (SD), the efficacy according to Henderson-Tilton (1955) and statistically analyzed by an ANOVA and the Fisher LSD test for the confidence interval of 95%, in the statistical program R (version 4.1.0).

RESULTS

The results of testing the efficacy of the insecticides based on spirodiclofen, spirotetramat, and their combination with foliar fertilizer CMC-B for the management of pear psyllid (*C. pyri*) in pear orchards at the localities of Kula and Vrbas, are shown in Tables 1–3.

Based on experiments conducted during 2020 (Table 1), the number of larvae of the pear psyllid

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Table 1. The number of *Cacopsylla pyri* larvae (L1–L3, L4–L5) slightly before treatment (Kula and Vrbas, 2020/21)

Locality/insecticide	2020		2021	
	L_1–L_3	L_4–L_5	L_1–L_3	L_4–L_5
Kula				
Spirodiclofen	48.2 ± 10.9[a]	16.3 ± 4.8[a]	37.5 ± 6.9[a]	18.0 ± 2.5[a]
Spirotetramat	46.0 ± 6.10[a]	17.8 ± 3.9[a]	37.0 ± 9.4[a]	16.7 ± 1.7[a]
Spirodiclofen + CMC-B	53.8 ± 10.2[a]	16.3 ± 3.8[a]	30.5 ± 7.2[a]	17.0 ± 2.8[a]
Spirotetramat + CMC-B	48.0 ± 11.2[a]	17.0 ± 4.8[a]	31.0 ± 9.5[a]	17.2 ± 4.9[a]
Control	55.8 ± 12.9[a]	19.0 ± 5.9[a]	39.5 ± 8.9[a]	17.5 ± 4.8[a]
Vrbas				
Spirodiclofen	30.2 ± 9.6[a]	25.0 ± 7.8[a]	42.2 ± 7.1[a]	18.5 ± 2.4[a]
Spirotetramat	29.5 ± 5.6[a]	24.2 ± 6.1[a]	40.2 ± 9.5[a]	17.2 ± 3.6[a]
Spirodiclofen + CMC-B	30.8 ± 9.9[a]	21.0 ± 2.9[a]	36.5 ± 9.9[a]	16.5 ± 1.0[a]
Spirotetramat + CMC-B	29.0 ± 7.8[a]	20.7 ± 6.6[a]	42.5 ± 5.3[a]	17.0 ± 2.9[a]
Control	31.5 ± 9.9[a]	24.5 ± 4.6[a]	41.0 ± 7.8[a]	17.2 ± 2.2[a]

[a]Same letters indicate that there were no significant differences between groups
Data are presented as average number of larvae ± standard deviation

Table 2. The number of *Cacopsylla pyri* larvae (L1–L3, L4–L5) seven days after treatment (Kula and Vrbas, 2020/21)

Locality/treatment	2020				2021			
	L_1–L_3		L_4–L_5		L_1–L_3		L_4–L_5	
	$\bar{x}$ ± SD	E (%)	$\bar{x}$ ± SD	E (%)	$\bar{x}$ ± SD	E (%)	$\bar{x}$ ± SD	E (%)
Kula								
Spirodiclofen	1.8 ± 0.9[a]	94.8	2.3 ± 1.5[a]	87.4	3.7 ± 1.7[a]	90.5	1.5 ± 0.6[a]	93.8
Spirotetramat	3.0 ± 0.8[a]	91.2	3.5 ± 2.4[a]	82.5	5.2 ± 1.3[a]	86.5	2.5 ± 1.3[a]	88.9
Spirodiclofen + CMC-B	0.5 ± 0.6[a]	99.8	1.5 ± 0.6[a]	91.8	2.5 ± 0.6[a]	92.1	1.7 ± 0.5[a]	92.6
Spirotetramat + CMC-B	1.2 ± 1.3[a]	96.6	2.0 ± 1.2[a]	89.5	3.2 ± 0.9[a]	90.1	2.0 ± 0.8[a]	91.4
Control	41.5 ± 7.8[b]	–	21.3 ± 5.5[b]	–	41.2 ± 7.8[b]	–	23.7 ± 2.9[b]	–
LSD	4.66		3.40		4.29		1.74	
Vrbas								
Spirodiclofen	3.0 ± 1.8[a]	91.4	2.7 ± 1.7[a]	90.3	1.7 ± 0.9[a]	95.4	2.3 ± 1.5[a]	89.8
Spirotetramat	5.3 ± 0.9[a]	84.5	2.2 ± 0.9[a]	91.8	3.0 ± 0.8[a]	91.5	3.2 ± 2.6[a]	85.0
Spirodiclofen + CMC-B	2.5 ± 0.6[a]	90.3	1.7 ± 0.5[a]	92.7	0.5 ± 0.6[a]	98.4	1.5 ± 0.6[a]	92.5
Spirotetramat + CMC-B	3.3 ± 0.9[a]	90.2	1.7 ± 0.9[a]	92.6	1.2 ± 1.3[a]	96.8	1.7 ± 0.9[a]	91.8
Control	36.5 ± 5.8[b]	–	27.2 ± 5.6[b]	–	36.0 ± 9.6[b]	–	21.0 ± 4.1[b]	–
LSD	3.29		3.16		4.9		2.75	

E – efficacy; LSD – Fisher least significant difference test
[a,b]Letters indicate significant differences between groups

aged L1–L3 immediately before treatment was at the same level of significance in all variants and it ranged from 46–55.8 (Kula) and 29–31.5 (Vrbas), while the number of L4–L5 larvae was also at the same level of significance in all variants and ranged from 16.3–19 (Kula) and 20.7–25 (Vrbas). Seven days after treatment (Table 2), the number of larvae of pear psyllid aged L1–L3, in all variants was significantly reduced compared to the control variant and the efficacy ranged from 84.5% to 91.2% (spirotetramat), 91.4–94.8% (spirodiclofen), 90.2–96.6% (spirotetramat + CMC-B) and 90.3–99.8% (spirodiclofen + CMC-B) at both sites. The same can be concluded for the L4–L5 aged larvae, in both localities where the efficacy of the applied preparations was 82.5% to 91.8% (spirotetramat), 87.4–90.3% (spirodiclofen),

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Table 3. The number of *Cacopsylla pyri* larvae (L1–L3, L4–L5) 14 days after treatment (Kula and Vrbas, 2020/21)

Locality/treatment	2020				2021			
	L_1–L_3		L_4–L_5		L_1–L_3		L_4–L_5	
	$\bar{x}$ ± SD	E (%)	$\bar{x}$ ± SD	E (%)	$\bar{x}$ ± SD	E (%)	$\bar{x}$ ± SD	E (%)
Kula								
Spirodiclofen	3.8 ± 0.9[a]	90.5	2.3 ± 2.2[a]	85.9	4.2 ± 1.7[a]	91.2	2.2 ± 0.8[a]	84.9
Spirotetramat	7.0 ± 3.5[b]	81.7	3.1 ± 0.7[a]	82.6	6.5 ± 1.9[a]	86.3	3.2 ± 0.6[a]	86.7
Spirodiclofen + CMC-B	2.0 ± 0.8[a]	95.5	1.8 ± 0.5[a]	88.9	2.0 ± 0.8[a]	94.9	2.7 ± 1.5[a]	91.4
Spirotetramat + CMC-B	3.0 ± 0.8[a]	92.5	3.0 ± 1.0[a]	82.3	5.0 ± 0.8[a]	87.4	2.0 ± 0.5[a]	91.9
Control	46.3 ± 5.6[c]	–	19.0 ± 4.9[b]	–	50.5 ± 9.6[b]	–	25.2 ± 3.4[b]	–
LSD	3.97		2.99		6.31		2.20	
Vrbas								
Spirodiclofen	4.2 ± 1.7[ab]	88.9	3.0 ± 1.8[a]	90.4	3.7 ± 0.9[a]	92.0	3.5 ± 2.6[a]	87.0
Spirotetramat	6.2 ± 2.2[b]	83.2	3.7 ± 1.3[a]	91.7	7.0 ± 4.1[b]	84.1	4.7 ± 2.2[a]	81.2
Spirodiclofen + CMC-B	2.0 ± 0.8[a]	94.8	2.8 ± 0.9[a]	89.3	2.0 ± 0.8[a]	95.0	1.7 ± 0.5[a]	97.5
Spirotetramat + CMC-B	5.3 ± 0.5[b]	85.4	3.5 ± 1.3[a]	86.4	4.2 ± 0.6[a]	90.9	4.3 ± 1.7[a]	82.6
Control	39.5 ± 2.9[c]	–	30.5 ± 4.6[b]	–	45.0 ± 7.8[c]	–	25.0 ± 6.5[b]	–
LSD	2.20		2.83		4.67		4.2	

E – efficacy; LSD – Fisher least significant difference test
[a–c]Letters indicate significant differences between groups

89.5–92.6% (spirotetramat + CMC-B) and 91.8–92.7 (spirodiclofen + CMC-B). Two weeks after treatments (Table 3), the number of L1–L3 larvae was significantly lower in all variants compared to the control, in both localities. The preparation based on spirotetramat showed the lowest efficacy in relation to other tested variants, and it ranged from 81.7–83.2%. Other preparations showed high efficacy ranging from 88.9–90.5% (spirodiclofen), 85.4–92.5% (spirotetramat + CMC-B) and 94.8–95.5% (spirodiclofen + CMC-B). In L4–L5 aged larvae, the tested preparations showed high efficacy in both localities. The number of larvae was at a statistically significantly lower level compared to the control variant. The lowest efficacy was recorded in: spirotetramat + CMC-B (82.3–86.4%), spirodiclofen (85.9–90.4%), spirodiclofen + CMC-B (88.9–89.3%), while spirotetramat was the most effective (82.6–91.7%). Also, in the experiments conducted during 2021, the number of larvae of the pear psyllid aged L1–L3 immediately before treatment was at the same level of significance in all variants and ranged from 30.5–39.5 (Kula) and 36.5–42.5 (Vrbas), while the number of larvae aged L4–L5 was at the same level of significance in all variants and ranged from 16.7–18 (Kula) and 16.5–18.5 (Vrbas). Seven days after treatment (Table 2), the number of L1–L3 pear psyllid larvae was significantly reduced in all variants compared to the control variant and the efficacy ranged from 86.5% to 91.5% (spirotetramat), 90.5–95.4% (spirodicylofen), 90.1–96.8% (spirotetramat + CMC-B) and 92.1–98.4% (spirodiclofen + CMC-B) at both sites. The same can be concluded for the L4–L5 aged larvae, in both localities where the efficacy of the applied preparations ranged from 85% to 88.9% (spirotetramat), 89.8–93.8% (spirodiclofen), 91.4–91.8% (spirotetramat + CMCB) and 92.5–92.6% (spirodiclofen + CMCB).

Two weeks after treatment (Table 3), in the L1–L3 stadium of larvae, the tested preparations showed high efficacy, at both sites. The number of larvae was at a statistically significantly lower level compared to the examined control variant. The lowest efficacy was observed in variants with: spirotetramat (84.1–86.3%), followed by spirotetramat + CMC-B (87.4–90.9%), spirodiclofen (91.2–92%) and spirodiclofen + CMC-B (94.9–95%). Also, statistically significant differences were observed in L4–L5 aged larvae in all examined variants compared to the control. The lowest efficacy was recorded in variants with spirotetramat (81.2–86.7%), spirodiclofen (84.9–87%), and spirotetramat + CMC-B (82.6–91.9%), while spirodiclofen + CMC-B showed the highest efficacy (91.4–97.5%).

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DISCUSSION

The intensive application of pesticides leads to negative consequences such as the appearance of phytotoxicity and the development of resistant populations of harmful species, including *C. pyri*. Numerous studies for many years have been focused on the use of chemical insecticides to control this pest. However, *C. pyri* has the ability to develop resistance rapidly to the insecticides used in its suppression (Jerinić-Prodanović et al. 2010). Also, due to the large amount of honeydew, which larvae produce during feeding, insecticides do not give a satisfactory effect (Erler 2004; Sigsgaard et al. 2006). Precisely for these reasons, the attention of the scientific and professional public is increasingly directed towards finding the most adequate methods of suppressing *C. pyri*, which involves the preservation of natural enemies of the pear psyllid (Marčić et al. 2009). Spirotetramat offers good control of young and old larvae of *C. pyri*, both on the shoot tips and on cluster leaves in the central part of the tree. A directed spray in the central part of the tree guarantees full control of *C. pyri* and avoids honeydew and sooty mould staining (Schoevaerts et al. 2015). Jaworska et al. (2012) investigated the efficacy of spirotetramat in the control of pear psylla (*C. pyri*) on pear trees in five field experiments. In all the experiments, spirotetramat applied at a dose of 2.25 L/ha effectively reduced the pest population after only a single application (a total reduction of larvae after one-week post-treatment 75.3–91.4%, and 83.7–97.6% at two weeks posttreatment). It is not only effective against the pest but also, as other studies of Kumar and Kuttalam (2009) and Mansour et al. (2011) have shown, it is a relatively safe product for predators and parasitoids. Field trials conducted by Pasqualini and Scannavini (2014), Civolani et al. (2015), and Arnaudov (2016a) also showed a remarkable efficacy (> 90%) of spirotetramat on *C. pyri* already two weeks after application. Overall, spirotetramat is one more choice for *C. pyri* control in order to minimize the risks of insecticide resistance occurrence (Civolani et al. 2015).

The efficacy of spirodiclofen in the control of pear psylla (*C. pyri*) on pear trees was evaluated in field experiments by Arnaudov (2016b), where spirodiclofen effectively reduced populations of the pest, achieving from 92.6% to 96.4% efficacy, 21 days after treatment. Also study of Saour et al. (2010) showed good efficacy of spirodiclofen acaricide in control of *C. pyri*. In Serbia, the efficacy of spirodiclofen in the control of eggs and larvae of the first generation of *C. pyri* was investigated by Marčić et al. (2007). Applied in a concentration of 0.14%, spirodiclofen achieved efficacy which ranged from 83.2% to 95% (14 days after treatment).

All of the mentioned outcomes are in accordance with our results which indicate good efficacy for all variants in pear psyllid control in pear orchards. The high efficacy of spirodiclofen, spirotetramat, spirodiclofen + CMC-B, and spirotetramat + CMC-B was achieved at both localities seven and 14 days after treatment during 2020/21 field trials. According to the performed tests and the obtained results on the performance evaluation of insecticides based on spirodiclofen (Envidor 240 SC) and spirotetramat (Movento 100 SC) as well as their combinations with foliar fertilizer (CMC-Boron), for the control of pear psyllid (*C. pyri*) in Serbian pear orchards (locality Kula, Vrbas) it can be concluded that there are obvious differences in efficiency that largely depend on the larval stage of the insect and also it can be noted that high sensitivity of pear psyllid populations depends on the applied insecticides and their mixtures with CMC-B. The results of our experiments indicate that spirodiclofen and spirotetramat mixtures with carboxymethyl cellulose-B have the potential for the significant suppression of *C. pyri* populations in pear orchards.

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