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

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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 LD_{80} 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 LD_{50} 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 LD_{80} 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 LD_{50} 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 forcasting resistance evolution in various sampled populations, Brown and Payne (1988) proposed six insecticide selections in the laboratory with doses causing ≥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 LD_{50} of deltamethrin, the resistance ratios of that insecticide increased significantly, so that the initial 7.0 and 7.2 at the LD_{50} and LD_{95} levels increased to 32.1 and 51.9, respectively. In a Belgrade Port population of weevils, a single selection with the LD_{70} 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 LD_{80} 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 LD_{80} of pirimiphos-methyl, and once with the LD_{80} of deltamethrin, and 3) field population sampled in a Jakovo silo and selected once with the LD_{80} 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±1°C and relative humidity 60±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 LD_{80} (0.016 μg/insect) and once with deltametrin LD_{80} (0.014 μg/insect), while insects from the field population Jakovo (silo) were selected once with pirimiphos-methyl LD_{80} (0.013 μg/insect) and deltamethrin LD_{80} (0.013 μg/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 aplication. The beetles were immobilized before treatment by anaestethization for 30 seconds with CO_2 and then each adult was treated with 0.5 μL of each insecticide dissolved in acetone (6-8 concetrations) 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 LD$_{50}$, i.e. 40.6-fold more toxic than the weakest malathion, while pirimiphos-methyl, the most toxic insecticide at the LD$_{95}$, was 3300-fold more toxic than the weakest malathion. Table 1 shows insecticide toxicity data for Nikinci beetles before selection, and deltametrin was the most toxic insecticide at the LD$_{50}$, while chlorpyrifos-methyl was the most toxic at the LD$_{95}$, 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 LD$_{50}$ and 11 at LD$_{95}$.

Table 1. Insecticide toxicity to *T. castaneum* adults of the laboratory population and Nikinci field population (warehouse) selected with pirimiphos-methyl and deltamethrin LD$_{80}$

Insecticide	LD$_{50}$ (µg /insect) FL (0.05)	RR** (LD$_{50}$)	LD$_{95}$ (µg /insect) FL (0.05)	RR** (LD$_{95}$)	Slope of *ld-p* 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)				
	*Before selection**				
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 LD_{80} and it was 320.0- and 1302.8-fold more toxic at the LD_{50} and LD_{95} 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 LD_{95} (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 LD_{50}), and 1.8- and 2.3-fold (at LD_{95}) lower, respectively, after selection with pirimiphos-methyl LD_{80} 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 LD_{50} and LD_{95}, respectively) and deltamethrin, from 0.9 and 1.2 to 2.2 and 2.2 (at LD_{50} and LD_{95}, respectively). Nikinci beetles selected with deltamethrin LD_{80} 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 LD_{50} and LD_{95}, while it was 1.7- and 1.6-fold less toxic compared to laboratory beetles. At the LD_{50}, deltamethrin was 2.1-fold less toxic after selection, and 2.0-fold less toxic than it was to the laboratory population.

Considering the LD_{50} 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 LD_{95}, 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 LD_{50} level, and 6.1 at the LD_{95}. 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[#] LD_{80}

Insecticide	LD_{50} (µg/insect) FL (0.05)	RR** (LD_{50})	LD_{95} (µg/insect) FL (0.05)	RR** (LD_{95})	Slope of *ld-p* 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)				
	*Before selection**				
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
	After selection with pirimiphos-methyl LD_{80}				
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 LD_{80} could not be processed by probit analysis toxic and malthion the least toxic to *T. castaneum* adults from Jakovo at the LD_{50} before and after selection with pirimiphos-methyl LD_{80}. Selection of that population had no effect on insecticide toxicity, except of malathion, whose RRs increased from 26.0 to 29.8 (LD_{50}) and from 6.1 to 13.4 (LD_{95}), 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 LD_{50},, 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 LD_{95} 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 LD_{50}, while chlorpyrifos-methyl was the weakest. At the level of LD_{95}, 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 LD_{50} 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 LD_{50}, while pyrethroids, i.e. synergized pyrethrin and resmethrin, were 1.7- and 4.7-fold less toxic. On the other side, considering the LD_{99} 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 LD_{50} and LD_{95} 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 LD_{50} in both populations, while chlorpyrifos-methyl was the most toxic at the LD_{95} 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 LD_{70} 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 LD_{50}, and 18.8 after selection. Deltamethrin selection at the LD_{70} 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 LD_{80} 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 LD_{50} to the selected red flour beetles than before selection. In the Nikinci population, selection with deltamethrin LD_{80} caused also a significant fall in deltamethrin and bifenthrin toxicity as they were 1.7- and 3.1-fold less toxic at the LD_{95} than they were before selection. On the other side, selection with the LD_{80} of pirimiphos-methyl in the Jakovo population increased dichlorvos toxicity 1.4-fold and chlorpyrifos-methyl toxicity 1.3-fold (at LD_{50} and LD_{95}), 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.

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

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 LD_{80} pirimifos-metila i deltametrina utvrdi toksičnost dihlorvosa, 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 LD_{50} 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 LD_{50} utvrđeno povećanje faktora rezistentnosti sa 26,0 na 29,8.

Ključne reči: Insecticidi; Toksičnost; Kestenjasti brašnar