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Control of cabbage stem weevil and pollen beetle with one insecticide application

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Abstract: Over the course of three years (2016–2018), the effects of insecticides on stem-mining weevils [(*Ceutorhynchus pallidactylus* (Marsham, 1802), *Ceutorhynchus napi* (Gyllenhal, 1837)] were assessed under field conditions. The dates for spraying were determined on the basis of the recorded percentages of weevil females carrying mature eggs in their ovaries (timing I: the first females with mature eggs present in yellow water traps; timing II: more than 50% of the females with mature eggs present). Delaying the first spring insecticide application till timing II made it possible to combine the control of the stem weevil along with the control of the pollen beetle, *Brassicogethes aeneus* (Fabricius, 1775). However, the poor effectiveness of the tested insecticides on the stem-mining weevils, regardless of the date they were sprayed, indicates it is impossible to successfully control the insect pests with one insecticide application during the seasons with prolonged egg-laying periods.

Keywords: *Ceutorhynchus pallidactylus*; *Ceutorhynchus napi*; *Brassicogethes aeneus*; chlorpyrifos-ethyl; cypermethrin; etofenprox

In Europe, the cabbage stem weevil *Ceutorhynchus pallidactylus* (Marsham, 1802) (Coleoptera: Curculionidae), the rape stem weevil *Ceutorhynchus napi* (Gyllenhal, 1837) (Coleoptera: Curculionidae) and the pollen beetle *Brassicogethes aeneus* (Fabricius, 1775) (Coleoptera: Nitidulidae) are some of the most important insect pests of the winter oilseed rape.

On the basis of the field trials firstly made and published by Büchs (1998), it can be expected that about 9 to 11 days after recording the first flight activity of *C. napi* adults, approximately 50% of the females present in the crop will be able to lay eggs. *C. pallidactylus* shows certain differences in behaviour during migration from its hibernation sites to the winter oilseed rape crop. Experiments have confirmed that cabbage stem weevil males and females leave their hibernation sites at distinctly different times (Büchs 1998; Klukowski 2006). The females leave the hibernation sites with some delay and, as a consequence, they migrate to crops later than the males. At the beginning of their flight activity, the proportion of males in yellow water traps is markedly higher. The ratios of male to female *C. pallidactylus* adults appearing in the yellow water traps gradually equalise over time (Büchs 1998; Klukowski 2006; Seidenglanz et al. 2009). This limits the possibilities of copulation at the beginning of the immigration into the crops. So, there may be a higher proportion of *C. pallidactylus* females carrying mature eggs recorded in the crops markedly later than in the case of *C. napi.* According to Büchs (1998), it can be expected that about 28 days after the first recorded flight activity of *C. pallidactylus* adults in winter oilseed rape crops, approximately 50% of the females will be able to lay eggs. So, the process can take almost three weeks longer in the *C. pallidactylus* than in the

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C. napi populations. The time when higher proportions of *C. pallidactylus* females carrying mature eggs are present in crops often coincides with the first higher abundances of pollen beetles in the crop.

This raises the question of whether it would be possible to control stem-mining weevils and pollen beetles with just one insecticidal application, at least in places or seasons in which *C. napi* are less abundant.

The recommended control threshold for both of the mentioned stem-mining weevils varies among European growing regions from 9 to 30 adult weevils per yellow water trap within three consecutive days (Alford et al. 2003; Williams 2010; Eickermann et al. 2015). In the Czech Republic, a threshold of ≥ 9 adult specimens of *C. napi* per yellow trap within 3 days is used as the common standard. The same threshold is used for *C. pallidactylus* in the Czech Republic (Kocourek et al. 2018).

Farmers in the Czech Republic regularly apply three consecutive insecticidal sprays every spring: the first one against stem weevils in March/April and the second spray primarily to combat the pollen beetle during the second half of April or at the beginning of May. Unfortunately, farmers, and even advisors, mostly perceive stem weevils and pollen beetles as two, temporally separate problems which need different approaches to be successfully controlled (Büchs 1998; Kocourek et al. 2018; Seidenglanz et al. 2019). The third insecticide is usually applied during the second half of the flowering stage (the second half of May–beginning of June in the Czech Republic) and is targeted especially at pod midges [(*Dasineura brassicae* Winnertz, 1853)].

In this study, we compared the effects of two types of insecticides with a different residual activity and modes of action on reducing the levels of stem damage induced by the weevil's larvae. The insecticides were applied on two different dates determined according to the results of dissecting the *C. pallidactylus* and *C. napi* females caught in yellow water traps. At the same time, we assessed the effects of the same treatments on reducing the damage induced by the pollen beetle. The aim was to answer the question of whether stem-mining weevils and pollen beetles could be controlled with one spring application or whether an additional (second) spring application is needed.

MATERIAL AND METHODS

Small plot (25 m^2 per plot) trials containing 10 treatments in four repetitions were established in 2016, 2017 and 2018. The trials were located near the town of Šumperk (North-eastern part of the Czech Republic, 49.9815608N, 16.9999725E) in all three years. The winter oilseed rape variety Orava was used. Three yellow water traps were placed in an untreated crop immediately adjacent to the trial (acreage: 80 × 80 m = 6 400 m^2) every year. The aim of the monitoring was to record the total length of the flight activity (the date the adults were first recorded in the traps – the date the adults were last recorded in the traps) and the total length of the egg-laying period (the date of the first record of females with mature eggs in their ovaries in the traps – the date of the last record of such females in the traps) for *C. pallidactylus* as well as *C. napi*. The traps were placed in the crop in mid-February and emptied twice a week up until the end of June. According to a previous study carried out in the same region (Seidenglanz et al. 2009) the numbers of the *C. pallidactylus* adults could be expected to predominate markedly over the *C. napi* adults in the yellow water traps in spring. For each of the sampling dates, the following traits were determined: the number of adults of *C. pallidactylus* and *C. napi*, the number of males and females of the two species and the number of females with mature eggs in their ovaries. The ovaries were dissected and assessed in accordance with Büchs 1998 and Seidenglanz et al. 2009, 2013. In addition, the pollen beetles caught in yellow water traps were counted on the same dates as the stem weevils. The results were used to determine the following characteristics of the *B. aeneus* flight activity: the total length of the flight activity and the maximum flight activity in the season.

On the basis of the results of monitoring the stem weevil flight activity and the dissection of the females, two different dates for the first spring applications of the insecticides (Table 1) were determined: timing I and II. Timing I was the date when the first weevil females with mature eggs in their ovaries were recorded in the yellow water traps. Timing II was the date when the majority (more than 50%) of the females caught in the traps had mature eggs in their ovaries. The interval between the two dates was at least 7 days (Table S1 in ESM).

The first spring application was either followed (treatment (tr.) 6–9) or not followed (tr. 2–5) by a second (additional) spring application made at timing III (Table 1 and S1).

For more abundances of pollen beetle adults present on main racemes were counted in plots sprayed

Table 1. The list of treatments compared in 2016, 2017 and 2018

Treatment no.	Treatment description1	1st spring application (timing I or II)	2nd spring application (timing III)
1	untreated control I	–	–
2	25 g cypermethrin/ha (57.5 g etofenprox/ha)	I	
3	25 g cypermethrin/ha (57.5 g etofenprox/ha)	II	
4	30 g cypermethrin/ha + 300 g chlorpyrifos-ethyl/ha	I	
5	30 g cypermethrin/ha + 300 g chlorpyrifos-ethyl/ha	II	
6	25 g cypermethrin/ha (57.5 g etofenprox/ha)	I	75 g pymetrozine/ha in 2016, 2017; 25.5 g indoxacarb/ha in 2018
7	25 g cypermethrin/ha (57.5 g etofenprox/ha)	II	
8	30 g cypermethrin/ha + 300 g chlorpyrifos-ethyl/ha	I	
9	30 g cypermethrin/ha + 300 g chlorpyrifos-ethyl/ha	II	
10	untreated control II	–	

[1] pyrethroid in treatment 2, 3, 6 and 7 – cypermethrin applied in 2016 and 2017, etofenprox in 2018

with pyrethroids at timing II (tr. 3 and 7) after the application. Twenty plants per plot were examined two times per week. According to the results of this monitoring, the dates for the second spring application (timing III) were determined. The second sprays were applied when the abundance of the pollen beetles in treatments 3 and 7 reached the CZ (Czech) thresholds: 1 adult per plant at BBCH 51–53 or 3 adults per plant at BBCH 55–57(59). The interval between the later first spring application (timing II) and the second spring application (timing III) was at least 7 days. Despite the fact the abundance of the pollen beetles did not achieve the threshold in 2018, the application (timing III) was made 7 days after the later first (timing II) spring application (Table S1).

The pollen beetle adults were also counted in the control plots (tr. 1 and 10) to find out when the abundance of the beetles first exceeded the CZ threshold values and how the occurrences of the insect pest developed in the crop over time (Table S1).

The level of the damage to the plants caused by the weevil larvae and the pollen beetle adults were assessed when the crop achieved its green maturity stage (14. 6. 2016, 9. 6. 2017, 11. 6. 2018). On these dates, only a negligible number of weevil larvae (only *C. pallidactylus*) were still present in the plants, the majority of the larvae having already left the plants to pupate in the soil. So, it is possible to consider the level of stem damage caused by the larvae recorded on these dates to be final. At the same time, it was already possible to count the final numbers of the green pods on the main racemes. From every plot, 20 plants (80 per treatment) were randomly selected and the following was determined for each plant: (*i*) the length of the damage to the inner tissues caused by the *C. pallidactylus* and *C. napi* larvae per stem (= the length of the damaged part of the stem) and (*ii*) the number of pods per the main raceme (this is probably the place where the pollen beetles most frequently damage the buds and may cause a decrease in the pod numbers).

When the crop had achieved full maturity, the individual plots were separately harvested with a small plot harvester (Wintersteiger Quantum, Germany). The seeds obtained from the individual plots were then (after being cleaned and dried) weighed and the recorded data was statistically analysed.

The primary data were analysed using Statistica software (version 12). One-way ANOVA (tests were performed for all the sets of data). The differences between the means were evaluated using Tukey's HSD test ($P < 0.05$). For the ANOVA, the homogeneity of variance was previously checked using the Bartlett test ($P < 0.05$). When comparing the stem damage caused by the *C. pallidactylus* and *C. napi* larvae, the level of effectiveness for the individual treatments was expressed using Abbott's formula (1925). The untreated control I (tr. 1) served as a base for these comparisons (effectiveness of tr. 1 = 0.00%). Similarly, the degree to which the second spring application (timing III) contributed to increasing the effects of the first spray on the stem weevils was stated for the related pairs of treatments: tr. 2 and tr. 6; tr. 3 and tr. 7; tr. 4 and tr. 8; tr. 5 and tr. 9). The first application was identical in each of the five pairs. The treatments were sprayed only once (tr. 2, 3, 4 and 5) served as the base (their effectiveness = 0.00) for the related treatments which were sprayed twice (tr. 6, 7, 8 and 9).

RESULTS

The number of *C. napi* adults caught in the yellow water traps did not exceed the mean value of the three specimens per trap per three days in 2016 and 2017. Only in 2018, the numbers were somewhat higher. Contrary to that, the number of *C. pallidactylus* adults exceeded the common thresholds in each of the three years. The mean number of males of the species recorded in the yellow water traps at the time of maximal flight activity varied between the individual seasons much more than the mean number of females (Table S2). So, the interannual variabilities in the number of *C. pallidactylus* adults caught in the traps were particularly caused by the differences in the counts of the males (on average 35.67–116.33 males per trap at the maximum flight activity). Interannually, the difference in the counts of the females did not vary so much (on average 9–12.33 *C. pallidactylus* females per trap at the maximum flight activity), (Table S2).

The first *C. napi* adults appeared in the yellow water traps markedly earlier than the first *C. pallidactylus* migrants in one season only (2017). In two seasons (2016, 2018), the total lengths of flight activity periods of *C. pallidactylus* were markedly longer than the flight periods of *C. napi* at the locality. In all three years, the flight activity of *C. pallidactylus* lasted at least until the end of May (Table S2).

In the three seasons, the first females with mature eggs of both *C. pallidactylus* and *C. napi* appeared in the traps at practically the same time, i.e., from the end of March (28.3 in 2017) to the first third of April (9.4 in 2018). So, in each of the three seasons, the females of both species began laying eggs at the same time. This means that the oviposition period of *C. napi* did not start earlier than those of *C. pallidactylus*. The oviposition period estimated for *C. pallidactylus* was markedly longer than that for *C. napi* in all three years, especially in 2016 (2.5 months vs. 1 month) and 2018 (2 months vs. 1 month). In all three years, the females of *C. pallidactylus* were still able to lay eggs throughout May. In 2018, they prolonged the oviposition up till June, (Table S2).

In 2016 and 2017, the first pollen beetles appeared in the yellow water traps relatively early (30.3, BBCH 31). In 2018, the first migrants arrived on April 6th (BBCH 31–50). There were markedly higher numbers of pollen beetles in the yellow water traps in 2016 and 2017 than in 2018. In 2016, the abundances rapidly increased after April 10th. The threshold (1–3 pollen beetles per inflorescence according to the growth stage, Kocourek et al. 2018) in the control plots (tr. 1, 10) was exceeded on April 12th, while the maximal flight activity was recorded on April 15th. Relatively high levels of infestation (approximately 4–7 adults per inflorescence on plots of tr. 1, 10) remained till the end of April, i.e., between the growth stages BBCH 53 and BBCH 59. In the plots of tr. 3 and 7, the pollen beetle abundances reached the threshold on April 19th and the timing III sprays were applied on April 22nd (Tables S1 and S2). Even though the mean number of beetles caught in the yellow water traps at the time of maximal flight activity were similar in 2016 and 2017 (on average, 300 adults/trap/3 days in 2016; on average, 259 adults/trap/3 days in 2017) the situation was substantially different in the two seasons. Due to the unusually cold weather in the course of April 2017, the abundance and flight activity of the pollen beetles remained low during the most susceptible period for the oilseed rape (between BBCH 33 and BBCH 59). The abundance increased slightly above the threshold in the control plots (tr. 1, 10) and even tr. 3 and 7 also for the first time at the beginning of May (BBCH 57–59). The timing III sprays were applied on May 3rd (Table S1), but the highest numbers of adults on the inflorescences and the highest level of the flight activity were recorded even later, when the plants were already in flower (15. 5. 2017, BBCH 63–65). So, the pollen beetles were more dangerous in 2016 than in 2017 (Table S2). During 2018, the numbers of pollen beetles present on the racemes (counted on tr. 1) did not exceed the Czech thresholds at all. So, the timing III sprays were applied on April 26th, 7 days after the timing II application. The number of adults caught in the yellow water traps were also low in that season (Table S2).

The mean final levels of the stem damage recorded in both control treatments (tr. 1 and 10) were high in all three years. The mean length of the damaged parts of the stems ranged between 21.40 cm and 32.53 cm in the control treatments. Even though the differences in the level of damage between the control and sprayed treatments was, in many cases, significant in the three seasons, overall, the level of damage recorded on the sprayed plots were relatively high, especially in 2018 (on average, 17.05–31.35 cm). The level of effectiveness expressed for the sprayed treatments was relatively low. In 2016, the season in which the insecticides showed the best efficacy in general, a total of six sprayed treatments showed a level of effectiveness above 50%. In 2017, the level of effectiveness exceeded 50% in just two cases: tr. 7 and 9. In 2018, none of the insecticide applications achieved a 50% level of effectiveness (Table S3).

In 2016, all the insecticidal applications (tr. 2–9) resulted in significantly less stem damage in comparison with both control treatments (tr. 1 and 10). Cypermethrin (tr. 2, 3, 6 and 7) showed better results when the spraying was made at timing I (1. 4. 2016: on average 7.69% of females with mature eggs in the traps) regardless of whether the second application (at timing III) followed or not. Contrary to that, spraying with cypermethrin + chlorpyrifos-ethyl (tr. 4, 5, 8 and 9) showed better results when the application was made at timing II (8. 4. 2016: on average, 50.45% of females with mature eggs present in the traps). In 2017, there were fewer differences in the level of damage among the individual treatments compared with the results recorded in 2016. Cypermethrin applied at timing II (8. 4. 2017: on average, 86.73% of females with mature eggs in the traps) did not cause a significant decrease in the level of stem damage when the additional second spray was absent (tr. 3). When the second application was added, the stem damage decreased substantially and the difference between the treatment (tr. 7) and the untreated controls (tr. 1 and 10) proved to be significant. In 2018, only treatments 5, 7 and 9 showed significantly lower levels of stem damage in comparison with both controls. Etofenprox was more suitable for spraying at timing I (12. 4. 2018: on average, 26.67% of females with mature eggs), when the second spring application was absent. A combination of cypermethrin and chlorpyrifos-ethyl applied at timing II (19.4.2018: on average, 73.91% of females with mature eggs) proved to be more effective than the same combination of insecticides applied at timing I (Table S3).

In all three years, the applications made only at timing III (tr. 10) had a negligible effect on reducing the level of the stem damage caused by the larvae. On the other hand, the insecticides applied at timing III markedly contributed to improving the effectiveness of some sprays. The contributions of pymetrozine (2016, 2017) or indoxacarb (2018) applied as a second spring spray to increase the effects of the first spray on the stem weevils were markedly higher in the case of the treatments with the first application made at timing II, tr. 7, 9. Regarding these two treatments, in 2016, pymetrozine increased the effect of cypermethrin + chlorpyrifos-ethyl more than the effect of cypermethrin alone, but, in 2017 and 2018, the second spring spray increased the effects of the pyrethroids applied solo (cypermethrin in 2017, etofenprox in 2018) more than the effects of cypermethrin and chlorpyrifos-ethyl combined (Table S3).

In 2016, the plants from tr. 9 had significantly more pods on their main racemes in comparison with all the other treatments. The plants from tr. 7 and 9 had significantly more pods on the main racemes than the plants from tr. 1 in 2017. In 2018, the plants from tr. 5, 7 and 9 had significantly more pods, not only in comparison with tr. 1 but also in comparison with tr. 2, 6 and 8 (Table 2).

Table 2. The differences in the mean numbers of the pods on the main racemes in 2016–2018

Tr.	Number of pods on main racemes								
	2016			2017			2018		
	mean no. of pods/main raceme^1	SD	95 % CL (cm)	mean no. of pods/raceme^1	SD	95 % CL (cm)	mean no. of pods/main raceme^1	SD	95 % CL (cm)
1	28.70^{a}	10.37	26.39–31.01	36.20^{a}	11.50	33.64–38.76	27.37^{a}	8.27	25.23–29.50
2	29.34^{a}	7.42	27.69–30.99	39.05^{ab}	10.13	36.80–41.30	28.48^{a}	8.58	26.27–30.10
3	27.53^{a}	7.18	25.93–29.12	38.48^{ab}	11.20	35.98–40.97	31.52^{abc}	8.05	29.44–33.60
4	27.86^{a}	5.47	26.65–29.08	40.75^{ab}	10.71	38.37–43.13	31.58^{abc}	8.22	29.46–33.71
5	30.15^{a}	7.66	28.45–31.85	38.75^{ab}	10.18	36.48–41.02	34.32^{c}	8.38	32.15–36.48
6	29.39^{a}	5.98	28.06–30.72	39.11^{ab}	10.84	36.70–41.52	29.28^{ab}	10.50	26.57–31.99
7	30.78^{a}	7.85	29.03–32.52	41.09^{b}	9.54	38.97–43.21	35.45^{c}	10.85	32.65–38.25
8	30.24^{a}	7.49	28.57–31.90	38.96^{ab}	10.56	36.61–41.31	28.70^{a}	9.52	26.24–31.16
9	38.19^{b}	8.88	36.21–40.16	41.58^{b}	10.76	39.18–43.97	33.82^{bc}	9.01	31.49–36.15
10	30.15^{a}	7.86	28.40–31.90	37.43^{ab}	11.20	34.93–39.92	31.32^{abc}	10.21	28.68–33.95
S.A.	$F = 11.976$; $P < 0.001$			$F = 1.9131$; $P < 0.05$			$F = 5.2556$; $P < 0.001$		

Tr. – treatment; S.A. – statistical analysis;^{1} the mean values placed in the same column – significantly different when they are marked with different letters; CL – confidence limit

Table 3. The mean plot yields (plot area = 25 m^2) recorded in the trials in 2016–2018

Tr.	2016			2017			2018		
	mean plot yld. of seeds (kg/25 m^2)^{1,2}	SD	95 % CL (cm)	mean plot yld. of seeds (kg/25 m^2)^{1,2}	SD	95 % CL (cm)	mean plot yld. of seeds (kg/25 m^2)^{1,2}	SD	95 % CL (cm)
1	9.87^{a}	0.25	9.48–10.27	9.38^{a}	0.27	8.95–9.81	9.22^{a}	0.55	8.35–10.08
2	10.11^{ab}	0.27	9.68–10.54	9.58^{ab}	0.21	9.25–9.91	9.81^{a}	0.25	9.41–10.20
3	10.28^{ab}	0.25	9.88–10.68	9.93^{abc}	0.18	9.64–10.22	9.92^{ab}	0.29	9.46–10.37
4	10.33^{ab}	0.25	9.94–10.73	10.35^{cde}	0.25	9.96–10.75	9.83^{a}	0.15	9.58–10.07
5	11.86^{d}	0.21	11.53–12.18	11.20^{ef}	0.31	10.71–11.69	10.94^{c}	0.09	10.78–11.09
6	10.83^{bc}	0.23	10.46–11.20	10.73^{def}	0.24	10.35–11.11	10.70^{c}	0.13	10.49–10.91
7	10.45^{ab}	0.23	10.09–10.82	10.26^{bcd}	0.27	9.84–10.68	10.00^{a}	0.14	9.77–10.23
8	11.58^{cd}	0.32	11.08–12.08	10.93^{def}	0.36	10.35–11.50	10.82^{c}	0.14	10.60–11.03
9	12.13^{d}	0.30	11.66–12.60	11.48^{f}	0.32	10.97–11.98	11.16^{c}	0.21	10.82–11.50
10	10.32^{ab}	0.26	9.91–10.73	10.12^{abcd}	0.34	9.58–10.65	10.66^{bc}	0.19	10.36–10.96
S.A.	$F = 37.956$; $P < 0.001$			$F = 24.140$; $P < 0.001$			$F = 26.068$; $P < 0.001$		

Tr. – treatment; S.A. – statistical analysis; [1]the plot yields (seeds after cleaning) were corrected according to the moisture content recorded at the date of weighing (standardised at a moisture content of 8 %); [2]the mean values placed in the same column – significantly different when they are marked with different letters; CL – confidence limit

In 2016, tr. 5, 6, 8 and 9 showed significantly higher seed yields than tr. 1. The yields from tr. 5, 8 and 9 were also significantly higher than the yield from tr. 10 in that season. In 2017, tr. 4–9 had a significantly higher yield in comparison with tr. 1. Tr. 5 and 9 also showed a significantly higher yield than tr. 10 that year. In 2018, tr. 5, 6, 8, 9 and tr. 10 had a significantly higher yield than tr. 1, but none of the compared treatments showed a higher yield than tr. 10 (Table 3).

DISCUSSION

In all three seasons, stem-mining weevils were serious insect pests at the site (*C. pallidactylus*, in all three years, *C. napi* in 2018), while pollen beetles were more dangerous in 2016 only.

According to Büchs (1998), the first egg-carrying females should appear in the yellow water traps, on average, 15 days after the first flight activity is recorded. Our results were similar: the first females with mature eggs in their ovaries appeared in the yellow water traps 18 days after the first recorded flight activity in 2016, 12 days after in 2017 and 11 days after in 2018 (Table S2).

It should take about 28 days after the first recorded flight activity of C. pallidactylus before approximately 50% of its females with mature eggs are present in the crops (Büchs 1998). Our results (2016–2018) indicate the period should be somewhat shorter for *C. pallidactylus*. In 2016, it was 25 days, in 2017 it was about 20 days and in 2018 it was only 17 days (Table S2).

In the cases where only one spring application was used (sprayed at timing I or II; no spray at timing III), pyrethroids were shown to be more effective on the stem weevils when they were applied earlier, i.e., at the time when the first females of *C. pallidactylus* with mature eggs in their ovaries were recorded in the traps. This tendency proved to be obvious in all three years, even if a statistically significant difference in the levels of damage between tr. 2 and 3 occurred in 2016 only. The effectiveness of the delayed pyrethroid spray, i.e., applied at a time when the majority of females present in traps already had mature eggs in their ovaries, did not achieve 50% effectiveness in any of the three years. It is somewhat surprising that the delayed application of pyrethroid showed lesser effects than the earlier application. It is possible that the delayed application was made at the time when a certain number of eggs had already been laid in the plants. So, the pyrethroids applied at that time effectively controlled neither the first females which were able to lay eggs nor the females which laid eggs markedly later due to the shorter persistence of the applied insecticides. The pyrethroids applied on the first date effectively protected the plants at least against the first females. So, when a farmer plans to use pyrethroids against stem weevils and does not know if another insecticide application will follow later, he should not delay spraying too long and should follow recent common practice. In this study, timing I was delayed 3–9 days after the time when the threshold flight activity (≥ 9 adults per trap within 3 days) was recorded in the three years.

In contrast, the combination of organophosphate + pyrethroid (tr. 4 and 5) showed better results when applied later. The difference between the effects of organophosphate + pyrethroid applied either at timing I or at timing II became more noticeable in the seasons with prolonged egg-laying periods, i.e., in the 2017 and 2018 seasons. This was most apparent in 2018. In other words, in the season with a very long oviposition period of *C. pallidactylus* and also with a high abundance of the other stem weevil, *C. napi*.

The effects of pymetrozine (2016, 2017) or indoxacarb (2018) sprays made at timing III were negligible on the stem weevils in all three years when no application had been made previously (tr. 10), regardless of the fact that the egg-laying periods of the *C. pallidactylus* females were still in progress on the dates of spraying (22. 4. 2016, 3. 5. 2017, 26. 4. 2018). The contribution of the sprays made at timing III in reducing the damage caused by the weevil larvae proved to be somewhat more apparent only in the cases where they followed sprays made at timing II. So, when two insecticidal applications were made during the spring, it was more convenient to delay the first spray to the time when the majority of *C. pallidactylus* females had mature eggs in their ovaries (timing II) regardless of the type of insecticide used. So, even the pyrethroids were better applied on the later date (in 2017 and 2018) when another spray (at timing III) was applied.

In general, the relatively high levels of stem damage and low level of effectiveness, recorded even in the best single-spray treatments (tr. 2 and 5) in this study, raise the question of whether stem weevils can be successfully controlled with only one spring spray in seasons with long egg-laying periods and of how necessary a second spring application is to successfully control insect pests. This is regardless of whether pollen beetles are present in the crop or not. Some studies (Roy & Sparks 2000; Junk et al. 2012; Eickermann et al. 2014) predict a more complicated timing for insecticidal sprays against some insect pests on brassicaceous host plants due to shifts in their migration linked to climate change. According to Junk et al. (2012), for *C. pallidactylus*, a prolonged period of flight activity or crop invasion can be expected under changing climatic conditions. Eickermann et al. (2014) conclude their study aimed at assessing the effects of climate change on shifts in the migration of the rape stem weevil (*C. napi*) with the statement: On the one hand, periods of crop invasion will start earlier while, on the other hand, the timespans of possible crop invasions will be prolonged, potentially making additional insecticide applications necessary. If, in the near future, such predictions are confirmed, a second spring application will become necessary to successfully control stem weevils. Our results indicate what can happen in seasons with long egg-laying periods. In seasons characterised by the prolonged migrations and egg-laying periods of stem weevils (especially *C. pallidactylus*), which will likely be more frequent (Junk et al. 2012; Eickermann et al. 2014), some problems may also arise with the choice of a convenient insecticide for the second spring application. Such an application made at the end of April or at the beginning of May is usually targeted at pollen beetles, but it can substantially influence the levels of stem damage caused by the stem weevil larvae, too. An insecticide effective against both the stem weevils and pollen beetles is needed for such an application. Unfortunately, the group of insecticides proven to be highly effective against stem weevils and at the same time against pollen beetles is considerably limited. Even if indoxacarb and pymetrozine show a high efficacy against pollen beetles, their effectiveness against stem weevils is low (Seidenglanz et al. 2019). On the other hand, pyrethroids (maybe with the exception of tau-fluvalinate and etofenprox, Brandes et al. 2018; Heimbach & Müller 2013) are not effective against pollen beetles due to the phenomenon of resistance (Wegorek et al. 2009; Zimmer & Nauen 2011; Heimbach & Müller 2013; Rubil et al. 2018). Another group of insecticides, neonicotinoids (thiacloprid and acetamiprid), are also threatened by the resistance. Significant shifts in the pollen beetle's susceptibility to thiacloprid have been reported in Europe (Kaiser et al. 2018; Rubil et al. 2018). Some studies have also demonstrated the low effects of thiacloprid, Milovac et al. (2017), on stem weevils under field conditions. This indicates that neonicotinoids are unsuitable for applications targeting both pollen beetles and stem weevils. Furthermore, neonicotinoids (thiacloprid or acetamiprid) are regularly applied against pod midges, usually as a third spring application. Their usage as a second spring application would pose a risk of overuse in crops and this is neither desirable nor advantageous. They also show relatively major negative effects on non-target organisms in rape crops (Jansen & Gomez 2014). So, of the commonly available insecticides, organophosphates (especially two similar active ingredients: chlorpyrifos-ethyl, chlorpyrifos-methyl) seemed to be the most effective choice for the second spring application. At present, growers often consider organophosphates to be the only type of insecticides that are really effective against spring insect pests in rape crops (Wegorek et al. 2009; Kocourek et al. 2018). As a consequence of this, there is a real threat of these insecticides being overused. However, organophosphates can probably disturb and destroy populations of natural enemies of rape insect pests through their long-term effects more than other insecticides can (Jansen & Gomez 2014). The following may be concluded based on our findings:

Delaying the first spring insecticide application to the time when the majority (more than 50%) of *C. pallidactylus* females present in the crop already have mature eggs does not result in a lower level of stem weevil control in comparison with the access based on the earlier spraying (first females with mature eggs in the crops) when suitable insecticides are used. A combination of pyrethroid and organophosphate, unlike pyrethroid alone, is suitable for the delayed spraying.

Delaying the first spring insecticide application to the time when the majority of the *C. pallidactylus* females present in the crop have mature eggs in their ovaries makes it possible for the stem weevil control to be combined with the pollen beetle control. This is because the date for the first spring application is shifted to when the crop achieves growth stages susceptible to damage induced by the pollen beetles.

The low effectiveness of the tested insecticides (a combination of pyrethroid and organophosphate; pyrethroid alone) on stem-mining weevils, regardless of the date of spraying, indicates that it is impossible to successfully control these insect pests with one insecticide application in seasons characterised by prolonged egg-laying periods.

Factors such as prolonged periods of *C. pallidactylus* and *C. napi* migrations to crops and the pollen beetle's resistance to pyrethroids have become a real obstacle to attempts aimed at reducing the usage of insecticides. It is unlikely that, in the near future, there will be any reduction in the number of insecticide applications usually made on winter oilseed rape crops during spring.

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