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The control of codling moth (*Cydia pomonella* L.) in apple trees

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Abstract

The efficiency of insecticides with different activity mechanisms in the control of codling moth (*Cydia pomonella* L.) was examined in three-year field trials, at the locality of Bela Crkva in Serbia. In the control of this pest, chlorantraniliprole and the combination of chlorpyrifos and cypermethrin exhibited the highest level of efficiency (up to 98.8% and 97.6%, respectively). Insect growth regulators, novaluron and pyriproxifen, showed high efficiency level (up to 97.6% and 95.1%, respectively) in the control of codling moth's first generation, but their efficiency was poor (up to 65.6% and 61.3%, respectively) in the control of the second one, the cause of which should be searched for in their activity mechanism and the pest biology. Azinphos-methyl showed the lowest efficiency in the control of both generations of codling moth (ranging from 30.8% to 61.3%).

Key words: *Cydia pomonella*, insecticides, efficiency.

Introduction

Codling moth (*Cydia pomonella* L.) is the most important apple pest in Serbia which occurs every year at various infestation levels at particular localities. Losses, which can be over 80% (Graora, Jerinić-Prodanović, 2005), are caused by larvae which penetrate into fruits, damaging them and causing them to fall. In our climate conditions, codling moth occurs in 2–3 generations a year. Stage of cocoon appears during April, while the flight of the first generation can last from the first half of May until the end of June. After copulation, imago lays eggs on leaves and young fruits. The flight of the second generation of codling moth imago begins in the second half of June, while the third generation appears in August (Miletić, Tamaš, 2009). During the period of the first generation, it is possible to clearly differentiate growth stages, such as freshly laid eggs, red ring, black head and the beginning of larval penetration into fruits. During the existence of later generations, all growth stages are present at the same time, which makes the control of this pest much more difficult.

The control of *C. pomonella* is very complex and includes several methods. Its natural enemies can reduce its population, but their efficiency often does not have any practical value. Also, the use of mating disruption method and the virus of granulosis have given good results in the control of this pest, but only with smaller populations and in combination with chemical treatment (Weddle et al., 2009).

Because of the mentioned short-comings of biological measures, chemical treatment plays an important part in the control of codling moth. Insecticides of various chemical types can be used for that purpose: organophosphates, pyrethroids, inhibitors of insect growth (inhibitors of chitin synthesis, juvenoids). Historically, the control of *C. pomonella* was first performed with organophosphate insecticides, most often azinphos-methyl, which came into use in 1960 (Barnes, Moffitt, 1963), and, according to Hagley and Chiba (1980), had high efficiency in the control of this pest. Pyrethroids came into use later. Both types of insecticides mostly affect larvae before they penetrate fruits. Insect growth regulators, which show high level of efficiency in the control of codling moth (Pollini, 2000; Tunaz, Uygun, 2004), came into use later. It should be emphasized that this type of insecticides affect only freshly laid eggs (Brunner et al., 2008). Chlorantraniliprole, which has ovicidal and larvicidal effect on *C. pomonella* and is reported to have high efficiency in its control (Bassi et al., 2007; Milanesi et al., 2008) has been in use since recently.

It is very important to efficiently suppress the first generation of this pest, so that the intensity of infestation could be reduced during the second generation. The control of the second generation causes much more problems. Imagoes flying out in succession and the presence of newly laid and almost hatched eggs at the same time make impossible the use of insect growth regulators, which proved highly efficient in the control of the first generation (Miletić, Tamaš, 2009).

Resistance development is one of the major problems in applying the insecticides for the control of *C. pomonella*. According to numerous reports, codling moth has developed the resistance to chemical insecticides with different activity mechanisms at various localities throughout its distribution area. The resistance to azinphos-methyl was first determined in California in 1989 (Varela et al., 1993). High level of the resistance to fosalon was reported in Czech Republic (Stara et al., 2006). Sauphanor et al. (1998) reported on the resistance development of *C. pomonella* to deltamethrin, bifenthrin, lambda-cyhalothrin, fosalone and azinphos-methyl in France, while Reuveny and Cohen (2004) determined its high resistance to azinphos-methyl in apple crops in Israel. They determined that populations resistant to azinphos-methyl are also cross-resistant to insecticides which are insect growth regulators, such as inhibitors of chitin synthesis (benzoyl-urea), mimics of juvenile hormone (pyriproxifen, fenoxycarb) and agonists of ecdysone (methoxyfenozide). The resistance of codling moth to azinphos-methyl is crossed with the resistance to diazinon, phosmet, carbaryl, esfenvalerate and fenpropathrin, and negatively crossed with that to chlorpyrifos and methyl-parathion (Dunley, Welter, 2000).

Until now, there have been no experimental reports in Serbia on the efficiency of insecticides with different activity mechanisms in the control of *C. pomonella*. Also, there are not any data on the resistance of this pest to the insecticides used in Serbia. However, lower efficiency of particular insecticides has been registered in practice.

The objective of this three-year investigation was to determine the efficiency of insecticides of different activity mechanisms in the control of *C. pomonella*.

Material and methods

Trials were conducted according to the experimental design of completely random block system in four replications, i.e. four apple tree rows with one block each, while the trial plot was five apple trees in size. Thus defined trial field enabled the exact processing of the results using statistical method of analysis of variance.

Treatments were performed by the back-sprayer "Solo", with the air flow of 590 $m^3 h^{-1}$ and liquid flow of 1.7 $l\ min^{-1}$.

Trials were conducted during 2008, 2009 and 2010, in a 12 year old apple crop of cultivar 'Idared', at the locality of Bela Crkva (GPS elevation 134 m; N 44º 55.200, E 21º 23.620).

The control of both the first and the second generations of codling moth was carried out with two insecticide treatments each. The time of the first treatment was determined on the basis of monitoring the imago flight by pheromone traps and the laying of eggs.

During the blossom phenophase, one pheromone trap ($Csal^{MTA\ NKI}$ m N®) was set in the central part of the trial field. It was used for determining the beginning of imago flight and further daily monitoring of imago number. Every third or fourth day after the blossom was over, the laying of eggs was evaluated on 100 fruits and leaves, randomly chosen within the control plots. These data were used for the timing of the first treatment. In the middle of June, another pheromone trap was set for monitoring the second generation imago flight. The second generation imago flight and laying of eggs were monitored in the same way.

Examined insecticides were chosen by two criteria: different mode of action and their current use in regular programs of codling moth control in apple orchards in Serbia.

Data about applied formulations, their concentrations, active ingredients, quantities of a.i. per ha and mode of action are shown in Table 1.

Table 1. Insecticides used in the trials

Trade names of insecticides	Active ingredient	Concentration of formulation %	Mode of action*	Active ingredient kg ha^{-1}
Nurelle-D	chlorpyrifos / cypermethrin	0.1	Acetylcholinesterase inhibitors / Sodium channel modulators	0.5/0.05
Gusathion WP-25	azinphos-methyl	0.15	Acetylcholinesterase inhibitors	0.375
Rimon 10-EC	novaluron	0.1	Inhibitors of chitin biosynthesis, type 0	0.1
Harpun	pyriproxifen	0.1	Juvenile hormone mimics	0.1
Coragen 20 SC	chlorantraniliprole	0.02	Ryanodine receptor modulators	0.04
Control (untreated plot)	–	–		–

Notes. Formulations were applied in 1000 l of water per ha. * – according to IRAC mode of action classification scheme (Anonymous, 2010).

Evaluation parameter: the number of apple fruits damaged by codling moth larvae.

Dates of treatments and result evaluation are shown in Table 2.

Table 2. Dates of insecticide treatments and result evaluation

Year	1st generation			2nd generation		
	First treatment	Second treatment	Evaluation	First treatment	Second treatment	Evaluation
2008	13 05	27 05	08 06	09 07	22 07	03 08
2009	15 05	26 05	10 06	08 07	21 07	04 08
2010	12 05	25 05	07 06	06 07	18 07	01 08

Evaluation mode:

1st generation: all fruits were examined, both in trees and fallen ones. The number of damaged fruits was determined, as well as the presence of codling moth larvae in them.

2nd generation: within each trial plot, 300 fruits, picked from the trees, were examined, as well as all the fallen ones (second evaluation). The number of damaged fruits and the presence of codling moth larvae in them were determined.

The efficiency was calculated according to Abbott's formula, and the significance of differences between particular treatments was determined using the statistical method of variance analysis. The experimental plan itself was set in compliance with this statistical method.

Results and discussion

The results of examining the efficiency of insecticides applied for control of codling moth during 2008, 2009 and 2010, at the locality of Bela Crkva, are shown in Tables 3–5.

1st generation (2008). Statistically significant and very significant differences were determined between the treatments with azinphos-methyl and all the other insecticide treatments. Statistically significant and very significant differences were also determined between the control (untreated plot) and all treatments with the insecticides.

Evaluation of the results of the first generation control in 2008 showed that fruit damage level varied with different treatments. The highest percentage of damage was recorded in the control (untreated plot) (18.2%), while it was significantly lower in treatments with chlorantraniliprole (0.3%), chlorpyrifos and cypermethrin (1%), novaluron (1.1%) and pyriproxifen (1.9%), which indicates high efficiency of these compounds in the control of the first *C. pomonella* generation. High level of fruit damage in the treatment with azinphos-methyl indicates poor efficiency of this compound in the control of this pest (7.9%) (Table 3).

2nd generation (2008). There were no statistically significant differences between the treatment with chlorpyrifos and cipermetrin and the treatment with chlorantraniliprole. Statistically significant and very significant differences were determined between the treatments with these compounds and all the other insecticide treatments. Also, there were statistically significant and very significant differences between the treatments with novaluron and azinphos-methyl. Statistically significant differences were determined between the treatments with pyriproxifen and azinphos-methyl. Between all the insecticide treatments and the control (untreated plot) there were statistically significant and very significant differences.

Table 3. Efficiency of applied insecticides in the control of codling moth 1st and 2nd generation
Bela Crkva, 2008

Treatments	1st generation		2nd generation	
	Average fruit damage % ± Sd	Efficiency %	Average fruit damage % ± Sd	Efficiency %
Chlorpyrifos / Cypermethrin	1.0 ± 0.21	94.5	4.4 ± 0.43	92.2
Azinphos-methyl	7.9 ± 0.34	56.6	38.8 ± 4.62	30.8
Novaluron	1.1 ± 0.27	94.0	23.7 ± 3.19	57.8
Pyriproxifen	1.9 ± 0.41	89.6	27.8 ± 1.97	50.4
Chlorantraniliprole	0.3 ± 0.07	98.4	2.0 ± 0.37	96.4
Control (untreated plot)	18.2 ± 3.47	–	56.1 ± 4.81	–
	$LSD_{0.05}$ = 1.61, $LSD_{0.01}$ = 2.52		$LSD_{0.05}$ = 9.47, $LSD_{0.01}$ = 14.85	

During the result evaluation after the control of the second generation in 2008, very high percentage of fruit damage was recorded in the control (56.1%), while it was significantly lower in the treatments with chlorantraniliprole (2%) and chlorpyrifos and cypermethrin (4.4%), indicating high efficiency of these compounds in the control of codling moths second generation. Novaluron and pyriproxifen had poor efficiency, i.e. high level of fruit damage was recorded in the treatments with these compounds (23.7% and 27.8%). In the control of the second generation, azinphos-methyl had very poor efficiency, indicated by high level of fruit damage recorded in the treatment with this compound (38.8%) (Table 3).

1st generation (2009). Between the treatment with azinphos-methyl and all the other insecticide treatments statistically significant and very significant differences were determined. Statistically significant differences were also determined between the treatments with chlorantraniliprole and pyriproxifen. There were statistically significant and very significant differences between the control (untreated plot) and all the insecticide treatments.

Evaluation of trial results of the first generation control in 2009 revealed a similar tendency in insecticide efficiency levels to that in 2008. The highest percentage of fruit damage was recorded in the control (untreated plot) (14.2%), and it was much lower in the treatments with preparations chlorantraniliprole (0.2%), chlorpyrifos and cypermethrin (0.5%), novaluron (0.5%) and pyriproxifen (1.1%), which indicated high efficiency of these compounds in the control of *C. pomonella* first generation. Great fruit damage recorded in the treatment with azinphos-methyl (5.5%) indicated poor efficiency of this compound in the control of this pest (Table 4).

Table 4. Efficiency of applied insecticides in the control of codling moth 1st and 2nd generation
Bela Crkva, 2009

Treatments	1st generation		2nd generation	
	Average fruit damage % ± Sd	Efficiency %	Average fruit damage % ± Sd	Efficiency %
Chlorpyrifos / Cypermethrin	0.5 ± 0.12	96.5	1.8 ± 0.32	95.4
Azinphos-methyl	5.5 ± 0.58	61.3	25.6 ± 2.60	34.7
Novaluron	0.5 ± 0.10	96.5	14.7 ± 1.82	62.5
Pyriproxifen	1.1 ± 0.16	92.3	17.0 ± 1.01	56.6
Chlorantraniliprole	0.2 ± 0.12	98.6	1.1 ± 0.25	97.2
Control (untreated plot)	14.2 ± 1.93	–	39.2 ± 5.95	–
	$LSD_{0.05}$ = 0.65, $LSD_{0.01}$ = 1.02		$LSD_{0.05}$ = 6.89, $LSD_{0.01}$ = 10.80	

2nd generation (2009). Result evaluation showed that there were no statistically significant differences between the treatment with chlorpyrifos and cypermethrin and the treatment with chlorantraniliprole. Statistically significant and very significant differences were determined between the treatments with these compounds and all the others. There were also statistically significant and very significant differences between the treatments with novaluron and azinphos-methyl, and statistically significant differences between the treatments with pyriproxifen and azinphos-methyl. Between all the insecticide treatments and the control (untreated plot) statistically significant and very significant differences were determined.

During the result evaluation after the control of the second generation, high percentage of fruit damage was recorded in the control (untreated plot) (39.2%), while it was significantly lower in the treatments with preparations chlorantraniliprole (1.1%) and chlorpyrifos and cypermethrin (1.8%), which indicated high efficiency of these compounds in the control of the second codling moths generation in 2009. The efficiency of novaluron and pyriproxifen was poor, resulting in high level of fruit damage recorded in the treatments with preparations novaluron (14.7%) and pyriproxifen (17%). Azinphos-methyl had very poor efficiency in the control of the second generation causing high level of fruit damage in the treatment with this compound (25.6%) (Table 4).

1st generation (2010). Statistically significant and very significant differences were determined between the treatment with azinphos-methyl and all the other insecticide treatments. There were also statistically significant and very significant differences between the treatment with pyriproxifen and the treatments with chlorpyrifos and cipermetrin, novaluron and chlorantraniliprole. Statistically significant difference was established between the treatment with chlorantraniliprole and the treatments with chlorpyrifos and cypermethrin and with novaluron. Between the control (untreated plot) and all the insecticide treatments there were statistically significant and very significant differences.

Evaluation of the trial results after the control of the first generation in 2010 shows similar levels of insecticide efficiency to those in 2008 and 2009. High level of fruit damage was recorded in the control (untreated plot) (4.1%), while it was much lower in the treatments with chlorantraniliprole (0%), chlorpyrifos and cypermethrin (0.1%), novaluron (0.1%) and pyriproxifen (0.2%), indicating high efficiency of these compounds in the control of the *C. pomonella* first generation. Azinphos-methyl again exhibited very poor efficiency with fruit damage of 5.5% in the treatment with this compound (Table 5).

2nd generation (2010). Statistically significant differences were determined between the treatment with chlorpyrifos and cypermethrin and the treatment with chlorantraniliprole. Between the treatments with these compounds and all the others there were statistically significant and very significant differences, as well as between the treatment with pyriproxifen and the treatments with azinphos-methyl and novaluron. Statistically significant and very significant differences were also determined between the control (untreated plot) and all the insecticide treatments.

During the result evaluation after the control of the second generation in 2010, high level of fruit damage was recorded in the control (21.2%), and it was significantly lower in the treatments with chlorantraniliprole (0.3%) and chlorpyrifos and cypermethrin (0.8%), which indicates high efficiency of these compounds in the control of the codling moths second generation in 2010. Novaluron and pyriproxifen exhibited poor efficiency and there was high level of fruit damage in the treatments with these compounds (7.3% and 8.2%). Azinphos-methyl had very poor efficiency in the control of second generation, with high level of fruit damage in the treatment with this compound (14.2%) (Table 5).

Fruit damage level in the control was significantly lower in 2009 than in 2008 (Tables 3 and 4), and the tendency of infestation weakening also continued in 2010 (Table 5).

Table 5. Efficiency of applied insecticides in the control of codling moth 1st and 2nd generation
Bela Crkva, 2010

Treatments	1st generation		2nd generation	
	Average fruit damage % ± Sd	Efficiency %	Average fruit damage % ± Sd	Efficiency %
Chlorpyrifos / Cypermethrin	0.1 ± 0.07	97.6	0.8 ± 0.19	96.2
Azinphos-methyl	1.7 ± 0.37	58.5	14.2 ± 0.94	33.0
Novaluron	0.1 ± 0.10	97.6	7.3 ± 0.61	65.6
Pyriproxifen	0.2 ± 0.07	95.1	8.2 ± 0.38	61.3
Chlorantraniliprole	0.05 ± 0.05	98.8	0.3 ± 0.07	98.6
Control (untreated plot)	4.1 ± 0.37	–	21.2 ± 1.26	–
	$LSD_{0.05}$ = 0.04, $LSD_{0.01}$ = 0.06		$LSD_{0.05}$ = 0.45, $LSD_{0.01}$ = 0.71	

During the entire period of investigation, chlorantraniliprole and the combination of chlorpyrifos and cypermethrin demonstrated the highest level of efficiency in the control of codling moth. The efficiency of chlorantraniliprole, a compound with a new mode of action, ranged from 98.4% to 98.8% in the control of the first, and from 96.4% to 98.6% in the control of the second generation of codling moth. High efficiency of this compound was also reported by other authors (Bassi et al., 2007; Milanesi et al., 2008). The results of this investigation point out the importance of chlorantraniliprole in the control of both *C. pomonella* generations, especially when the efficiency of other insecticides is reduced, either because of the possible resistance development or their specific mode of action.

The combination of chlorpyrifos and cypermethrin also proved very efficient in the control of codling moth both generations. Its efficiency ranged from 94.5% to 97.6% in the control of the first, and from 92.2% to 96.2% in the control of the second generation. Using of a combination of insecticides with different activity mechanisms in pest control represents an important and often very efficient measure of resistance management, which is also recommended by IRAC (Anonymous, 2004). It should be emphasized that negative cross-resistance between chlorpyrifos and azinphos-methyl was confirmed (Dunley, Welter, 2000), which could be the reason for high efficiency of the formulation with chlorpyrifos and cipermetrin. In our investigation, azinphos-methyl had very poor efficiency, which is possible indication of the development of codling moths resistance to this compound.

During the investigation, insect growth regulators, pyriproxifen and novaluron showed high efficiency in the control of *C. pomonella* first generation, ranging from 89.6% to 95.1%, and from 94% to 97.6%, respectively. Their high efficiency was also reported by other authors (Pollini, 2000; Tunaz, Uygun, 2004). However, both novaluron and pyriproxifen had poor efficiency in the control of second generation, ranging from 57.8% to 65.6%, and from 50.4% to 61.3%, respectively. Because they proved highly efficient in the control of the first *C. pomonella* generation, we presume that resistance was not the cause of their poor efficiency in the control of the second one. Rational explanation should be searched for in the mode of action of these compounds and the biology of pest species. Since growth regulators directly affect freshly laid eggs (Brunner et al., 2008) and larvae (strong ovicidal and larvicidal effect), both compounds are efficient in the control of the first generation, when the pest mainly exists in its early growth stages, before larvae penetrate into fruits. Thus, their poor efficiency against the second generation could be explained by the simultaneous presence of different growth stages (e.g. both freshly laid and 2–9 day old eggs), and, according to Brunner et al. (2008), such compounds are less effective against older eggs.

During the entire period of investigation, azinphos-methyl had the poorest efficiency against both generations of codling moth, ranging from 56.6% to 61.3%, and from 30.8% to 34.7%, respectively. Considering the history of its application and very high efficiency during the first years of its use (Hagley, Chiba, 1980), we could assume that there is a strong indication of reduced susceptibility of *C. pomonella* population at this locality, i.e. possible resistance development. The resistance of codling moth to azinphos-methyl and other organophosphates was also confirmed at numerous production localities worldwide (Varela et al., 1993; Sauphanor et al., 1998; Reuveny, Cohen, 2004; Stara et al., 2006).

Conclusions

1. Chlorantraniliprole and the combination of chlorpyrifos and cypermethrin showed high efficiency level and azinphos-methyl showed the lowest efficiency level in the control of *C. pomonella* both generations, during the whole experimental period.

2. Insect growth regulators, pyriproxifen and novaluron, showed high efficiency level in the control of *C. pomonella* 1st generation, but their efficiency was poor in the control of the 2nd generation.

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Obuolinio vaisėdžio (*Cydia pomonella* L.) gausumo reguliavimas obelų soduose

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Santrauka

Skirtingo poveikio insekticidų efektyvumas nuo obuolinio vaisėdžio (*Cydia pomonella* L.) tirtas trejus metus lauko bandymų metu Bela Crkva vietovėje, Serbijoje. Kontroliuojant šį kenkėją efektyviausi buvo chlorantraniliprolas ir chlorpyrifoso bei cipermetrino mišinys (atitinkamai 98,8 ir 97,6 %). Vabzdžių augimo reguliatoriai novaluronas ir piriproksifenas buvo itin efektyvūs (97,6 ir 95,1 %) kontroliuojant pirmosios generacijos obuolinius vaisėdžius, bet jų efektyvumas buvo mažesnis (atitinkamai 65,6 ir 61,3 %) kontroliuojant antrąją šių kenkėjų generaciją. Tam galėjo turėti įtakos augimo reguliatorių poveikio pobūdis ir kenkėjų biologija. Mažiausiai efektyvus (nuo 30,8 iki 61,3 %) abiem obuolinio vaisėdžio generacijoms buvo azinfosmetilas.

Reikšminiai žodžiai: *Cydia pomonella*, insekticidai, efektyvumas.