

Toxicity of several contact insecticides to *Tribolium castaneum* (Herbst) populations after selection with pirimiphos-methyl and deltamethrin

Goran Andrić*, Marijana Pražić Golić and Petar Kljajić

Institute of Pesticides and Environmental Protection, Banatska 31b, 11080 Belgrade, Serbia
(*goran.andric@pesting.org.rs)

Received: December 17, 2015

Accepted: December 31, 2015

SUMMARY

Laboratory bioassays were conducted to detect possible alteration in susceptibility of two field *Tribolium castaneum* (Herbst) populations (sampled in a warehouse in Nikinci and a silo in Jakovo) to dichlorvos, malathion, chlorpyrifos-methyl, pirimiphos-methyl, deltamethrin and bifenthrin after previous selection with the LD₈₀ of pirimiphos-methyl and deltamethrin.

Data from the topical application bioassays show that chlorpyrifos-methyl was the most toxic insecticide to *T. castaneum* adults of the Nikinci population selected with pirimiphos-methyl and deltamethrin, while malathion was the weakest, and both selection procedures changed/reduced significantly only the toxicity of deltamethrin and bifenthrin, increasing their resistance ratios (RR) at the LD₅₀ from 1.1 to 1.8 (bifenthrin) and from 0.9 to 2.2 (deltamethrin). Deltamethrin was the most toxic insecticide for Jakovo adults selected with the LD₈₀ of pirimiphos-methyl, while malathion was again the least toxic. Selection of that population had no effect on insecticide toxicity, except of malathion, which had a rise in RR at the LD₅₀ from 26.0 to 29.8.

Keywords: Insecticides; Toxicity; Red flour beetle

1. INTRODUCTION

The red flour beetle *Tribolium castaneum* (Herbst) is one of the most damaging insect species invading warehouses and mills around the world (Rees, 2004; Almaši, 2008; Mahroof & Hagstrum, 2012). Regarding the control of that and some other stored-product pests, a variety of factors decide the effectiveness of contact insecticides, the most important of which is insect resistance (Subramanyam & Hagstrum, 1996; Kljajić & Perić, 2005; Kljajić & Perić, 2006; Kljajić & Perić, 2009; Boyer et al., 2012; Opit et al., 2012). In the late 1960s, only a few years after malathion was put on the markets,

initial data appeared confirming changes in susceptibility of *T. castaneum* to that insecticide (Champ & Campbell-Brown, 1969), while Speirs and Zettler (1969), after four years of monitoring the resistance of *T. castaneum* populations, found 8.8-fold higher resistance levels than at the beginning of trials. Realizing the significance and ensuing detriment, FAO organized in 1972 and 1973 a global campaign of investigating the susceptibility/resistance of stored-product insects to insecticides, and detected changes in malathion susceptibility in 87% of the investigated *T. castaneum* populations (Champ & Dyte, 1976). Loyd and Ruczkowski (1980) used topical application to determine the toxicity of permethrin and

eight other synthetic pyrethroids to three populations of *T. castaneum*: a laboratory population, a malathion-resistant population, and an organophosphate-resistant population. The population resistant to malathion did not show any cross-resistance with pyrethroids, while the population resistant to organophosphates displayed cross-resistance with pyrethrin (RR-resistance ratio = 34.0), resmethrin (RR 2.2), bioresmethrin (RR 3.3) and phenothrin (RR 4.0). Haliscak and Beeman (1983) applied discriminating doses of malathion to filter paper and detected malathion resistance in 31 of 36 *T. castaneum* populations collected from cereal storages in the U.S. as an addition of the synergist triphenylphosphate helped the discriminating malathion dose to cause 100% mortality in most populations. In 15 populations with mortality ranging from 0 to 62%, a single selection with the discriminating malathion dose resulted in RRs exceeding 20 in 14 populations, and RR >83 in one population.

Monitoring the activities aimed at forecasting resistance evolution in various sampled populations, Brown and Payne (1988) proposed six insecticide selections in the laboratory with doses causing $\geq 80\%$ mortality to enable identification of genes responsible for resistance. However, subsequent trials showed that 1-3 selections were sufficient for detecting changes in insecticide toxicity. Kljajić and Perić (2007a) determined the toxicity of six contact insecticides to local populations of granary weevil, *Sitophilus granarius* (L.), after selection with pirimiphos-methyl and deltamethrin. In a population originating from Apatin that underwent three selections with the LD₅₀ of deltamethrin, the resistance ratios of that insecticide increased significantly, so that the initial 7.0 and 7.2 at the LD₅₀ and LD₉₅ levels increased to 32.1 and 51.9, respectively. In a Belgrade Port population of weevils, a single selection with the LD₇₀ of pirimiphos-methyl did not change pirimiphos-methyl toxicity significantly, but it reduced deltamethrin susceptibility (RR 5.7 and 5.0 before selection increasing to RR 18.7 and 15.2 after selection, respectively), which is an indicator of cross-resistance between the compounds.

Topical application was used in the present study which focused on determining possible susceptibility changes in two field populations of *T. castaneum* (from a warehouse and a silo) to the organophosphate insecticides dichlorvos, malathion, chlorpyrifos-methyl and pirimiphos-methyl, and the pyrethroids deltamethrin and bifenthrin, after previous selection with the LD₈₀ of pirimiphos-methyl and deltamethrin. The results were expected to reveal potentials for altered susceptibility or resistance to those insecticides developing in the tested populations.

2. MATERIAL AND METHODS

2.1. Populations and selection procedure

The following *T. castaneum* populations were tested: 1) laboratory population with normal susceptibility to insecticides, 2) field population sampled in a Nikinci warehouse and selected once with the LD₈₀ of pirimiphos-methyl, and once with the LD₈₀ of deltamethrin, and 3) field population sampled in a Jakovo silo and selected once with the LD₈₀ pirimiphos-methyl and deltamethrin.

All populations were reared as described by Harein and Soderstrom (1966), and Bry and Davis (1985) in 2.5 L glass jars containing white wheat flour with 5% dry yeast. Insectary air temperature was $25 \pm 1^\circ\text{C}$ and relative humidity $60 \pm 5\%$. Unsexed beetles, 2-4 weeks old, were used in bioassays, and *F*₁ generation beetles in susceptibility trials testing the selected *T. castaneum* populations.

As recommended by Brown and Payne (1988) and using a modified method of Halliday et al. (1988), insects from the field population Nikinci (warehouse) were selected once in the laboratory with pirimiphos-methyl LD₈₀ (0.016 $\mu\text{g}/\text{insect}$) and once with deltamethrin LD₈₀ (0.014 $\mu\text{g}/\text{insect}$), while insects from the field population Jakovo (silo) were selected once with pirimiphos-methyl LD₈₀ (0.013 $\mu\text{g}/\text{insect}$) and deltamethrin LD₈₀ (0.013 $\mu\text{g}/\text{insect}$).

2.2 Contact insecticides

Technical-grade concentrates of the following insecticide active ingredients were used: dichlorvos 98% (Diachem, Italia), malathion 96% (Cheminova, Denmark), chlorpyrifos-methyl 97% (DowElanco, UK), pirimiphos-methyl (product Actellic EC containing 50% a.i, Galenika-Fitofarmacija, Serbia), deltamethrin 98% (Veterinarski zavod, Serbia) and bifenthrin 94.7% (FMC, USA).

2.3. Bioassay

Insecticide toxicity to *T. castaneum* adults and susceptibility/resistance of the selected populations were tested according to Halliday et al. (1988) using topical application. The beetles were immobilized before treatment by anaesthetization for 30 seconds with CO₂ and then each adult was treated with 0.5 μL of each insecticide dissolved in acetone (6-8 concentrations) by application to the last thoracic segment with a Burkard microapplicator

(needle no. 18 in 1.0 mL syringe). Control insects received acetone alone. After application, groups of 25 beetles in 4 replicates were transferred to clean Petri dishes, and 1 g of wheat flour was added to each after 4–6 hours. Lethal effects were checked 7 days after microapplication. The experiment was repeated 2–3 times.

2.4. Data analysis

Mortality data were corrected for mortality in the control using Abbott's (1925) formula. The data were processed by Probit analysis as described by Finney (1971) and using a computer software developed by Raymond (1985). Statistical significance of the differences in toxicity indicators for the insecticides was assessed based on the overlapping/non-overlapping of confidence intervals.

3. RESULTS

The data (LD levels, *ld-p* lines and resistance ratios - RRs) presented in Tables 1 and 2 show that deltamethrin was the most toxic insecticide to adults of the laboratory population of *T. castaneum* at the LD₅₀, i.e. 40.6-fold more toxic than the weakest malathion, while pirimiphos-methyl, the most toxic insecticide at the LD₉₅, was 3300-fold more toxic than the weakest malathion. Table 1 shows insecticide toxicity data for Nikinci beetles before selection, and deltamethrin was the most toxic insecticide at the LD₅₀, while chlorpyrifos-methyl was the most toxic at the LD₉₅, the two being respectively 748- and 4097-fold more toxic than the weakest malathion. The calculated RRs indicate a significantly changed susceptibility of that population only to malathion, whose RR was 18 at the LD₅₀ and 11 at LD₉₅.

Table 1. Insecticide toxicity to *T. castaneum* adults of the laboratory population and Nikinci field population (warehouse) selected with pirimiphos-methyl and deltamethrin LD₈₀

Insecticide	LD ₅₀ (µg /insect) FL (0.05)	RR** (LD ₅₀)	LD ₉₅ (µg /insect) FL (0.05)	RR** (LD ₉₅)	Slope of <i>ld-p</i> line (± SE)
Laboratory population*					
Dichlorvos	0.040 (0.038-0.043)	/	0.087 (0.079-0.097)	/	4.98±0.34
Malathion	0.28 (0.21-0.36)	/	5.97 (4.08-9.66)	/	1.24±0.08
Chlorpyrifos-methyl	0.011 (0.0104-0.0115)	/	0.019 (0.018-0.021)	/	6.52±0.42
Pirimiphos-methyl	0.0091 (0.0087-0.0095)	/	0.0018 (0.017-0.019)	/	5.680.27
Deltamethrin	0.0069 (0.0062-0.0075)	/	0.024 (0.021-0.027)	/	3.05±0.15
Bifenthrin	0.049 (0.041-0.056)	/	0.27 (0.22-0.35)	/	2.19±0.16
Nikinci field population (warehouse)					
<i>Before selection*</i>					
Dichlorvos	0.042 (0.039-0.044)	1.0	0.087 (0.080-0.096)	1.0	5.15±0.33
Malathion	4.94 (4.23-5.72)	17.6	65.56 (49.25-93.58)	11.0	1.46±0.01
Chlorpyrifos-methyl	0.0098 (0.0093-0.010)	0.9	0.016 (0.015-0.018)	0.8	7.21±0.60
Pirimiphos-methyl	0.011 (0.010-0.011)	1.2	0.025 (0.022-0.029)	1.4	4.48±0.34
Deltamethrin	0.0066 (0.0058-0.0073)	0.9	0.029 (0.025-0.035)	1.2	2.53±0.17
Bifenthrin	0.054 (0.049-0.060)	1.1	0.14 (0.11-0.17)	0.5	4.07±0.37
After selection with pirimiphos-methyl LD ₈₀					
Dichlorvos	0.049 (0.045-0.052)	1.2	0.12 (0.11-0.14)	1.4	4.04±0.27
Malathion	3.84 (2.98-4.74)	13.7	36.48 (28.22-50.63)	6.1	1.68±0.13
Chlorpyrifos-methyl	0.0120 (0.0118-0.0133)	1.1	0.028 (0.025-0.031)	1.5	4.72±0.28
Pirimiphos-methyl	0.0140 (0.0137-0.0152)	1.5	0.035 (0.031-0.040)	1.9	4.30±0.29
Deltamethrin	0.015 (0.014-0.016)	2.2	0.053 (0.046-0.064)	2.2	3.02±0.18
Bifenthrin	0.087 (0.079-0.096)	1.8	0.33 (0.28-0.41)	1.2	2.83±0.20
After selection with deltamethrin LD ₈₀					
Dichlorvos	0.037 (0.033-0.040)	0.9	0.10 (0.09-0.12)	1.1	3.68±0.27
Malathion	3.51 (2.88-4.15)	12.5	47.35 (36.17-66.95)	7.9	1.45±0.10
Chlorpyrifos-methyl	0.0108 (0.0102-0.011)	1.0	0.023 (0.021-0.025)	1.2	5.10±0.32
Pirimiphos-methyl	0.011 (0.0107-0.012)	1.2	0.031 (0.027-0.036)	1.7	3.89±0.30
Deltamethrin	0.014 (0.013-0.015)	2.0	0.05 (0.04-0.06)	2.1	3.03±0.18
Bifenthrin	0.085 (0.075-0.095)	1.7	0.43 (0.35-0.54)	1.6	2.83±0.20

* Andrić et al. (2010); ** RR = LD tested/LD laboratory population

Chlorpyrifos-methyl was the most toxic insecticide for *T. castaneum* adults of the Nikinci population selected with pirimiphos-methyl LD₈₀ and it was 320.0- and 1302.8-fold more toxic at the LD₅₀ and LD₉₅ than the weakest malathion. The results show that selection had no influence only on dichlorvos and chlorpyrifos-methyl toxicity, while a change was detected for pirimiphos-methyl only at the LD₉₅ (1.4-fold lower after selection), which is supported by the confidence interval data. Comparing the nominal LD values, a slight increase was detected in malathion toxicity after selection, but the difference was not statistically significant because the confidence intervals before and after selection overlapped. However, deltamethrin and bifenthrin toxicity was 2.3- and 1.8-fold (at LD₅₀), and 1.8- and 2.3-fold (at LD₉₅) lower, respectively, after selection with pirimiphos-methyl LD₈₀ than it was before selection. Compared to the laboratory population of red flour beetles, there was a small but significant increase in resistance level only of bifenthrin, from 1.1 and 0.5 to 1.8 and 1.2 (at LD₅₀ and LD₉₅, respectively) and deltamethrin, from 0.9

and 1.2 to 2.2 and 2.2 (at LD₅₀ and LD₉₅, respectively). Nikinci beetles selected with deltamethrin LD₈₀ along with those selected with pirimiphos-methyl, showed the highest susceptibility to chlorpyrifos-methyl. Deltamethrin selection did not change the organophosphate toxicity, while the pyrethroids bifenthrin and deltamethrin had significantly lower toxicity after selection, compared to data before selection, so that bifenthrin was 1.6- and 3.1-fold less toxic at the LD₅₀ and LD₉₅, while it was 1.7- and 1.6-fold less toxic compared to laboratory beetles. At the LD₅₀, deltamethrin was 2.1-fold less toxic after selection, and 2.0-fold less toxic than it was to the laboratory population.

Considering the LD₅₀ dose, deltamethrin was the most toxic insecticide against *T. castaneum* adults originating from Jakovo (silo) before selection, while pirimiphos-methyl was the most toxic at the LD₉₅, and they were 1348.1- and 2238.0-fold more toxic, respectively, than the weakest malathion (Table 2). Their computed RRs revealed that both populations had significantly altered susceptibility only to malathion with RR 26.0 at the LD₅₀ level, and 6.1 at the LD₉₅. Deltamethrin was the most

Table 2. Insecticide toxicity to *T. castaneum* adults of the laboratory population and Jakovo field population (silo) selected with pirimiphos-methyl[#] LD₈₀

Insecticide	LD ₅₀ (µg/insect) FL (0.05)	RR** (LD ₅₀)	LD ₉₅ (µg/insect) FL (0.05)	RR** (LD ₉₅)	Slope of <i>ld-p</i> line (±SE)
Laboratory population*					
Dichlorvos	0.040 (0.038-0.043)	/	0.087 (0.079-0.097)	/	4.98±0.34
Malathion	0.28 (0.21-0.36)	/	5.97 (4.08-9.66)	/	1.24±0.08
Chlorpyrifos-methyl	0.011 (0.0104-0.0115)	/	0.019 (0.018-0.021)	/	6.52±0.42
Pirimiphos-methyl	0.0091 (0.0087-0.0095)	/	0.0018 (0.017-0.019)	/	5.68±0.27
Deltamethrin	0.0069 (0.0062-0.0075)	/	0.024 (0.021-0.027)	/	3.05±0.15
Bifenthrin	0.049 (0.041-0.056)	/	0.27 (0.22-0.35)	/	2.19±0.16
Jakovo field population (silo)					
<i>Before selection*</i>					
Dichlorvos	0.035 (0.033-0.037)	0.8	0.079 (0.071-0.090)	0.9	4.65±0.34
Malathion	7.28 (6.54-8.03)	26.0	36.48 (30.85-44.85)	6.1	2.35±0.14
Chlorpyrifos-methyl	0.012 (0.0113-0.0127)	1.1	0.024 (0.022-0.027)	1.3	5.55±0.40
Pirimiphos-methyl	0.0090 (0.0085-0.0094)	0.9	0.0163 (0.0154-0.0176)	0.9	6.31±0.38
Deltamethrin	0.0054 (0.0047-0.0060)	0.7	0.024 (0.020-0.029)	1.0	2.55±0.19
Bifenthrin	0.040 (0.034-0.045)	0.8	0.17 (0.14-0.21)	0.6	2.65±0.23
<i>After selection with pirimiphos-methyl LD₈₀</i>					
Dichlorvos	0.025 (0.024-0.028)	0.6	0.057 (0.051-0.065)	0.6	4.83±0.35
Malathion	8.34 (6.41-10.81)	29.8	80.29 (41.51-161.79)	13.4	1.67±0.21
Chlorpyrifos-methyl	0.009 (0.0081-0.0094)	0.8	0.018 (0.016-0.020)	0.9	5.28±0.47
Pirimiphos-methyl	0.0097 (0.0092-0.010)	1.1	0.018 (0.017-0.020)	1.0	5.91±0.38
Deltamethrin	0.006 (0.005-0.007)	0.9	0.04 (0.03-0.05)	1.7	2.15±0.19
Bifenthrin	0.02 (0.007-0.045)	0.4	0.20 (0.09-0.49)	0.7	1.57±0.34

* Andrić et al. (2010); ** RR = LD tested/LD laboratory population

[#] Results obtained after selection with deltamethrin LD₈₀ could not be processed by probit analysis

toxic and malathion the least toxic to *T. castaneum* adults from Jakovo at the LD₅₀ before and after selection with pirimiphos-methyl LD₈₀. Selection of that population had no effect on insecticide toxicity, except of malathion, whose RRs increased from 26.0 to 29.8 (LD₅₀) and from 6.1 to 13.4 (LD₉₅), but the differences were not significant.

4. DISCUSSION

Our analysis of data in trials involving topical application of chemical insecticides to our laboratory population of *T. castaneum* (Andrić et al., 2010) revealed that deltamethrin was the most toxic insecticide at the LD₅₀, 1.3-, 1.6-, 5.8-, 7.1- and 40.6-fold more toxic than pirimiphos-methyl, chlorpyrifos-methyl, dichlorvos, bifenthrin and malathion, respectively. The toxicity order of insecticides is somewhat different at the LD₉₅ level, where pirimiphos-methyl and chlorpyrifos-methyl were the most toxic insecticides and deltamethrin, dichlorvos, bifenthrin and malathion following. Halliday et al. (1988) used microapplication of organophosphates and found pirimiphos-methyl and malathion, with the following dichlorvos, to be the most toxic insecticides to their laboratory red flour beetles at the LD₅₀, while chlorpyrifos-methyl was the weakest. At the level of LD₉₅, that study also revealed a different order in toxicity strength among the insecticides, finding pirimiphos-methyl at the top and malathion at the bottom of the list. In trials on filter paper, Subramanyam et al. (1989) found chlorpyrifos-methyl to be the most toxic of the examined organophosphates to laboratory *T. castaneum* adults as it was 4.8-fold more toxic than pirimiphos-methyl at the LD₅₀ and 8.0-fold more toxic than the weakest malathion. In microapplication trials, Zettler (1991) detected no differences in toxicity among dichlorvos, chlorpyrifos-methyl and malathion against a laboratory population of *T. castaneum* at the LD₅₀, while pyrethroids, i.e. synergized pyrethrin and resmethrin, were 1.7- and 4.7-fold less toxic. On the other side, considering the LD₉₉ level, the most toxic insecticide was chlorpyrifos-methyl, and then dichlorvos, which was 1.9-fold more toxic than malathion, while pyrethroids were again the least effective.

Positive correlation was detected between the effects of discriminating doses and toxicity parameter in both tested populations (Andrić et al., 2010), in which malathion caused the lowest mortality of 70 and 64%. Their RRs at the LD₅₀ and LD₉₅ were 17.6 and 11.0 in the Nikinci population, and 26.0 and 6.1 in Jakovo population, while resistance was not detected to the other insecticides tested. Deltamethrin was the most toxic insecticide at the LD₅₀ in both populations, while

chlorpyrifos-methyl was the most toxic at the LD₉₅ to the Nikinci population and pirimiphos-methyl to the Jakovo population. Zettler and Arthur (1997) found in their microapplication trials that all examined populations of *T. castaneum* (14 populations) and *T. confusum* (10) collected from U.S. mills were resistant to malathion and dichlorvos. It was a study in which a record level of malathion resistance so far was reported (FR = 29081). Analyzing their results, the authors confirmed a positive correlation between the effects of discriminating doses and toxicity parameter, and inferred that the efficacy of malathion and dichlorvos in practice could be predicted this way, but only when resistance is weak. These findings and data reported by Andrić et al. (2010), correlating directly with our present results, infer that 58% of the tested Serbian populations have already displayed altered susceptibility to malathion alone.

Testing an organophosphate-resistant population of *T. castaneum*, Loyd and Ruczkowski (1980) found a 34-fold lower toxicity of pyrethrin, while resmethrin had a 2.2-fold lower toxicity and bioresmethrin 3.3-fold lower. On the other side, a population resistant to malathion alone showed no cross-resistance with pyrethroids. Haliscak and Beeman (1983) tested malathion-resistant populations of *T. castaneum* and found that the discriminating dose of malathion after a single selection resulted in a multiple increase in resistance factor. Kljajić and Perić (2007a) used a filter paper method and found that a single selection with the LD₇₀ of pirimiphos-methyl caused no change in insecticide toxicity to a Belgrade Port population of *Sitophilus granarius*, while significantly decreasing the toxicity of deltamethrin, which is indicative of cross-resistance. Deltamethrin RR was 5.8 before selection at the LD₅₀, and 18.8 after selection. Deltamethrin selection at the LD₇₀ reduced significantly the toxicity of that insecticide to weevils originating from Bijeljina and Kikinda, while it also significantly decreased malathion and cypermethrin toxicity to weevils from Kikinda. In a residual test on wheat grain, Kljajić and Perić (2009) found that the detected resistance of granary weevils from Apatin and Belgrade Port to deltamethrin had significantly changed the effectiveness of that insecticide applied at 0.5 mg/kg rate in deposits aged up to 90 days. The effectiveness of 150-days old deposits was even worse. Evidently, a high percentage of selected weevils from Apatin that had RR 51.9 for deltamethrin after three selections on filter paper (Kljajić and Perić, 2007a) and those from Belgrade Port with RR 5.0 for deltamethrin on wheat grains (Kljajić and Perić, 2007b) show that they are able to survive contact with deltamethrin-treated wheat.

In our topical application experiments, a single selection using the LD₈₀ of pirimiphos-methyl reduced the toxicity of all tested insecticides in the Nikinci population, rather than malathion alone. The most significant drop in toxicity was revealed for deltamethrin and bifenthrin, which were respectively 2.3- and 1.6-fold less toxic at the LD₅₀ to the selected red flour beetles than before selection. In the Nikinci population, selection with deltamethrin LD₈₀ caused also a significant fall in deltamethrin and bifenthrin toxicity as they were 1.7- and 3.1-fold less toxic at the LD₉₅ than they were before selection. On the other side, selection with the LD₈₀ of pirimiphos-methyl in the Jakovo population increased dichlorvos toxicity 1.4-fold and chlorpyrifos-methyl toxicity 1.3-fold (at LD₅₀ and LD₉₅), while, considering confidence intervals, malathion toxicity did not change in either selected population, even though the nominal LD values changed significantly.

In conclusion, the present study and our previous research show that insecticide choices need to be made carefully, considering the target species of stored-product insects and their susceptibility to malathion and other insecticides. Attention should also be focused on a crucial role of insecticide selection of different stored-grain insect populations in order to enable predictions of resistance evolution in individual populations and, based on such knowledge, sound choices of the most adequate resistance management strategy. A reliable assessment of resistance in individual populations should also include further data about the toxicity of insecticides and their effects on treated wheat grain, as well as genetic and biochemical studies.

ACKNOWLEDGEMENT

This study was funded by the Serbian Ministry of Education, Science and Technological Development, Grant No. III 46008.

REFERENCES

- Abbott, W.S. (1925). A method of computing the effectiveness of an insecticide. *Journal of Economic Entomology*, 18, 265-267.
- Almaši, R. (2008). Štetne artropode uskladištenog žita. In P. Kljajić (Ed.), *Zaštita uskladištenih biljnih proizvoda od štetnih organizama* (pp 9-38). Belgrade, Serbia: Institut za pesticide i zaštitu životne sredine.
- Andrić, G., Kljajić, P., Perić, I., & Pražić Golić, M. (2010). Susceptibility of red flour beetle *Tribolium castaneum* (Herbst) populations from Serbia to contact insecticides. In *Proceedings of the 10th International Working Conference on Stored Product Protection*, (pp 868-872). Estoril, Portugal: Julius-KühnArchiv.
- Boyer, S., Zhang, H., & Lempérière, G. (2012). A review of control methods and resistance mechanisms in stored-product insects. *Bulletin of Entomological Research*, 102(2), 213-229. pmid:22126937
- Brown, T.M., & Payne, G.T. (1988). Experimental selection for insecticide resistance. *Journal of Economic Entomology*, 81, 49-56. pmid:2895128
- Bry, R.E., & Davis, R. (1985). *Tribolium confusum* and *Tribolium castaneum*. In P., Singh & R.F Moore (Eds.), *Handbook of Insect Rearing*, Vol. 1 (pp 291-293). Amsterdam-Oxford-NewYork-Tokyo: Elsevier.
- Champ, B.R., & Campbell-Brown, M. (1969). Genetics of lindane resistance in *Tribolium castaneum* (Herbst) (Coleoptera, Tenebrionidae). *Journal of Stored Products Research*, 5, 399-406.
- Champ, B.R., & Dyte, C.E. (1976). *Report of the FAO global survey of pesticide susceptibility of stored grain pests* (FAO Plant Production and Protection Series No. 5). Rome, Italy: FAO.
- Finney, D.J. (1971). Probit analysis (3rd ed). Cambridge, UK: Cambridge University Press.
- Haliscak, J.P., & Beeman, R.W. (1983). Status of malathion resistance in five genera of beetles infesting farm-stored corn, wheat and oats in the United States. *Journal of Economic Entomology*, 76, 717-722.
- Halliday, W.R., Arthur, F.H., & Zettler, J.L. (1988). Resistance status of red flour beetle (Coleoptera: Tenebrionidae) infesting stored peanuts in Southeastern United States. *Journal of Economic Entomology*, 81, 74-77.
- Harein, C.R., & Soderstrom, E.L. (1966). Coleoptera infesting stored products. In C.N. Smith (Ed.), *Insect colonization and mass production* (pp 241-257). New York, London: Academic Press.
- Kljajić, P., Andrić, G., & Perić, I. (2009). Impact of short-term heat pre-treatment at 50 °C on the toxicity of contact insecticides to adults of three *Sitophilus granarius* (L.) populations. *Journal of Stored Products Research*, 45, 272-278.
- Kljajić, P., & Perić, I. (2005). Rezistentnost skladišnih insekata prema insekticidima. *Pesticidi i fitomedicina*, 20, 9-28.
- Kljajić, P., & Perić, I. (2006). Susceptibility to contact insecticides of granary weevil *Sitophilus granarius* (L.) (Coleoptera: Curculionidae) originating from different locations in the former Yugoslavia. *Journal of Stored Products Research*, 42, 149-161.
- Kljajić, P., & Perić, I. (2007a). Altered susceptibility of granary weevil *Sitophilus granarius* (L.) (Coleoptera: Curculionidae) population to insecticides after selection with pirimiphos-methyl and deltamethrin. *Journal of Stored Products Research*, 43, 134-141.

- Kljajić, P., & Perić, I. (2007b). Effectiveness of wheat-applied contact insecticides against *Sitophilus granarius* (L.) originating from different populations. *Journal of Stored Products Research*, 43, 523-529.
- Loyd, C.J., & Ruczkowski, G.E. (1980). The cross-resistance to pyrethrins and eight synthetic pyrethroids, of an organophosphorus-resistant strain of the rust-red flour beetle, *Tribolium castaneum* (Herbst). *Pesticide Science*, 11, 331-340.
- Mahroof, R.M., & Hagstrum, D.W. (2012). Biology, behavior, and ecology of pests in processed commodities. In D. W. Hagstrum, T. W. Philips, & G. Cuperus, (Eds.), *Stored product protection* (pp. 33-44). Manhattan, KS: Kansas State University.
- Opit, G., Collins, P.J., & Daghli, G.J. (2012). Resistance management. In D. W. Hagstrum, T. W. Philips & G. Cuperus (Eds.), *Stored product protection* (pp 143-155). Manhattan, KS: Kansas State University.
- Raymond, M. (1985). Presentation d'un programme "Basic" d'analyse log-probit pour micro-ordinateur (Cahier ORSTOM, série). *Entomologie, Médecine et Parasitologie*, 22, 117-121.
- Rees, D.P. (2004). *Insects of stored products*. Collingwood, Australia: CSIRO Publishing.
- Speirs, J., & Zettler, L. (1969). Toxicity of three organophosphorus compounds and pyrethrins to malathion-resistant *Tribolium castaneum* (Herbst) (Coleoptera, Tenebrionidae). *Journal of Stored Products Research*, 4, 279-283.
- Subramanyam, B., & Hagstrum, D.W. (1996). Resistance measurement and management. In B. Subramanyam & D.W. Hagstrum (Eds.), *Integrated management of insects in stored products* (pp 331-397). New York, Basel, Hong Kong: Marcel Dekker.
- Subramanyam, B.H., Harein, P.K., & Cutkomp, L.K. (1989). Organophosphate resistance in adults of red flour beetle (Coleoptera: Tenebrionidae) and sawtoothed grain beetle (Coleoptera: Cucujidae) infesting barley stored on farms in Minnesota. *Journal of Economic Entomology*, 82, 989-995.
- Zettler, J.L. (1991). Pesticide resistance in *Tribolium castaneum* and *T. confusum* (Coleoptera: Tenebrionidae) from flour mills in the United States. *Journal of Economic Entomology*, 84, 763-767.
- Zettler, J.L., & Arthur, F.H. (1997). Dose-response tests on red flour beetle and confused flour beetle (Coleoptera: Tenebrionidae) collected from flour mills in the United States. *Journal of Economic Entomology*, 90, 1157-1162.

Toksičnost kontaktnih insekticida za populacije *Tribolium castaneum* (Herbst) posle selekcije pirimifos-metilom i deltametrimom

REZIME

Kestenjasti brašnar *Tribolium castaneum* (Herbst) je jedna od najznačajnijih štetnih vrsta insekata u skladištima i mlinovima u svetu. U suzbijanju ove i drugih skladišnih insekata više faktora utiče na efektivnost primenjenih kontaktnih insekticida od kojih je najznačajnija rezistentnost populacija skladišnih insekata. Sa ciljem praćenja i predviđanja razvoja rezistentnosti, namera u ovom radu je bila da se kod dve populacije *T. castaneum*, prikupljene iz podnog skladišta iz Nikinaca i silosa iz Jakova, mikroaplikacijom insekticida posle selekcije sa LD₈₀ pirimifos-metila i deltametrina utvrdi toksičnost dihlorvosu, malationa, hlorpirifos-metila, pirimifos-metila, deltametrina i bifentrina.

Rezultati istraživanja su pokazali da je za selekcionisanu populaciju iz Nikinaca hlorpirifos-metil najtoksičniji insekticid, a malation najmanje toksičan. Selekcija je značajno uticala na promenu faktora rezistentnosti (FR) na nivou LD₅₀ samo kod bifentrina sa 1,1 na 1,8 i kod deltametrina sa 0,9 na 2,2. Za selekcionisanu populaciju iz Jakova najtoksičniji insekticid je deltametrin, a najmanje toksičan malation. Selekcija pirimifos-metilom kod ove populacije nije značajno uticala na promenu toksičnosti insekticida, osim kod malationa, kod kojeg je na nivou LD₅₀ utvrđeno povećanje faktora rezistentnosti sa 26,0 na 29,8.

Ključne reči: Insekticidi; Toksičnost; Kestenjasti brašnar