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Negative Correlations between the Susceptibilities of Czech and Slovak Pollen Beetle Populations to Lambda-cyhalothrin and Chlorpyrifos-ethyl in 2014 and 2015

Marek SEIDENGLANZ[1], Jana POSLUŠNÁ[1], Pavel KOLAŘÍK[2], Jiří ROTREKL[2], Eva HRUDOVÁ[3], Pavel TÓTH[3], Jiří HAVEL[4], Eva PLACHKÁ[4], Ján TÁNCIK[5] and Kamil HUDEC[5]*

[1]Agritec Plant Research Ltd., Department of Plant Protection, Šumperk, Czech Republic; [2]Agriculture Research Ltd., Troubsko, Czech Republic; [3]Department of Crop Science, Breeding and Plant Medicine, Faculty of Agronomy, Mendel University in Brno, Brno, Czech Republic; [4]OSEVA Development and Research Ltd., Workplace at Opava, Opava, Czech Republic; [5]Department of Plant Protection, Faculty of Agrobiology and Food Resources, Slovak University of Agriculture in Nitra, Nitra, Slovak Republic

**Corresponding author: seidenglanz@agritec.cz*

Abstract

Seidenglanz M., Poslušná J., Kolařík P., Rotrekl J., Hrudová E., Tóth P., Havel J., Plachká E., Táncik J., Hudec K. (2017): Negative correlations between the susceptibilities of Czech and Slovak pollen beetle populations to lambda-cyhalothrin and chlorpyrifos-ethyl in 2014 and 2015. Plant Protect. Sci., 53: 108–117.

Sixty-five Czech *Meligethes* populations were tested against lambda-cyhalothrin and chlorpyrifos-ethyl in 2014. In 2015, totally sixty *Meligethes* populations, some of which sampled also in Slovakia, were tested against the two insecticides. Adult vial tests by IRAC (Insecticide Resistance Action Committee) were used for testing (No. 011 v. 3 for lambda-cyhalothrin and No. 025 for chlorpyrifos-ethyl). For each of the tested populations the LC_{50}, LC_{90}, and in 2015 also LC_{95} values were determined for both these insecticides. Correlation analyses were made with transformed (log10 transformation) LC values. No significant correlation was recorded between the LC_{50} values. Contrary to that, significant ($P < 0.05$) negative (*r* values for negative) correlations were recorded between the LC_{90} and LC_{95} values. Pyrethroid resistance in pollen beetle populations should indicate their slightly higher susceptibility to chlorpyrifos-ethyl.

Keywords: *Meligethes aeneus*; pyrethroid resistance; susceptibility to organophosphates; IRAC adult vial tests

Pollen beetle (*Meligethes aeneus* F., Coleoptrera: Nitidulidae) resistance to pyrethroids is a reality in Europe and will also affect future oilseed rape production (Zlof 2008). At present pyrethroid-resistant populations are most dominant in Western and Central Europe and are becoming established in the North and East (Slater *et al.* 2011). The development of this phenomenon and the progressive spread of pollen beetle populations resistant to pyrethroids through the various countries and regions of Europe have been described and documented in many papers (e.g. Derron *et al.* 2004; Heimbach 2005; Nauen 2005, 2007; Wegorek 2005; Heimbach & Műller 2006, 2013; Thieme *et al.* 2006, 2008; Wegorek *et*

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al. 2006, 2009; Ballanger *et al.* 2007; Djurberg & Gustafsson 2007; Heimbach *et al.* 2007; Eickermann *et al.* 2008; Tiilikainen & Hokkanen 2008; Philippou *et al.* 2011). Seidenglanz *et al.* (2015a, b) documented the spread of resistant populations in the Czech Republic (CZ) and also partly in Slovakia (SK) from 2009.

In contrast to the situation with pyrethroids, European pollen beetle populations seem to be fully susceptible to organophosphate chlorpyrifos-ethyl although the active ingredient has been used for control of insect pests in oilseed rape for many years, too. The applications are primarily aimed at stem weevils, but pollen beetles have been also frequently affected by these sprays. Although some information regarding the lower susceptibility (or resistance) of pollen beetles to some organophosphate insecticides has been published (and all of it originating from Poland: Lakocy 1967; Wegorek *et al.* 2009), their resistance to organophosphate chlorpyrifos-ethyl has not been documented anywhere in Europe (http://www.irac-online.org).

Although, most of the CZ and SK populations have in general shown high levels of resistance to lambda-cyhalothrin in recent years, the LC_{50}–LC_{95} values stated for the active ingredient have often been significantly different in individual populations (Seidenglanz *et al.* 2015a, b). Similarly, LC_{50}–LC_{95} values estimated for chlorpyrifos-ethyl in the same populations have not been uniform either (Seidenglanz *et al.* 2015c). Hence, some questions emerge: Are the populations with higher levels of resistance to esteric pyrethroid lambda-cyhalothrin less or more susceptible to organophosphate chlorpyrifos-ethyl? And how could the knowledge of this influence a future utilization of chlorpyrifos-ethyl in Insecticide Resistance Management programmes in oilseed rape?

MATERIAL AND METHODS

Sixty-five Czech *Meligethes* populations were tested against both lambda-cyhalothrin and chlorpyrifos-ethyl in 2014 (Figure 1). In 2015, totally sixty *Meligethes* populations were tested against the two insecticides. Some of the populations tested in 2015 were sampled in Slovakia (Figures 2A and B).

For testing, adult vial tests recommended for the purposes by the Insecticide Resistance Action Committee (IRAC) were used. For testing of pollen beetles susceptibility to lambda-cyhalothrin, test No. 011 v. 3 was used. Unlike the methodology, one more concentration (the highest) was used in our tests. So, the following concentrations were tested: 0 g a.i./ha (untreated control), 0.3, 1.5, and 7.5 g a.i./ha (recommended field rate in Europe), 37 and 112.5 g a.i./ha. For chlorpyrifos-ethyl test No. 025 was used. In contrast to the methodology, substantially more concentrations were used in our tests: 0 g a.i./ha (untreated control), 0.3, 0.9, 2.9, 30.0, 96.0, and 307.2 g a.i./ha (approximate field rate in CZ and SK). In all other aspects the IRAC laboratory methods described in detail on http://www.irac-online.org/teams/methods/ were fully respected. Lambda-cyhalothrin (analytical standard; batch number: HUD6A 3514) was obtained from Syngenta Czech Ltd., chlorpyrifos-ethyl (analytical standard; batch number: E2978-50-A) was obtained from Dow AgroSciences Ltd.

For each population the values of LC_{50}, LC_{90} (and in 2015 also of LC_{95}) were estimated for each of the two active ingredients in both years (2014 and 2015). The probit regression (Polo Plus v.2; LeOra Software, Berkeley, USA) was used for the calculations. That resulted in 65 and 60 pairs of simultaneously related LC values for correlation analyses in 2014 and 2015 respectively. The correlation analyses were made with log10 transformed LC values. The reason for log transformation of LC values was to achieve a normal distribution of data in the individual collections of LC values. Spearman's correlation coefficients were determined ($P < 0.05$) for the related pairs of LC values (lambda-cyhalothrin $LC_{50,90,95}$ × chlorpyrifos-ethyl $LC_{50,90,95}$). Calculations were made using Statistica software v. 10 (1984–2013).

RESULTS

Variability in lambda-cyhalothrin LC_{50} values estimated for *Meligethes* populations tested in 2014 and 2015 is illustrated in Tables 1 and 2. The variability in LC values estimated for chlorpyrifos-ethyl is not so high, but on the other side the number of populations with markedly higher LC values (more pronounced in LC_{90} compared to LC_{50} values) is not negligible (Tables 1 and 2). The results of the correlation analysis are listed in Table 3. Correlation coefficients showed negative value in all cases and in three cases the negative correlation proved to be significant ($P < 0.05$): between LC_{90} and LC_{95} values in both years (Figure 3). However, the nu-

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Table 1. Log dose probit mortality data obtained for lambda-cyhalothrin and chlorpyrofos-ethyl from an adult vial test (24 h) against *Meligethes aeneus* collected in Czech winter oilseed rape (year 2014): lethal concentrations for 50 and 90% of the beetles (LC_{50}, LC_{90}; g/ha) and corresponding 95% confidence limits (95% CL; g/ha)

Population No.	Chlorpyrifos-ethyl				Lambda-cyhalothrin			
	LC_{50}	95% CL	LC_{90}	95% CL (g/ha)	LC_{50}	95% CL	LC_{90}	95% CL
1	2.28	1.58–3.32	10.78	6.67–23.01	4.81	3.10–7.41	13.96	8.77–34.83
2	0.56	0.26–0.94	7.95	4.36–22.07	3.33	2.23–4.90	15.98	9.94–33.46
3	0.75	0.44–1.15	7.66	4.46–18.17	5.98	4.14–8.74	24.69	15.45–53.30
4	0.49	0.21–0.83	6.63	3.69–17.47	5.15	3.00–9.32	26.42	13.49–95.91
5	0.55	0.32–0.81	4.19	2.62–9.09	9.51	6.84–13.17	30.56	20.64–58.55
6	0.37	0.16–0.62	4.48	2.64–10.64	6.79	4.89–9.49	23.03	15.31–45.22
7	0.68	0.42–0.99	5.04	3.20–10.32	7.69	5.67–10.63	23.29	15.73–45.52
8	0.59	0.33–0.89	4.57	2.84–9.91	4.09	2.89–5.79	16.25	10.58–31.97
9	0.47	0.26–0.70	3.33	2.12–6.95	2.79	1.37–5.58	9.93	5.09–52.74
10	6.97	3.14–17.19	60.24	22.73–480.41	2.74	1.53–5.17	12.90	6.50–51.07
11	9.21	4.94–18.65	54.56	25.12–259.60	6.03	4.43–8.21	15.14	10.59–29.54
12	10.81	7.63–15.44	77.73	48.33–150.13	2.82	1.88–4.22	15.67	9.40–35.14
13	3.61	2.19–5.76	65.48	33.67–177.57	3.81	2.87–5.03	8.31	6.14–13.56
14	7.13	4.27–12.55	54.92	27.13–181.54	3.98	2.43–6.60	15.85	9.03–44.41
15	14.58	9.60–22.62	72.27	42.25–172.38	4.29	3.21–5.56	8.84	6.69–13.84
16	4.82	2.83–8.26	39.52	20.10–120.22	5.00	1.68–11.38	14.29	7.12–140.71
17	5.43	3.71–8.04	26.43	16.12–57.47	7.75	5.59–10.51	23.30	16.18–42.65
18	5.28	2.88–8.58	31.37	17.38–96.52	8.08	4.76–13.10	27.19	16.15–76.89
19	6.40	3.68–11.02	131.04	59.47–461.73	2.69	1.52–5.13	10.86	5.58–43.31
20	7.21	3.21–17.66	49.78	19.75–378.75	3.23	2.32–4.55	14.16	9.16–27.328
21	12.03	5.93–29.98	36.32	17.81–358.28	1.18	0.62–2.00	9.59	4.96–32.18
22	13.97	11.78–16.57	22.07	18.41–28.87	1.83	1.23–2.68	10.97	6.63–23.95
23	12.24	8.16–19.63	36.81	22.29–98.01	2.85	1.35–7.21	38.03	12.67–480.19
24	8.82	3.55–26.02	60.86	21.77–767.40	2.92	2.02–4.27	17.36	10.59–36.42
25	0.27	0.18–0.34	0.56	0.45–0.83	16.78	8.74–46.45	372.62	104.12–5584.96
26	0.25	0.12–0.34	0.61	0.45–1.38	25.62	14.13–69.23	323.72	104.28–3941.08
27	0.30	0.18–0.40	0.76	0.56–1.54	4.97	1.49–27.22	59.05	14.55–17375.13
28	7.69	3.11–21.05	46.71	17.91–547.20	11.74	5.76–32.32	83.82	30.92–1112.44
29	4.76	1.68–14.01	31.39	11.40–588.22	8.72	3.61–33.48	135.52	34.78–6879.05
30	0.57	0.23–1.04	2.00	1.08–17.88	11.07	5.76–26.77	101.75	37.83–931.99
31	1.21	1.01–1.44	2.02	1.67–2.71	63.21	25.53–514.92	1600.15	264.03–218 083.20
32	0.27	0.06–0.47	1.48	0.86–6.23	3.61	1.50–9.04	275.48	59.27–13196.44
33	0.94	0.76–1.15	1.79	1.43–2.56	5.40	2.48–13.60	31.79	12.84–320.95
34	14.49	12.22–17.15	22.34	18.73–28.75	28.88	16.48–74.57	279.74	98.47–2892.23
35	0.75	0.60–0.94	1.55	1.18–2.54	3.87	2.13–7.16	72.40	29.11–399.58
36	2.66	0.64–12.01	19.03	5.72–2183.73	30.29	13.42–180.58	410.27	93.64–39055.32
37	2.08	1.22–3.60	7.90	4.35–29.26	20.35	12.28–40.96	90.10	43.77–528.54
38	0.34	0.26–0.43	0.67	0.52–1.19	49.88	19.68–428.84	1949.57	276.25–446 894.75
40	8.22	5.81–11.86	25.90	16.87–54.18	35.65	19.98–104.45	328.09	109.86–4594.94
41	8.82	6.21–12.82	28.21	18.23–59.81	14.83	6.13–69.97	102.25	31.65–7223.22

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Table 1 to be continued

Population No.	Chlorpyrifos-ethyl				Lambda-cyhalothrin			
	LC_{50}	95% CL	LC_{90}	95% CL (g/ha)	LC_{50}	95% CL	LC_{90}	95% CL
43	6.28	3.57–11.40	43.93	21.68–145.96	3.37	1.67–7.08	10.60	5.46–63.71
44	8.28	5.51–12.91	37.54	22.02–90.20	5.87	4.17–8.14	13.52	9.43–30.20
45	6.52	3.83–11.76	52.15	25.20–177.14	3.16	1.89–5.43	12.32	6.84–38.20
46	0.71	0.52–0.93	2.06	1.51–3.38	2.59	1.01–5.82	28.31	10.78–300.94
47	5.97	2.52–9.67	22.97	13.50–93.00	7.82	3.98–16.72	44.92	20.03–276.47
48	0.89	0.65–1.14	2.21	1.67–3.51	5.65	3.34–10.20	73.43	31.86–333.96
49	0.45	0.28–0.62	1.88	1.30–3.48	4.62	1.80–8.97	30.12	14.00–235.54
51	1.10	0.76–1.49	3.20	2.24–6.04	9.82	4.14–31.26	198.41	51.02–12454.10
52	0.36	0.24–0.49	1.06	0.77–1.84	4.09	2.09–8.19	92.29	32.64–789.48
53	0.58	0.45–0.73	1.24	0.96–1.87	9.27	2.63–28.51	122.77	35.78–48905.99
54	0.50	0.36–0.64	1.47	1.09–2.41	1.02	0.19–2.34	13.96	5.55–157.61
55	0.58	0.43–0.75	1.70	1.24–2.79	5.75	2.94–10.75	65.78	27.98–425.14
56	0.45	0.31–0.60	1.42	1.04–2.38	16.15	11.67–21.78	29.09	21.58–45.57
57	0.30	0.16–0.42	1.11	0.78–2.08	9.95	5.40–14.94	24.25	15.93–79.20
58	0.30	0.16–0.43	1.18	0.82–2.21	7.34	2.82–33.00	48.04	15.21–2963.52
59	0.29	0.15–0.41	1.11	0.78–2.06	9.12	4.59–22.23	129.55	42.58–2073.38
60	0.32	0.19–0.45	1.22	0.87–2.15	7.67	5.27–11.42	28.10	17.46–64.84
61	0.37	0.22–0.51	1.31	0.92–2.39	9.93	6.66–13.49	23.76	17.00–44.91
64	0.26	0.13–0.38	1.08	0.74–2.10	2.00	0.74–4.22	13.30	5.91–89.76
65	0.37	0.21–0.52	1.39	0.97–2.58	5.68	3.31–9.50	21.55	12.23–68.56
69	0.60	0.42–0.81	1.19	0.87–2.17	6.30	3.93–9.69	29.60	17.50–76.20
70	0.65	0.48–0.84	1.52	1.14–2.40	5.09	2.58–11.28	35.72	14.82–306.24
71	0.56	0.41–0.73	1.18	0.89–1.91	9.49	3.61–50.66	85.38	22.96–7206.61
72	0.42	0.28–0.55	1.21	0.89–2.05	3.85	2.20–6.97	38.03	17.51–155.81

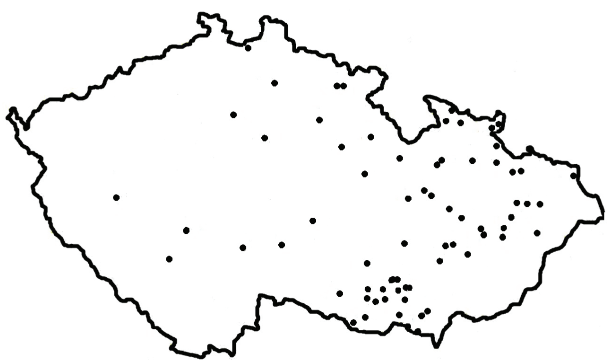

Figure 1. Sixty-five *Meligethes* populations were tested for both lambda-cyhalothrin and chlorpyrifos-ethyl simultaneously in 2014 (i.e. totally 65 pairs were subjected to correlation analysis)

merical values of the correlation coefficients (r) are relatively low even in the cases where the negative correlation proved to be significant. They vary from −0.374 to −0.425. This indicates a rather weak (or intermediate) correlation intensity. In addition, for LC_{50} values the negative correlations showed a very low intensity (r ranged from −0.037 to −0.115) and were insignificant ($P > 0.05$).

DISCUSSION

It is immediately obvious from the results that lower susceptibility to lambda-cyhalothrin does not mean a predisposition to lower susceptibility to chlorpyrifos-

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Table 2. Log dose probit mortality data obtained for chlorpyrofos-ethyl and lambda-cyhalothrin from an adult vial test (24 h) against *Meligethes aeneus* collected in Czech winter oilseed rape (year 2015): lethal concentrations for 50, 90, and 95% of the beetles (LC_{50}, LC_{90}, LC_{95}; g/ha) and corresponding 95% confidence limits (95% CL; g/ha)

Population No.	Chlorpyrifos-ethyl						Lambda-cyhalothrin					
	LC_{50}	95% CL	LC_{50}	95% CL	LC_{50}	95% CL	LC_{50}	95% CL	LC_{50}	95% CL	LC_{50}	95% CL
1	3.24	2.63–3.99	7.31	5.69–10.66	9.21	6.92–14.40	4.19	2.92–5.93	21.00	13.61–39.55	33.15	20.12–70.88
5	3.15	2.49–3.93	8.62	6.61–12.53	11.46	8.47–17.93	6.62	4.49–9.79	28.98	18.06–60.71	44.03	25.65–106.45
6	2.72	1.95–3.76	8.01	5.51–14.58	10.88	7.12–22.24	4.26	2.78–6.44	34.62	20.23–76.09	62.69	33.55–162.12
7	5.46	4.10–7.32	18.23	12.62–31.95	25.66	16.84–50.03	8.57	6.19–12.02	28.25	18.90–52.85	39.62	25.10–83.07
8	5.84	4.23–8.00	30.12	20.21–52.35	47.95	30.29–92.69	10.03	7.32–13.55	34.26	23.60–61.77	48.55	31.57–98.96
9	1.04	0.84–1.28	2.25	1.78–3.17	2.79	2.14–4.20	1.94	1.11–3.17	32.40	16.67–89.56	71.96	32.53–254.97
10	0.88	0.70–1.12	2.56	1.89–4.13	3.46	2.42–6.17	3.22	1.81–5.00	10.84	6.74–26.37	15.29	8.95–46.18
11	5.22	3.51–7.91	36.22	20.86–83.84	62.74	33.09–171.12	6.55	4.78–9.05	24.46	16.35–45.13	35.53	22.41–73.57
12	9.03	6.51–12.64	26.02	17.59–50.88	35.13	22.48–78.29	4.74	2.93–6.75	14.86	9.98–31.89	20.55	12.96–53.97
13	7.02	5.60–8.78	16.19	12.43–24.08	20.51	15.20–32.84	4.17	2.48–7.31	17.13	9.28–56.63	25.57	12.75–107.14
14	4.72	3.45–6.68	21.31	13.62–41.56	32.66	19.54–71.78	2.84	2.04–3.81	6.28	4.58–10.44	7.87	5.56–14.42
15	0.16	0.04–0.28	1.11	0.70–2.51	1.94	1.13–6.67	1.67	1.14–2.45	9.79	5.88–21.97	16.17	8.92–43.05
17	0.47	0.19–0.86	8.83	4.89–22.20	20.25	9.83–70.24	2.91	2.01–4.11	8.68	5.81–17.80	11.84	7.48–28.35
18	0.27	0.17–0.35	0.58	0.45–0.94	0.71	0.54–1.39	8.73	4.28–18.21	48.02	22.07–233.58	77.86	32.36–522.89
19	0.42	0.29–0.55	1.16	0.85–1.95	1.55	1.09–2.98	11.72	7.59–18.21	96.95	54.22–233.00	176.45	89.81–505.93
20	0.44	0.28–0.61	1.15	0.80–2.32	1.52	1.00–3.66	17.2	11.48–25.36	97.35	59.34–210.07	159.13	89.54–403.93
21	0.40	0.27–0.52	1.15	0.84–1.95	1.55	1.08–3.05	1.63	0.89–2.71	21.91	11.40–61.61	45.77	21.04–166.94
22	0.35	0.22–0.48	1.13	0.81–1.98	1.57	1.07–3.27	7.99	4.22–14.23	48.72	25.20–154.65	81.35	38.37–331.64
23	0.29	0.14–0.41	1.08	0.75–2.03	1.58	1.04–3.71	5.11	1.97–12.34	120.3	38.37–1409.91	294.6	75.76–6348.69
24	0.28	0.13–0.42	1.23	0.84–2.36	1.87	1.19–4.59	8.47	5.83–12.21	37.34	23.91–73.223	56.88	34.16–127.09
25	0.22	0.08–0.36	1.09	0.73–2.19	1.72	1.08–4.65	5.41	2.31–12.81	39.97	16.01–287.75	70.49	24.92–773.52
26	0.36	0.21–0.51	1.36	0.96–2.46	1.97	1.30–4.32	9.08	5.03–17.38	27.50	14.97–121.09	37.65	19.09–224.33
27	0.35	0.21–0.49	1.28	0.90–2.31	1.84	1.22–4.01	11.23	2.95–50.35	138.80	35.57–16764.68	283.13	58.93–106305.79
28	0.34	0.20–0.47	1.19	0.85–2.15	1.70	1.14–3.70	11.11	3.98–32.54	152.50	46.68–3173.46	320.48	80.73–13509.38
29	0.33	0.17–0.47	1.42	0.97–2.69	2.15	1.38–5.09	7.64	4.31–13.29	74.70	37.02–235.53	142.60	63.06–574.54
30	1.82	1.33–2.50	7.61	5.06–14.11	11.41	7.12–23.90	6.71	4.36–10.13	46.02	27.33–99.94	79.43	43.45–202.41
31	0.51	0.39–0.64	1.18	0.90–1.85	1.50	1.10–2.59	5.47	3.68–8.02	27.77	17.40–55.80	44.02	25.75–101.56
32	0.33	0.20–0.45	1.11	0.79–2.00	1.57	1.06–3.39	14.50	3.74–63.10	77.23	25.46–5363.57	124.08	36.38–22765.96
33	0.64	0.48–0.81	1.67	1.25–2.64	2.20	1.58–3.84	2.70	1.10–5.71	39.07	15.56–238.64	83.32	28.23–802.03
34	0.31	0.17–0.44	1.10	0.77–2.01	1.57	1.05–3.52	6.81	2.64–18.55	61.43	21.65–688.35	114.6	34.89–2161.47
35	0.19	0.07–0.29	0.90	0.63–1.59	1.41	0.93–3.23	3.65	1.02–12.58	32.10	10.00–960.98	59.44	15.89–3947.15
36	0.25	0.12–0.37	0.91	0.66–1.53	1.31	0.91–2.68	1.60	0.29–4.64	30.30	9.07–942.65	69.73	16.85–6081.30
37	0.21	0.08–0.34	0.97	0.65–1.79	1.49	0.96–3.58	6.56	2.81–14.66	45.84	19.43–257.29	79.530	30.18–645.85
38	0.24	0.11–0.37	1.01	0.69–1.82	1.51	0.99–3.44	4.09	2.30–7.26	24.52	12.64–76.45	40.73	19.16–159.34
39	0.35	0.23–0.48	1.15	0.82–2.08	1.61	1.08–3.46	11.14	5.93–19.83	71.64	36.63–237.16	121.42	56.24–523.01
40	0.59	0.38–0.90	1.10	0.75–2.85	1.31	0.86–4.15	21.54	10.86–32.63	93.65	57.56–279.40	142.04	79.36–597.63
41	0.60	0.49–0.71	1.22	0.98–1.71	1.49	1.16–2.25	4.47	2.05–9.63	26.87	11.90–155.02	44.67	17.72–377.26
43	0.51	0.41–0.62	1.19	0.93–1.75	1.51	1.14–2.42	3.36	0.71–11.85	46.07	12.78–2133.56	96.78	22.22–12164.41
44	0.57	0.47–0.70	1.26	0.99–1.86	1.58	1.19–2.50	8.51	2.74–27.01	36.68	14.27–712.77	55.50	19.69–2084.55
45	0.80	0.65–0.96	1.54	1.24–2.21	1.86	1.45–2.88	8.98	4.98–14.96	45.37	25.55–119.53	71.82	37.45–233.68
46	0.85	0.68–1.07	2.38	1.77–3.71	3.18	2.26–5.40	10.25	6.63–15.72	28.40	18.03–65.08	37.91	22.79–101.02

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Table 2 to be continued

Population No.	Chlorpyrifos-ethyl						Lambda-cyhalothrin					
	LC_{50}	95% CL	LC_{50}	95% CL	LC_{50}	95% CL	LC_{50}	95% CL	LC_{50}	95% CL	LC_{50}	95% CL
50	0.36	0.26–0.47	1.01	0.76–1.62	1.34	0.96–2.45	7.25	4.96–10.59	22.72	14.82–45.64	31.41	19.42–71.86
51	0.28	0.15–0.40	1.01	0.72–1.80	1.45	0.98–3.20	3.31	1.88–5.63	22.64	11.92–67.08	39.05	18.64–146.12
52	1.48	1.16–1.92	4.67	3.35–7.74	6.47	4.41–11.84	7.26	5.02–10.67	28.58	18.07–58.16	42.14	25.05–97.57
53	3.15	2.57–3.81	6.02	4.82–8.76	7.24	5.61–11.39	8.00	2.68–14.34	37.01	19.71–209.59	57.13	27.55–564.77
54	0.56	0.43–0.69	1.22	0.95–1.82	1.53	1.15–2.49	7.31	4.68–11.35	25.74	15.72–60.87	36.78	21.07–103.09
56	1.95	1.03–3.11	7.06	4.21–22.95	10.17	5.60–45.48	2.90	2.09–3.91	14.04	9.66–23.75	21.95	14.23–41.49
57	0.59	0.46–0.75	1.43	1.08–2.25	1.83	1.33–3.19	5.67	3.22–8.51	22.57	13.95–61.40	33.39	18.97–119.84
58	1.04	0.83–1.30	2.43	1.87–3.60	3.09	2.29–4.92	2.02	1.26–3.10	17.19	9.89–40.10	31.55	16.47–89.26
59	0.81	0.63–1.04	2.24	1.66–3.59	2.98	2.10–5.28	3.22	2.07–4.95	24.06	13.89–54.94	42.54	22.49–115.21
60	0.46	0.34–0.59	1.17	0.88–1.90	1.53	1.09–2.77	2.95	1.82–4.50	14.51	8.85–31.79	22.80	12.94–59.22
61	0.22	0.08–0.34	0.91	0.62–1.78	1.38	0.89–3.60	4.82	2.40–8.65	46.08	22.61–161.00	87.42	38.03–414.22
62	3.24	2.28–4.33	9.71	6.83–18.51	13.26	8.77–29.71	0.58	0.21–1.11	7.18	3.53–26.38	14.65	6.30–81.22
63	0.44	0.33–0.56	1.08	0.83–1.66	1.39	1.02–2.38	1.81	1.03–3.00	16.07	8.51–45.00	29.87	14.22–105.75
64	0.80	0.55–1.10	4.23	2.75–8.42	6.79	4.07–15.96	1.94	1.01–3.32	27.66	14.32–76.16	58.76	26.99–208.15
67	0.34	0.20–0.47	1.27	0.89–2.31	1.85	1.22–4.10	0.25	0.06–0.51	3.05	1.60–9.82	6.16	2.88–31.62
68	1.59	1.23–2.08	4.50	3.22–7.71	6.03	4.11–11.53	3.18	1.93–4.89	20.96	12.26–50.07	35.77	19.09–105.07
74	0.25	0.12–0.36	0.90	0.65–1.53	1.30	0.89–2.74	6.36	3.41–11.33	37.68	19.61–114.94	62.39	29.75–240.02
75	0.28	0.14–0.41	1.06	0.76–1.90	1.55	1.04–3.42	4.36	2.61–7.21	32.18	17.20–88.29	56.73	27.51–191.62

ethyl in *Meligethes* populations. Furthermore, the results presented here even indicate higher susceptibility to chlorpyrifos-ethyl in the populations with higher levels of resistance to lambda-cyhalothrin.

Some other studies also demonstrate that lower susceptibility (or resistance) of pollen beetles to esteric pyrethroids does not increase the risk of lower susceptibility of the pest to chlorpyrifos-ethyl at the same time (Philippou *et al.* 2011; Slater *et al.* 2011; Zimmer & Nauen 2011, also on http://www.irac-online.org). Wegorek and Zamoyska (2008) even described and documented a strong negative cross resistance between pyrethroids and chlorpyrifos-ethyl in pollen beetle populations in Poland (also in Wegorek *et al.* 2009). The higher susceptibility to chlorpyrifos-ethyl in the pyrethroid resistant populations probably relates to the prevailing mechanism of resistance detected in populations from Central Europe (Philippou *et al.* 2011). That is metabolic resistance which is based mainly on enhanced oxi-

(**A**)

(**B**)

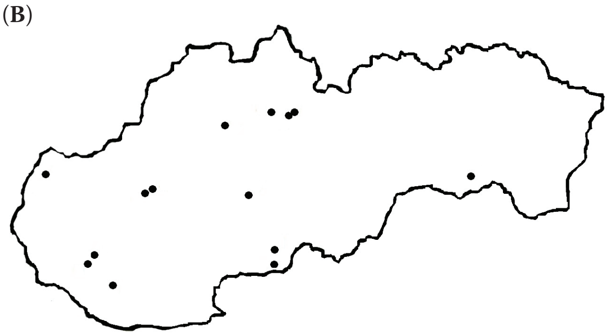

Figure 2. Sixty *Meligethes* populations were tested for both lambda-cyhalothrin and chlorpyrifos-ethyl simultaneously in 2015. Most of them were sampled in the Czech Republic (**A**), some in the Slovak Republic (**B**) (i.e. totally 60 pairs were subjected to correlation analysis)

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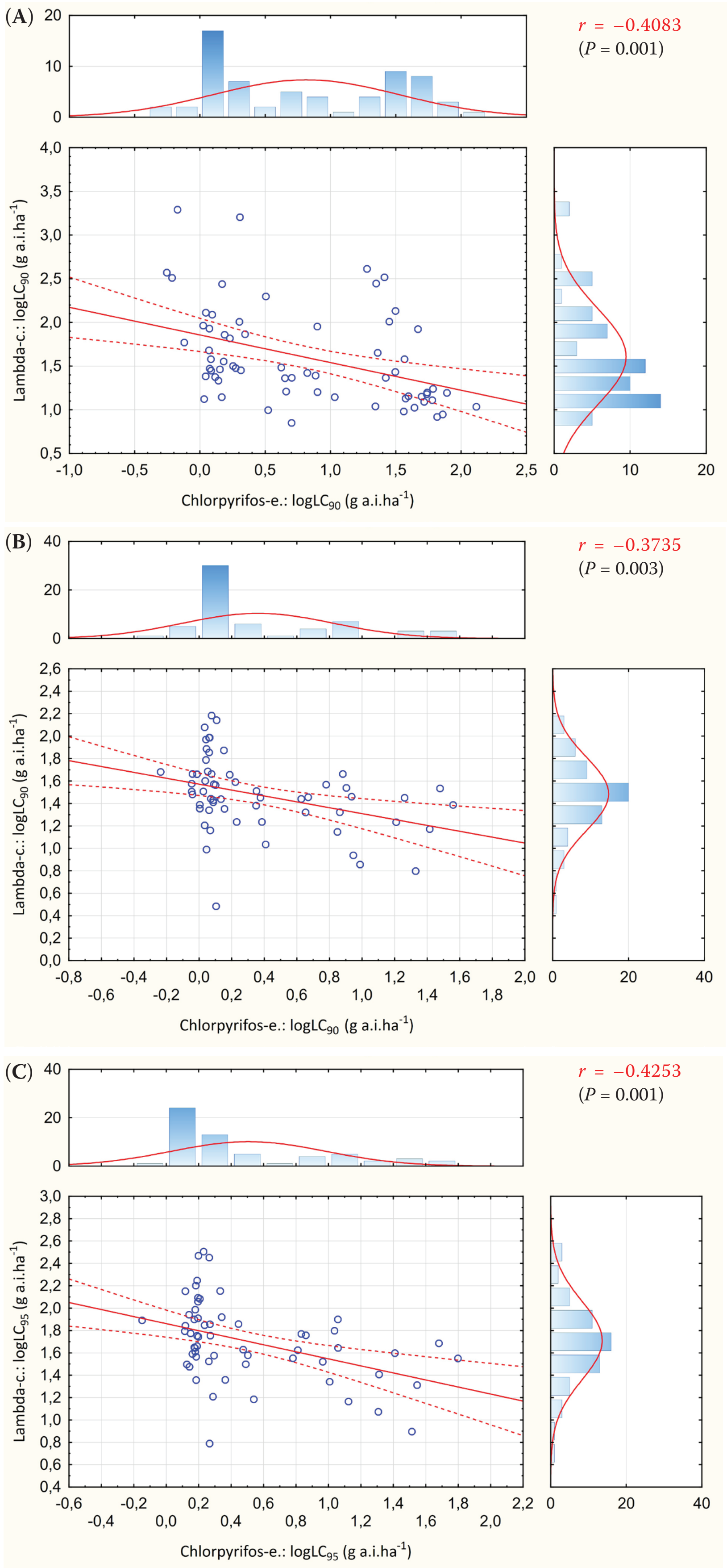

Figure 3. Significant negative correlation between Log LC_{90} values estimated for lambda-cyhalothrin and chlorpyrifos-ethyl in the Czech pollen beetle collection tested in 2014 (**A**), in Czech (CZ) + Slovak (SK) pollen beetle collections tested in 2015 (**B**), and Log LC_{95} values estimated for lambda-cyhalothrin and chlorpyrifos-ethyl in the CZ + SK pollen beetle collections tested in 2015 (**C**)

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Table 3. Results of correlation analyses between lethal concentrations (LC) values estimated for the two active ingredients when compared simultaneously: lambda-cyhalothrin vs chlorpyrifos-ethyl. In 2014 only Czech pollen beetle populations were tested. Both Czech and Slovak populations are included in tests from 2015

Year	No. of analysed pairs of LC values	Correlation analysis between values	Correlation coefficient r^2	Probability value (P)
2014	65	[1]Log LC_{50}	–0.115	0.364
		[1]Log LC_{90}	**–0.408**	**0.001**
2015	60	[1]Log LC_{50}	–0.037	0.780
		[1]Log LC_{90}	**–0.374**	**0.003**
		[1]Log LC_{95}	**–0.425**	0.001

[1]Log transformation of the LC values estimated for the both active ingredients was made before the analysis; [2]bolded values indicate the cases where a significant negative correlation (P < 0.05) was recorded between the analyzed LC values

dative metabolism in less susceptible individuals (Obrepalska-Steplowska *et al.* 2006; Slater & Nauen 2007). Oxidative enzymes (cytochrome P_{450} monooxygenases) play the most important role in detoxification of pyrethroids in insect bodies (Moores *et al.* 2009; Philippou *et al.* 2011). High synergy of pyrethroid insecticides with piperonyl butoxid (the inhibitor of oxidative enzymes) and low synergy with carbaryl and tributyltin acetate (Wegorek *et al.* 2007) confirm the above statements. However, whereas with pyrethroids the oxidation results in detoxification of the active ingredients, oxidative desulfuration of chlorpyrifos-ethyl leads to the creation of a much more toxic metabolite. A possible predisposition to higher susceptibility to chlorpyrifos-ethyl in *Meligethes* populations with lower susceptibility to esteric pyrethroids (higher activity of oxidative enzymes) should be explained by the findings. The results presented in this paper contribute to the conclusions made previously by the Polish authors (Wegorek & Zamoyska 2008; Wegorek *et al.* 2009) and support the possibility of existence of negative cross-resistance between chlorpyrifos-ethyl and lambda-cyhalothrin (esteric pyrethroids). However, contrary to these studies (Wegorek & Zamoyska 2008; Wegorek *et al.* 2009), results presented herein indicate a rather weak intensity of the negative cross resistance. According to Wegorek *et al.* (2009) the negative cross resistance with esteric pyrthroids is also a feature of the other organophosphorous active substances with the exception of phosalone.

The finding that higher levels of resistance against esteric pyrethroids can be a feature of higher susceptibility to some organophosphates seems to be very important at this time, especially with regard to the fact that the first possible signs of a decrease in the pollen beetle's susceptibility to neonicotinoids in populations from Central Europe start to be observable. Wegorek and Zamoyska (2008) and Wegorek *et al.* (2009) recorded a wide occurrence of populations resistant to acetamiprid in Poland, Seidenglanz *et al.* (2015c) described significant shifts in pollen beetle susceptibility to thiacloprid among CZ populations during 2011–2015. However, their results are in strong contrast to those published by Zimmer and Nauen (2011) and Zimmer *et al.* (2014). According to them no resistance of European *Meligethes* populations to thiacloprid and no shifting to lower susceptibility of the populations to thiacloprid have been recorded yet. But from some studies it is obvious that oxidative enzymes (cytochrome P_{450} monooxygenases) can play a similar role in resistance to neonicotinoids as in the case of pyrethroids (Jones *et al.* 2011). That means the mutual relationships between the susceptibility of pollen beetles to pyrethroids and neonicotinoids (thiacloprid, acetamiprid) can by completely different from the ones for pyrethroids and organophosphates. That could bring very unpleasant consequences for oilseed rape growers because the neonicotinoides are perceived as the only real and available alternative for pyrethroids in Insecticide Resistance Management programmes in contemporary practice. According to Seidenglanz *et al.* (2015d) there appeared significant positive correlations between LC values stated for lambda-cyhalothrin and thiacloprid in the CZ pollen beetle populations tested simultaneously to the two insecticides over recent years (2011–2015). But the results should be interpreted very carefully again because they are in strong contrast with the study of Zimmer and Nauen (2011), who observed no trends of cross-resistance between lambda-cyhalothrin and thiacloprid. In their study even the populations classified as highly resistant to pyrethroids did not show any lower susceptibility to thiacloprid, suggesting a complete lack of cross-resistance.

With regard to the results of this paper, chlorpyrifos-ethyl seems to be a suitable insecticide for use in Insecticide Resistance Management programmes in oilseed rape crops. On the other hand, it is not an adequate alternative for pyrtehroids in oilseed rape crops because of its toxicity for honey bees and their

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relatives (Rehman *et al.* 2012). Its usage is limited to the period before the start of flowering. The same is true for two other (relatively) new insecticides recommended for use against pollen beetles in oilseed rape in Europe: indoxacarb and pymetrozine. In conventional practice a great portion of sprays against pollen beetles is made at the beginning of flowering, because growers often need to postpone or repeat them (Kazda & Baranyk 2011). In fact the neonicotinoids, thiacloprid and acetamiprid (due to their low toxicity for honey bees) remain the only acceptable alternative for pyrethroids in most European countries at this time. If some indications of cross-resistance between pyrethroids (lambda-cyhalothrin) and thiacloprid (Seidenglanz *et al.* 2015d) would be confirmed, the situation could become serious for conventional growers.

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