ORIGINAL ARTICLE

Susceptibility level of cabbage seed weevil (*Ceutorhynchus assimilis* Payk.) (Coleoptera: Curculionidae) to selected active ingredients of insecticides in Poland

Joanna Zamojska*, Daria Dworzańska, Paweł Węgorek

Department of Zoology, Institute of Plant Protection – National Research Institute, Władysława Węgorka 20, 60-318 Poznań, Poland

Vol. 58, No. 1: 73–82, 2018

DOI: 10.24425/119120

Received: September 26, 2017
Accepted: March 13, 2018

*Corresponding address:
j.zamojska@iorpib.poznan.pl

Abstract

Cabbage seed weevil (*Ceutorhynchus assimilis* Payk.) is one of the most important and dangerous pests of oilseed rape in Poland and in other European countries. In contrast to another important oilseed rape insect pest – pollen beetle (*Meligethes aeneus* F.), little is known about cabbage seed weevil susceptibility level to insecticide active ingredients. Therefore, the aim of this study was to determine the cabbage seed weevil susceptibility to active ingredients from different insecticide groups. Research, carried out in 2015, 2016 and 2017 revealed very high susceptibility of the pest to organophosphates and all pyrethroid active ingredients, except for tau-fluvalinate, lower susceptibility to thiacloprid and very high resistance to indoxacarb from oxadiazines. This information is a basic element for creating integrated pest management strategies for oilseed rape in Poland.

Key words: *Ceutorhynchus assimilis*, cabbage seed weevil, insecticide resistance, oilseed rape, pest management

Introduction

Cabbage seed weevil (*Ceutorhynchus assimilis* Payk.), together with pollen beetle (*Meligethes aeneus* F.), are the most important oilseed rape pests in Poland and other European countries. Each year the economic thresholds of cabbage seed weevil or pollen beetle or both species together are significantly exceeded. For this reason all of the oilseed rape grown in Poland undergoes chemical treatment against both pests every year. The most serious problem associated with chemical protection during spring in Poland lies in the partially simultaneous appearance of both pests in oilseed rape fields. Cabbage seed weevil appears in oilseed rape plants during the period of pollen beetle control and this creates an additional selection pressure enhancing the development of resistance of cabbage seed weevil (Ferguson *et al.* 2003; Jajor *et al.* 2008).

Observations carried out in the Institute of Plant Protection – National Research Institute in Poznań, showed significant differences in the susceptibility of both pests to the same insecticide active ingredients. While the pollen beetle resistance level to insecticides from all chemical groups has been well investigated and documented (Heimbach *et al.* 2006; Richardson 2008; Węgorek and Zamojska 2008; Węgorek *et al.* 2009; Philippou *et al.* 2010; Slater *et al.* 2011; Heimbach and Müller 2013), very little research has been done on cabbage seed weevil susceptibility levels (Zamojska *et al.* 2014; Zimmer *et al.* 2014). Research concerning cabbage seed weevil resistance levels, usually focus only on a few active ingredients (Zamojska and Węgorek 2014; Zamojska 2017).

In Poland there are 12 insecticide active ingredients recommended for cabbage seed weevil control: nine from the pyrethroid group, two from the neonicotinoid group and one organophosphate. Additionally, there are three organophosphate active ingredients, one oxadioazine substance and one substance from pyridine azometines, recommended for pollen beetle control which are often used in the presence of cabbage seed weevils in the fields. Monitoring of cabbage seed weevil susceptibility to these active ingredients has been carried out in the Institute of Plant Protection – National Research Institute for years. Considering the lack of information in the literature, we carried out a comprehensive study to describe the existing cabbage seed weevil susceptibility to insecticides from different chemical groups. The most important goal was to create a scientific baseline in order to estimate changes in the pest susceptibility levels in the future. The data is also a base for working out integrated pest management strategies to prevent resistance as the main goal.

Materials and Methods

In the experiments IRAC (Insecticide Resistance Action Committee) Susceptibility Test Method No. 7 was used. The method was thoroughly described earlier (Węgorek *et al.* 2011; Zamojska and Węgorek 2014). The presented research was conducted from 2015 to 2017 on cabbage seed weevils, collected from five oilseed rape fields, in which no insecticides had been used.

Tested cabbage seed weevil populations

- Winna Góra (central Poland),
- Nowy Tomyśl (central Poland),
- Szczecinek (northern Poland),
- Buziole (northern Poland),
- Bożków (southern Poland).

Insecticides (commercially available products)

Insecticide concentrations were calculated (ppm), assuming that 200 l of water would be used per hectare.

Pyrethroids

- alpha-cypermethrin (Fastac 100 EC with 100 g · l^{-1} of active ingredient), recommended concentration: 65.2 ppm;
- deltamethrin (Decis Mega 50 EW with 50 g · l^{-1} of active ingredient), recommended concentration: 36 ppm;
- lambda-cyhalothrin (Karate Zeon 050 CS with 50 g · l^{-1} of active ingredient), recommended concentration: 36 ppm;
- tau-fluvalinate (Mavrik Vita 240 EW with 240 g · l^{-1} of active ingredient), recommended concentration: 220.6 ppm;
- zeta-cypermethrin (Fury 100 EW with 100 g · l^{-1} of active ingredient), recommended concentration 48.5 ppm.

Oxadiazines

- indoxacarb (Avaunt 150 EC with 150 g · l^{-1} of active ingredient), recommended concentration: 134.2 ppm.

Neonicotinoids

- thiacloprid (Biscaya 240 OD with 240 g · l^{-1} of active ingredient), recommended concentration: 345.15 ppm.

Organophosphates

- chlorpyrifos (Pyrinex 480 EC with 480 g · l^{-1} of active ingredient), recommended concentration: 1776 ppm;
- malathion (Fyfanon 440 EW with 440 g · l^{-1} of active ingredient), recommended concentration: 4000 ppm.

Indoxacarb is not recommended for controlling cabbage seed weevils in Poland. It is recommended however for pollen beetle control and is often applied when cabbage seed weevils are also present in oilseed rape fields. For scientific reasons, in order to compare the susceptibility levels of the two species to active ingredients from different chemical groups, we adopted indoxacarb recommendations for pollen beetle in our research.

Resistance tests

The laboratory conditions as well as statistical calculations have already been described in the aforementioned publications. LC_{50} and LC_{95} calculations were based on the mortality of cabbage seed weevils at each dose and expressed in ppm.

The resistance coefficient (RC) was calculated as follows:

RC = LC_{95}/recommended field dose (assuming that the recommended field dose resulted in 100% mortality of insects at the registration time).

The following criteria were assumed to assess resistance:

RC ≤ 1	– lack of resistance,
RC = 1.1–2	– low resistance,
RC = 2.1–5	– medium resistance,
RC = 5.1–10	– high resistance,
RC > 10	– very high resistance.

For indoxacarb, because the insect mortality was almost always 0%, it was not possible to calculate LC values. Therefore, we also used the IRAC method to classify the insects' resistance according to their mortality at the recommended dose and at 20% of the recommended dose. Since the 20% dose was not used in our experiments, the method was modified by changing assessment at the 20% dose to assessment at the 25% dose (Table 1). In this way it was possible to compare indoxacarb and other active ingredients.

Table 1. Resistance according to IRAC* classification

Percentage of field dose	Mortality rate	Resistance
100	100	high susceptibility
25	100	
100	100	susceptibility
25	<100	
100	<100 – ≥90	medium resistance
100	<90 – ≥50	resistance
100	<50	high resistance

*Insecticide Resistance Action Committee

Results

The research (2015–2017) showed slight differences in cabbage seed weevil susceptibility to the same insecticides among populations from various regions of Poland. There were however great differences among susceptibility levels to different active ingredients (Tables 2–6).

In all years and in all populations, resistance coefficient values calculated for alpha-cypermethrin, zeta-cypermethrin, deltamethrin and lambda-cyhalothrin were definitely below one, which resulted in "lack of resistance" classification. Mortality of insects at recommended doses was always 100%, and according to IRAC classification the pest susceptibility level was classified as "susceptible" or "highly susceptible". The only pyrethroid active ingredient, to which the pest exhibited resistance was tau-fluvalinate. Resistance coefficient values calculated for this active ingredient ranged from 2.21 (medium resistance) to 27.41 (very high resistance) and mortality of insects at the recommended dose was between 30% and 85% (medium resistance to high resistance).

Susceptibility of the pest to the only neonicotinoid active ingredient – thiacloprid was classified as low resistance or the lack of resistance with RC (resistance classification) values below 1 or slightly above 1. Mortality of insects at the recommended dose was 100% or slightly below this value, which gave susceptibility or medium resistance in IRAC classification.

Very high resistance was recorded to indoxacarb. Maximum insect mortality at the recommended dose was 5%. It was impossible to calculate LC values because of the lack of differences between data.

No resistance was noted for chlorpyrifos. Mortality of insects at the recommended dose was always 100% and IRAC classification ranged from susceptible to highly susceptible. All calculated LC values were much below 1 (lack of resistance).

The other organophosphate active ingredient – malathion, according to RC classification did not reveal any resistance. However, IRAC classification ranged between susceptible and medium resistance because of 99% mortality of insects in two cases.

Discussion

This study presents great differences between cabbage seed weevil susceptibility levels to active ingredients from different chemical groups: very high susceptibility to pyrethroids, except for tau-fluvalinate, susceptibility to chlorpyrifos and lower susceptibility to malathion, susceptibility or low resistance to thiacloprid and finally, total resistance to indoxacarb.

High susceptibility of cabbage seed weevils to pyrethroids has already been reported (Heimbach and Müller 2013; Zamojska *et al.* 2014; Zimmer *et al.* 2014). Susceptibility of the pest to the majority of pyrethroid active ingredients presented in this study has not changed and the pest still exhibits very high mortality in the pyrethroid tests. The only exception was tau-fluvalinate. In 2011 and 2012 the pest susceptibility to tau-fluvalinate was very high and did not differ from the susceptibility to other pyrethroids (Zamojska *et al.* 2014). In this study, a considerable shift was observed. High resistance of cabbage seed weevils to tau-fluvalinate, which emerged in such a short time, is difficult to explain. However, when comparing the results to those obtained for pollen beetle (Zamojska *et al.* 2014), in which tau-fluvalinate is the most effective pyrethroid active ingredients against pollen beetles, it is worth noticing that what is usually effective in controlling pollen beetles, is not effective in controlling cabbage seed weevils and vice versa. It can be supposed that differences in molecular properties between tau-fluvalinate and other pyrethroids, resulting in differences in their affinity to the target site, may be responsible for this. Extensive research needs to be conducted to confirm such a supposition.

High resistance of pollen beetles to pyrethroids has been reported many times (Heimbach *et al.* 2006; Węgorek and Zamojska 2008; Richardson 2008; Węgorek *et al.* 2009; Slater *et al.* 2011). High susceptibility of cabbage seed weevils to pyrethroids was also shown by Zimmer *et al.* (2014) and Heimbach and Müller (2013). In those studies cabbage seed weevil and pollen beetle susceptibility to lambda-cyhalothrin was tested. The authors showed high susceptibility of cabbage seed weevils and high resistance of pollen beetles to this active ingredient. Heimbach and Müller (2013) reported just slight resistance of one, single cabbage seed weevil population in northern Germany.

Table 2. Susceptibility levels of cabbage seed weevils of Bożków population to tested insecticides expressed as LC_{50} and LC_{95} in ppm and RC (resistance classification)

Year	Active ingredient	LC_{50}	LC_{95}	RC	Percentage of mortality of insects at 100% of recommended dose	Percentage of mortality of insects at 25% of recommended dose	IRAC* classification
2015	alpha-cypermethrin	1.114 (0.860–1.361)	9.251	0.1418 (lack of resistance)	100	98	susceptibility
	zeta-cypermethrin	0.821 (0.721–0.912)	2.115	0.0436 (lack of resistance)	100	100	high susceptibility
	deltamethrin	0.114 (0.004–0.289)	1.404	0.039 (lack of resistance)	100	100	high susceptibility
	lambda-cyhalothrin	0.833 (0.742–0.925)	2.431	0.0674 (lack of resistance)	100	100	high susceptibility
	tau-fluvalinate	57.145 (18.748–41.077)	489.412	2.2185 (medium resistance)	85	50	resistance
	thiacloprid	20.073 (7.161–35.137)	421.154	1.2202 (low resistance)	100	75	susceptibility
	indoxacarb	–	–	–	3	0	high resistance
	chlorpyrifos	23.030 (18.916–27.235)	191.620	0.1079 (lack of resistance)	100	100	high susceptibility
	malathion	528.747 (465.242–585.596)	1,298.646	0.3247 (lack of resistance)	100	90	susceptibility
2016	alpha-cypermethrin	1.865 (1.637–2.101)	7.435	0.114 (lack of resistance)	100	100	high susceptibility
	zeta-cypermethrin	0.494 (0.329– 0.630)	2.287	0.0472 (lack of resistance)	100	100	high susceptibility
	deltamethrin	0.992 (0.791–1.218)	10.697	0.2971 (lack of resistance)	100	95	susceptibility
	lambda-cyhalothrin	0.543 (0.459–0.613)	1.513	0.0419 (lack of resistance)	100	100	high susceptibility
	tau-fluvalinate	126.950 (86.360–199.941)	1,382.200	6.2656 (high resistance)	55	30	resistance
	thiacloprid	44.692 (36.046–54.738)	295.800	0.8570 (lack of resistance)	99	70	medium resistance
	indoxacarb	–	–	–	5	0	high resistance
	chlorpyrifos	26.078 (20.889–31.520)	344.819	0.1942 (lack of resistance)	100	95	susceptibility
	malathion	720.880 (581.585–865.423)	1,752.872	0.4382 (lack of resistance)	99	80	medium resistance
2017	alpha-cypermethrin	1.525 (1.056–1.998)	11.543	0.1770 (lack of resistance)	100	99	susceptibility
	zeta-cypermethrin	0.274 (0.109–0.435)	2.157	0.0445 (lack of resistance)	100	100	high susceptibility
	deltamethrin	0.410 (0.287–0.521)	2.540	0.0706 (lack of resistance)	100	100	high susceptibility
	lambda-cyhalothrin	0.333 (0.203–0.436)	1.465	0.0406 (lack of resistance)	100	100	high susceptibility
	tau-fluvalinate	293.911 (161.378–1215.012)	5,813.200	26.3518 (very high resistance)	40	25	high resistance
	thiacloprid	39.817 (16.786–76.610)	334.690	0.9697 (lack of resistance)	100	55	susceptibility
	indoxacarb	–	–	–	5	0	high resistance
	chloropyrifos	7.026 (3.181–11.271)	137.555	0.0775 (lack of resistance)	100	100	high susceptibility
	malathion	555.554 (362.102–710.133)	1,490.145	0.3725 (lack of resistance)	100	90	susceptibility

*Insecticide Resistance Action Committee

Table 3. Susceptibility levels of cabbage seed weevils of Buziole population to tested insecticides expressed as LC_{50} and LC_{95} in ppm and RC (resistance classification)

Year	Active ingredient	LC_{50}	LC_{95}	RC	Percentage of mortality of insects at 100% of recommended dose	Percentage of mortality of insects at 25% of recommended dose	IRAC* classification
2015	alpha-cypermethrin	4.219 (2.911–5.852)	42.270	0.6481 (lack of resistance)	100	85	susceptibility
	zeta-cypermethrin	0.487 (0.320–0.632)	2.755	0.0568 (lack of resistance)	100	100	high susceptibility
	deltamethrin	0.574 (0.458–0.680)	2.939	0.0816 (lack of resistance)	100	100	high susceptibility
	lambda-cyhalothrin	0.339 (0.212–0.458)	2.836	0.0786 (lack of resistance)	100	100	high susceptibility
	tau-fluvalinate	57.918 (27.381–106.277)	2,006.700	9.0966 (high resistance)	65	60	resistance
	thiacloprid	10.410 (6.234–14.494)	122.946	0.3562 (lack of resistance)	100	90	susceptibility
	indoxacarb	–	–	–	5	0	high susceptibility
	chloropyrifos	13.234 (9.988–16.327)	101.299	0.0570 (lack of resistance)	100	100	high susceptibility
	malathion	729.094 (520.094–938.564)	2,212.141	0.5530 (lack of resistance)	100	75	susceptibility
2016	alpha-cypermethrin	2.121 (1.810–2.446)	13.459	0.2064 (lack of resistance)	100	95	susceptibility
	zeta-cypermethrin	0.537 (0.372–0.643)	1.390	0.0287 (lack of resistance)	100	100	high susceptibility
	deltamethrin	0.463 (0.252–0.700)	10.417	0.2894 (lack of resistance)	100	90	susceptibility
	lambda-cyhalothrin	0.607 (0.410–0.795)	4.962	0.1375 (lack of resistance)	100	100	high susceptibility
	tau-fluvalinate	165.460 (111.190–261.823)	709.328	3.2154 (medium resistance)	55	10	resistance
	thiacloprid	31.683 (22.356–42.086)	647.504	1.8760 (low resistance)	90	65	medium resistance
	indoxacarb	–	–	–	2	0	high resistance
	chloropyrifos	7.075 (2.233–12.097)	84.391	0.0475 (lack of resistance)	100	100	high susceptibility
	malathion	684.937 (628.211–744.022)	1,371.065	0.3428 (lack of resistance)	100	85	susceptibility
2017	alpha-cypermethrin	1.749 (1.254–2.261)	12.616	0.1934 (lack of resistance)	100	100	high susceptibility
	zeta-cypermethrin	0.612 (0.411–0.772)	2.536	0.0523 (lack of resistance)	100	100	high susceptibility
	deltamethrin	0.342 (0.297–0.384)	1.100	0.0306 (lack of resistance)	100	100	high susceptibility
	lambda-cyhalothrin	0.549 (0.440–0.647)	2.443	0.0677 (lack of resistance)	100	100	high susceptibility
	tau-fluvalinate	136.218 (98.337–200.688)	2,014.500	9.1319 (high resistance)	60	25	resistance
	thiacloprid	71.836 (43.847–115.701)	539.050	1.5618 (low resistance)	100	45	susceptibility
	indoxacarb	–	–	–	0	0	high resistance
	chloropyrifos	18.195 (13.231–23.143)	157.022	0.0884 (lack of resistance)	100	100	high susceptibility
	malathion	585.021 (476.418–686.818)	1,345.595	0.3364 (lack of resistance)	100	90	susceptibility

*Insecticide Resistance Action Committee

Table 4. Susceptibility levels of cabbage seed weevils of Nowy Tomyśl population to tested insecticides expressed as LC_{50} and LC_{95} in ppm and RC (resistance classification)

Year	Active ingredient	LC_{50}	LC_{95}	RC	Percentage of mortality of insects at 100% of recommended dose	Percentage of mortality of insects at 25% of recommended dose	IRAC* classification
2015	alpha-cypermethrin	1.128 (0.863–1.370)	5.228	0.0802 (lack of resistance)	100	100	high susceptibility
	zeta-cypermethrin	0.584 (0.438–0.700)	2.025	0.0418 (lack of resistance)	100	100	high susceptibility
	deltamethrin	0.472 (0.387–0.559)	4.047	0.1124 (lack of resistance)	100	98	susceptibility
	lambda-cyhalothrin	0.549 (0.440–0.647)	2.443	0.0677 (lack of resistance)	100	100	high susceptibility
	tau-fluvalinate	88.929 (56.759–142.072)	737.236	3.3420 (medium resistance)	70	40	resistance
	thiacloprid	2.975 (0.105–7.004)	37.375	0.1083 (lack of resistance)	100	95	susceptibility
	indoxakarb	–	–	–	0	0	high resistance
	chloropyrifos	19.027 (15.751–22.253)	113.627	0.0640 (lack of resistance)	100	100	high susceptibility
	malathion	719.050 (600.988–842.188)	1,661.017	0.4153 (lack of resistance)	100	85	susceptibility
2016	alpha-cypermethrin	0.864 (0.707–0.973)	1.939	0.0297 (lack of resistance)	100	100	high susceptibility
	zeta-cypermethrin	0.494 (0.329–0.630)	2.287	0.0472 (lack of resistance)	100	100	high susceptibility
	deltamethrin	0.781 (0.520–1.046)	8.061	0.2239 (lack of resistance)	100	99	susceptibility
	lambda-cyhalothrin	0.827 (0.709–0.945)	3.688	0.1022 (lack of resistance)	100	100	high susceptibility
	tau-fluvalinate	185.903 (111.643–418.026)	2,706.300	12.2679 (very high resistance)	50	10	resistance
	thiacloprid	29.287 (23.737–35.445)	145.478	0.4215 (lack of resistance)	100	90	susceptibility
	indoxacarb	–	–	–	0	0	high resistance
	chloropyrifos	16.838 (12.396–21.062)	100.374	0.0565 (lack of resistance)	100	100	high susceptibility
	malathion	526.348 (277.859–719.355)	719.355	0.1793 (lack of resistance)	99	85	medium resistance
2017	alpha-cypermethrin	0.753 (0.350– 1.136)	7.446	0.1142 (lack of resistance)	100	100	high susceptibility
	zeta-cypermethrin	0.837 (0.704–0.958)	3.096	0.0638 (lack of resistance)	100	100	high susceptibility
	deltamethrin	0.220 (0.162– 0.271)	1.068	0.0297 (lack of resistance)	100	100	high susceptibility
	lambda-cyhalothrin	0.843 (0.741–0.949)	2.075	0.0575 (lack of resistance)	100	100	high susceptibility
	tau-fluvalinate	273.661 (142.864–1469.150)	5,022.200	22.7660 (very high resistance)	50	20	resistance
	thiacloprid	46.605 (31.718–67.392)	169.794	0.4919 (lack of resistance)	99	85	medium resistance
	indoxacarb	–	–	–	0	0	high resistance
	chloropyrifos	24.102 (14.474–34.887)	594.302	0.3346 (lack of resistance)	100	90	susceptibility
	malathion	574.292 (528.192–621.595)	1,091.958	0.2730 (lack of resistance)	100	92	susceptibility

*Insecticide Resistance Action Committee

Table 5. Susceptibility levels of cabbage seed weevils of Szczecinek population to tested insecticides expressed as LC_{50} and LC_{95} in ppm and RC (resistance classification)

Year	Active ingredient	LC_{50}	LC_{95}	RC	Percentage of mortality of insects at 100% of recommended dose	Percentage of mortality of insects at 25% of recommended dose	IRAC* classification
2015	alpha-cypermethrin	1.192 (0.974–1.399)	6.386	0.0979 (lack of resistance)	100	100	high susceptibility
	zeta-cypermethrin	0.764 (0.623–0.891)	3.151	0.0650 (lack of resistance)	100	100	high susceptibility
	deltamethrin	0.221 (0.088–0.340)	1.310	0.0364 (lack of resistance)	100	100	high susceptibility
	lambda-cyhalothrin	0.468 (0.358–0.560)	1.928	0.0534 (lack of resistance)	100	100	high susceptibility
	tau-fluvalinate	66.664 (52.400–83.992)	3,151.200	14.2847 (very high resistance)	75	45	resistance
	thiacloprid	6.835 (2.014–11.770)	93.797	0.2718 (lack of resistance)	100	90	susceptibility
	indoxacarb	–	–	–	5	0	high resistance
	chloropyrifos	24.999 (21.739–28.349)	111.190	0.0626 (lack of resistance)	100	100	high susceptibility
	malathion	568.443 (423.655–712.609)	1,125.302	0.2813 (lack of resistance)	100	95	susceptibility
2016	alpha-cypermethrin	0.912 (0.521–1.278)	7.753	0.1189 (lack of resistance)	100	100	high susceptibility
	zeta-cypermethrin	0.550 (0.484–0.616)	1.811	0.0373 (lack of resistance)	100	100	high susceptibility
	deltamethrin	0.972 (0.839–1.117)	6.905	0.1918 (lack of resistance)	100	98	susceptibility
	lambda-cyhalothrin	1.871 (1.239–2.726)	7.166	0.1986 (lack of resistance)	100	100	high susceptibility
	tau-fluvalinate	293.934 (222.997–432.750)	2,334.800	10.5839 (very high resistance)	35	10	high resistance
	thiacloprid	47.792 (40.413–56.312)	195.444	0.5663 (lack of resistance)	98	80	medium resistance
	indoxacarb	–	–	–	0	0	high resistance
	chloropyrifos	17.085 (10.703–23.291)	177.782	0.1001 (lack of resistance)	100	99	susceptibility
	malathion	615.778 (392.825–825.126)	1,454.780	0.3637 (lack of resistance)	100	90	susceptibility
2017	alpha-cypermethrin	1.433 (1.133–1.725)	6.628	0.1016 (lack of resistance)	100	100	high susceptibility
	zeta-cypermethrin	0.672 (0.446–0.870)	3.739	0.0771 (lack of resistance)	100	100	high susceptibility
	deltamethrin	0.331 (0.268–0.392)	1.977	0.0549 (lack of resistance)	100	100	high susceptibility
	lambda-cyhalothrin	0.496 (0.390–0.585)	1.923	0.0533 (lack of resistance)	100	100	high susceptibility
	tau-fluvalinate	149.618 (112.063–207.876)	918.580	4.1640 (medium resistance)	65	20	resistance
	thiacloprid	–	–	–	100	5	susceptibility
	indoxacarb	–	–	–	0	0	high resistance
	chloropyrifos	35.754 (29.966–41.941)	346.972	0.1954 (lack of resistance)	100	95	susceptibility
	malathion	435.513 (345.696–509.234)	1,491.762	0.3729 (lack of resistance)	100	85	susceptibility

*Insecticide Resistance Action Committee

Table 6. Susceptibility levels of cabbage seed weevils of Winna Góra population to tested insecticides expressed as LC_{50} and LC_{95} in ppm and RC (resistance classification)

Year	Active ingredient	LC_{50}	LC_{95}	RC	Percentage of mortality of insects at 100% of recommended dose	Percentage of mortality of insects at 25% of recommended dose	IRAC* classification
2015	alpha-cypermethrin	1.587 (1.065–2.114)	10.189	0.1562 (lack of resistance)	100	99	susceptibility
	zeta-cypermethrin	2.450 (1.801–3.290)	7.202	0.1485 (lack of resistance)	100	100	high susceptibility
	deltamethrin	0.830 (0.649–1.043)	3.649	0.1014 (lack of resistance)	100	100	high susceptibility
	lambda-cyhalothrin	0.443 (0.329–0.541)	2.014	0.0558 (lack of resistance)	100	100	high susceptibility
	tau-fluvalinate	44.754 (24.275–70.359)	2,860.100	12.9651 (very high resistance)	70	55	resistance
	thiacloprid	11.041 (6.089–15.360)	65.466	0.1896 (lack of resistance)	100	100	high susceptibility
	indoxakarb	–	–	–	2	0	high resistance
	chloropyrifos	17.102 (14.657–19.422)	62.820	0.0354 (lack of resistance)	100	100	high susceptibility
	malathion	566.480 (521.846–612.346)	1,058.757	0.2647 (lack of resistance)	100	95	susceptibility
2016	alpha-cypermethrin	2.178 (1.646–2.749)	23.540	0.3609 (lack of resistance)	100	90	susceptibility
	zeta-cypermethrin	0.773 (0.536–0.983)	3.959	0.0816 (lack of resistance)	100	100	high susceptibility
	deltamethrin	1.821 (1.309–2.417)	19.888	0.5524 (lack of resistance)	100	85	susceptibility
	lambda-cyhalothrin	0.511 (0.413–0.593)	1.717	0.0476 (lack of resistance)	100	100	high susceptibility
	tau-fluvalinate	330.067 (241.236–534.419)	2,634.200	11.9411 (very high resistance)	30	10	high resistance
	thiacloprid	53.485 (40.599–69.461)	400.762	1.1611 (low resistance)	90	90	medium resistance
	indoxacarb	–	–	–	5	0	high resistance
	chloropyrifos	29.254 (23.277–35.694)	145.580	0.0820 (lack of resistance)	100	100	high susceptibility
	malathion	533.657 (500.588–570.696)	855.364	0.2138 (lack of resistance)	100	98	susceptibility
2017	alpha-cypermethrin	1.528 (1.016–2.044)	11.062	0.1696 (lack of resistance)	100	100	high susceptibility
	zeta-cypermethrin	2.450 (1.801–3.290)	7.202	0.1485 (lack of resistance)	100	100	high susceptibility
	deltamethrin	0.942 (0.681–1.261)	5.376	0.1493 (lack of resistance)	100	100	high susceptibility
	lambda-cyhalothrin	0.500 (0.196–0.770)	3.756	0.1041 (lack of resistance)	100	100	high susceptibility
	tau-fluvalinate	476.951 (277.776–1867.496)	6,048.400	27.4180 (very high resistance)	35	10	high resistance
	thiacloprid	48.845 (27.604– 82.267)	242.627	0.7030 (lack of resistance)	100	100	high susceptibility
	indoxakarb	–	–	–	5	0	high resistance
	chloropyrifos	93.252 (68.947–123.890)	1,026.368	0.5779 (lack of resistance)	100	90	susceptibility
	malathion	623.595 (582.291–672.417)	995.512	0.2489 (lack of resistance)	100	95	susceptibility

*Insecticide Resistance Action Committee

However, when comparing LC calculations for this single population and the susceptible ones as well as with calculations obtained for susceptible populations by Zimmer *et al.* (2014), no significant differences were observed. It is possible that the reported resistance was an exception and may have resulted from assessing cabbage seed weevil mortality after 5, not after 24 h.

Pyrethroids affect sodium channels in insects' nerve cells. The other substance affecting sodium channels but in the opposite way is indoxacarb. The obtained results showed very high cabbage seed weevil resistance to indoxacarb, while pollen beetles exhibited very high susceptibility to this active substance (Zamojska 2017). It can be assumed that the underlying cause of such great differences in both pests' susceptibility levels to pyrethroids and indoxacarb, is the construction of sodium channels (Zamojska and Węgorek 2014; Zamojska 2017).

Cabbage seed weevil susceptibility to thiacloprid presented in this study contradict results reported by Zimmer *et al.* (2014) and Heimbach and Müller (2013). In our study cabbage seed weevil susceptibility to thiacloprid was not as high as the one presented by the abovementioned authors. Moreover, we observed slight resistance. However, resistance of pollen beetles to thiacloprid was much higher (Zamojska *et al.* 2014).

In our research cabbage seed weevils exhibited high susceptibility to chlorpyrifos and lower susceptibility to malathion – both organophosphate active ingredients. Pollen beetle susceptibility to chlorpyrifos reported in earlier studies was also very high (Węgorek *et al.* 2009; Zamojska and Węgorek 2014). This may result from the negative cross resistance phenomenon (Różański 1992). Oxidative enzymes, responsible for pollen beetle resistance to pyrethroids (Philippou *et al.* 2010; Węgorek *et al.* 2011; Nauen *et al.* 2012), change chlorpyrifos to its oxi-metabolite, which is a much stronger toxin than chlorpyrifos alone and makes pollen beetles very highly susceptible to chlorpyrifos. In cabbage seed weevils, which are highly susceptible to pyrethroids, this phenomenon does not exist. Probably the affinity of chlorpyrifos to acetylcholinesterase is very high, however the explanation needs further research.

The presented results, apart from the variability of cabbage seed weevil susceptibility to different insecticide active ingredients, were also significantly different from the pollen beetle susceptibility to the same active ingredients. They also showed a considerable shift in the pest's susceptibility to tau-fluvalinate. All these factors make it necessary to constantly monitor both pests' susceptibility/resistance levels. Resistance prevention strategies should always consider the coincidence of both species in oilseed rape plantations as well as updated results of both pests' susceptibility levels to all insecticide active ingredients currently recommended in oilseed rape.

References

Ferguson A.W., Klukowski Z., Walcak B., Clark S.J., Mugglestone M.A., Perry J.N., Williams I.H. 2003. Spatial distribution of pests insects in oilseed rape: implications for integrated pest management. Agriculture, Ecosystems and Environment 95 (2–3): 509–521. DOI: https://doi.org/10.1016/S0167-8809(02)00200-1

Heimbach U., Müller A., Thieme T. 2006. First steps to analyse pyrethroid resistance of different oilseed rape pests in Germany: An extended abstract. IOBC Bulletin 29 (7): 131–134.

Heimbach U., Müller A. 2013. Incidence of pyrethroid-resistance oilseed rape pests in Germany. Pest Management Science 69 (2): 209–216. DOI: https://doi.org/10.1002/ps.3351

Jajor E., Korbas M., Kozłowski J., Mrówczyński M., Pruszyński G., Wachowiak H., Walczak F., Węgorek P. 2008. Poradnik sygnalizatora ochrony rzepaku. 1st ed. Institute of Plant Protection – National Research Institute, Poznań, Poland, 153 pp.

Nauen R., Zimmer C.T., Andrews M., Slater R., Bass C., Ekbom B., Gustafsson G., Hansen L.M., Kristensen M., Zebitz C.P.W., Wiliamson M.S. 2012. Target-site resistance to pyrethroids in European populations of pollen beetle, *Meligethes aeneus*. Pesticide Biochemistry and Physiology 103 (3): 173–180. DOI: https://doi.org/10.1016/j.pestbp.2012.04.012

Philippou D., Field L., Węgorek P., Zamojska J., Andrews M., Slater R., Moores G. 2010. Characterising metabolic resistance in pyrethroid – insensitive pollen beetle (*Meligethes aeneus* F.) from Poland and Switzerland. Pest Management Science 67 (2): 239–243. DOI: https://doi.org/10.1002/ps.2061

Richardson D.M. 2008. Summary of findings from a participant country pollen beetle questionnaire. OEPP/EPPO Bulletin 38 (1): 68–72.

Różański L. 1992. Przemiany Pestycydów w Organizmach Żywych i w Środowisku. PWRiL, Warszawa, 275 pp.

Slater R., Ellis S., Genay J-P., Heimbach U., Huart G., Sarazin M., Longhurst C., Müller A., Nauen R., Rison J.L., Robin F. 2011. Pyrethroid resistance monitoring in European populations of pollen beetle (*Meligethes* spp.): a coordinated approach through the Insecticide Resistance Action Committee (IRAC). Pest Managment Science 67 (6): 633–638. DOI: https://doi.org/10.1002/ps.2101

Węgorek P., Zamoyska J. 2008. Current status of resistance in pollen beetle (*Meligethes aeneus* F.) to selected active substances of insecticides in Poland. OEPP/EPPO Bulletin 38: 91–94.

Węgorek P., Mrówczyński M., Zamojska J. 2009. Resistance of pollen beetle (*Meligethes aeneus* F.) to selected active substances of insecticides in Poland. Journal of Plant Protection Research 49 (1): 119–127. DOI: https://doi.org/10.2478/v10045-009-0016-2

Węgorek P., Zamojska J., Mrówczyński M. 2011. High resistance to pyrethroid insecticides in Polish pollen beetle (M*eligethes aeneus* F.) – the role of oxidative metabolism. Phytoparasitica 39 (1): 43–49. DOI: https://doi.org/10.1007/s12600-010-0138-0

Zamojska J., Węgorek P., Olejarski P., Mrówczyński M. 2014. Zróżnicowanie poziomów wrażliwości szkodników rzepaku na te same substancje czynne insektycydów na przykładzie słodyszka rzepakowego i chowacza podobnika. [Differentiation of susceptibility levels of oilseed rape pests to the same active substances of insecticides on the example of pollen beetle and cabbage seed weevil]. Progress in Plant Protection 54 (2): 163–166. (in Polish)

Zamojska J., Węgorek P. 2014. Preliminary studies on the susceptibility level of the cabbage seed weevil (*Ceutorchynhus assimilis* Payk.) to acetamiprid and chlorpyrifos in Poland and resistance mechanisms of the pest to acetamiprid. Journal of Insect Science 14 (1): 265–270. DOI: https://doi.org/10.1093/jisesa/ieu127

Zamojska J. 2017. Differences in susceptibility of the cabbage seed weevil (*Ceutorchynhus assimilis* Payk.) (Coleoptera: Curculionidae) and the pollen beetle (*Meligethes aeneus* F.) (Coleoptera: Nitidulidae) to indoxacarb and deltamethrin and resistance mechanisms of the cabbage seed weevil to indoxacarb. Phytoparasitica 45 (3): 407–418. DOI: https://doi.org/10.1007/s12600-017-0588-8

Zimmer C.T., Köhler H., Nauen R. 2014. Baseilne susceptibility and insecticide resistance monitoring in European populations of *Meligethes aeneus* and *Ceutorhynchus assimilis* collected in winter oilseed rape. Entomologia Experimentalis et Applicata 150 (3): 279–288. DOI: https://doi.org/10.1111/eea.12162