Crop Protection 196 (2025) 107286

Contents lists available at ScienceDirect

Crop Protection

journal homepage: www.elsevier.com/locate/cropro

Effects of insecticide treatment against blue stem weevil (*Ceutorhynchus sulcicollis*) and cabbage stem weevil (*C. pallidactylus*) on crop injury and yield in winter oilseed rape (*Brassica napus*)

Ola Lundin [a,*], Rebecka Alaton [a], Lovisa Eriksson [b], Fabian A. Boetzl [a,1]

[a] Swedish University of Agricultural Science, Department of Ecology, Uppsala, Sweden
[b] Swedish Board of Agriculture, Plant Protection Centre, Linköping, Sweden

ARTICLE INFO

Keywords:
Gamma-cyhalothrin
Integrated pest management
Pyrethroid
Tau-fluvalinate

ABSTRACT

Blue stem weevil (*Ceutorhynchus sulcicollis*) and cabbage stem weevil (*C. pallidactylus*) can occur in high numbers in winter oilseed rape (*Brassica napus*) fields in Sweden, but their impact on crop yield is poorly known, hindering the development of evidence-based pest management recommendations. We conducted five field experiments in two cropping seasons, where we tested pyrethroid insecticide application in autumn targeting *C. sulcicollis*, in spring targeting *C. pallidactylus*, as well as combined applications in autumn and spring targeting both species. We evaluated stem injury, emergence of the new generation of weevils and crop yield and oil content. Insecticide treatment in autumn reduced stem injury length and severity by *C. sulcicollis*, whereas insecticide treatment in spring did not affect stem injury. Emergence of the two species was similar across all treatments, which possibly was an artefact of limited sampling effort and small-scale spatial heterogeneity in emergence. Insecticide treatment in autumn, spring or a combined treatment all increased yield by 8–10 % (185–245 kg ha^{-1}) with minor effects on oil content. Our results show that *C. sulcicollis* cause significant yield loss that can be reduced by insecticide treatment in autumn, which therefore can be economically motivated, whereas the results for insecticide treatment in spring targeting *C. pallidactylus* are inconclusive. Stem mining weevils are just some of several insect pests that can be economically important in oilseed rape and the availability of insecticides is declining. This calls for research into preventative pest management and well-motivated use of the few insecticides that remain in use.

1. Introduction

Oilseed rape (*Brassica napus* L.) is a globally important crop for food, feed and fuel, but several insect pests are limiting yields (Williams, 2010; Zheng et al., 2020). In Europe, major stem mining pests include the cabbage stem weevil (*Ceutorhynchus pallidactylus* Marsham) and rape stem weevil (*C. napi* Gyllenhal) (Williams, 2010; Juran et al., 2011). In Sweden, only the cabbage stem weevil is present of these two species, while an additional stem mining weevil, the blue stem weevil (*C. sulcicollis* Paykull) occasionally also occurs in high numbers (Gustafsson, 1991; Ekbom, 1996).

Ceutorhynchus pallidactylus and *C. sulcicollis* have similar life histories but show differences in their overwintering strategy and when they colonise the crop. Adults of *C. sulcicollis* colonise winter oilseed rape fields in autumn following a summer aestivation in non-crop habitats, whereas adults of *C. pallidactylus* (Fig. 1a) colonise fields in spring following overwintering outside crop fields (Ekbom, 1996). For both species, mating and egg-laying occur in spring and the larvae mine the stem (Fig. 1b, Keszthelyi et al., 2025), with stem mining by *C. sulcicollis* occurring earlier in spring compared to *C. pallidactylus* (Gustafsson, 1991). The mining of the stem can cause physiological injury to the oilseed rape plants, increase the risk for lodging and fungal infection, and reduce yields (Kelm and Klukowski, 2000; Krause et al., 2006; Zaller et al., 2008). Both species pupate in the soil close to the stem of the mined plant and the new generation emerges during summer (Juran et al., 2011; Sulg et al., 2022). *Ceutorhynchus pallidactylus* is recognised as an important pest of oilseed rape in Europe and control thresholds of 20–30 *C. pallidactylus* collected over three days per yellow water trap

* Corresponding author. Swedish University of Agricultural Science, Department of Ecology, PO Box 7044, SE-750 07, Uppsala, Sweden.
E-mail address: ola.lundin@slu.se (O. Lundin).
[1] Present address: Department of Animal Ecology and Tropical Biology, Biocenter, University of Würzburg, Würzburg, Germany.

https://doi.org/10.1016/j.cropro.2025.107286
Received 24 January 2025; Received in revised form 6 May 2025; Accepted 21 May 2025
Available online 22 May 2025

have been recommended in Poland and Germany (Williams, 2010). The current threshold for *C. pallidactylus* in Germany is 15 individuals collected over three days per yellow water trap (Bartels et al., 2023). Scientifically based, peer reviewed thresholds for insecticide treatment have, however, not been established (Williams, 2010; Ramsden et al., 2017). Experimental trials from continental Europe have demonstrated reduced crop injury from stem weevils and increased crop yield following insecticide treatment (Kelm and Klukowski, 2000; Seidenglanz et al., 2009, 2022; Spitzer et al., 2014; Milovac et al., 2017). As *C. pallidactylus* co-occurs with the larger and more damaging *C. napi* in this area, the applicability of these results to regions where *C. pallidactylus* instead co-occurs with *C. sulcicollis* is, however, unknown.

Despite its wide distribution throughout Europe, *C. sulcicollis* seems to occur in numbers high enough to be considered a pest only in the northernmost part of the winter oilseed rape growing area in Europe, and there is little published on this pest in the international literature (but see Hayn, 1970). In Estonia, it has only recently been recognised as a potential pest species in winter oilseed rape (Sulg et al., 2022). In Sweden, *C. sulcicollis* is known as a potential pest of oilseed rape (Mühlow and Sylvén, 1953; Björkman, 1975) which is most common in the regions around the lakes Vänern, Vättern and Mälaren (Gustafsson, 1991; Ekbom, 1996). Older Swedish insecticide trials from the 1970–1990s against *C. sulcicollis* in winter oilseed rape indicated that the impact of this pest on crop yield often was minor (Gustafsson, 1991), but the relevance of these 30–50 year old trials for modern winter oilseed rape growing practices and pest pressure is unclear.

The aim of our study was to determine how insecticide treatment in autumn against *C. sulcicollis* and in spring against *C. pallidactylus* affect stem injury and crop yield in winter oilseed rape. Injury by stem mining weevils was assessed two times during the season. We captured the new generation of weevils emerging from the field in the summer using emergence traps to evaluate the relative abundance of the two species. To account for potential effects of the insecticide treatments on other pests, we also quantified crop injury by pollen beetle (*Brassicogethes aeneus* Fabricius) and brassica pod midge (*Dasineura brassicae* Winnertz) in the experiments. Finally, we also measured crop yield and oil content following each insecticide treatment. With an improved understanding of the relationship between crop injury from stem mining weevils and yield loss, the overall goal of this research is to contribute to developing recommendations that direct insecticide use only to situations where it is needed and cost-effective, thereby promoting the dual sustainability goals of improved economy for the growers and reduced unnecessary environmental impact.

2. Material and methods

2.1. Experimental design and treatments

A total of five field experiments (defined as site by year combinations) were established in the cropping seasons of 2022–2023 and 2023–2024 in the county of Östergötland in south central Sweden (Table 1). We performed the experiments in this region due to known high pest pressure from both *C. sulcicollis* and *C. pallidactylus*, while pest pressure from the additional stem mining species cabbage stem flea beetle (*Psylliodes chrysocephala* L.) is limited. All field experiments were hosted by farmers and placed at least 24 m into one of their winter oilseed rape fields. Selected fields were all in landscapes dominated by agriculture with embedded forest fragments, with forest fragments being relatively more common around the two fields situated around the city of Norrköping (Table 1). Common crops in the fields surrounding the field experiments were winter wheat, spring barley and winter oilseed rape. Farmers did not apply any insecticides in the experiments from mid-September onwards. In three cases, early pyrethroid application was done by the farmers in the fields as well as the experimental areas before September 15, targeting cabbage stem flea beetles. As pyrethroids are short-lived and contact-acting, and *C. sulcicollis* colonisation of the fields peaked in late September or early October (Table S1), we deemed that these pyrethroid applications would have a negligible effect on our target pests. In other aspects, such as fertiliser, herbicide and fungicide use, the farmers managed the experiments in the same way as the rest of the field. An exception to this occurred in Norrköping 2022–2023, however, where the experiment did not get treated with growth regulator like the rest of the field. This was because the farmer applied a tank mix of growth regulator and insecticide, and the insecticide could not be applied in the field experiment. The resulting lack of growth regulator in the field experiment negatively affected the overwintering of the crop, since by spring the field experiment had a noticeable lower plant density compared to the surrounding field. Each experiment had four treatments replicated four times in a complete randomised block design: (1) insecticide treatment in autumn (Nexide CS; gamma-cyhalothrin, 3.6 g ha^{-1}) against *C. sulcicollis*, (2) insecticide treatment in spring (Mavrik; tau-fluvalinate, 48 g ha^{-1}) against *C. pallidactylus*, (3) insecticide treatment both in autumn and spring (Nexide CS; gamma-cyhalothrin, 3.6 g ha^{-1} and Mavrik; tau-fluvalinate,48 g ha^{-1}) against both species and (4) untreated control. We chose to use different pyrethroid compounds in autumn and spring in order for the experiments to reflect an allowed and viable insecticide use strategy for winter oilseed rape that could be recommended to farmers. In the second season we, however, added an additional spring treatment with Nexide CS (gamma-cyhalothrin, 3.6 g ha^{-1}) in order to evaluate if the choice of pyrethroid compound affected any outcome. The spring treatment with Nexide thus has a lower replication (one out of two cropping seasons, three out of five experiments) compared to the other treatments that were present in all five experiments. All insecticide applications were conducted using a boom sprayer (Kelly 2500) equipped with ISO (International Organization for Standardization) 02 yellow nozzles (Hardi LD-020-110) using a pressure of 2.8 bar and a total applied volume (including water) of 200 l ha^{-1}. Plots were 12 m long and 6 m wide, with one half of each plot reserved for plant

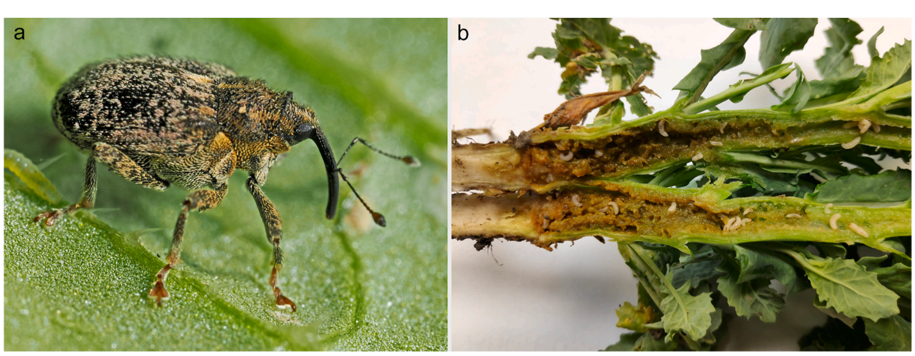

Fig. 1. (a) Adult cabbage stem weevil (*Ceutorhynchus pallidactylus*, photo made available to the authors by the courtesy of Felix Riegel) and (b) an oilseed rape plant with stem mining *Ceutorhynchus* spp. larvae and injury.

Table 1
Overview of the five experimental locations with the cropping season (year; either 2022–2023 or 2023–2024), the approximate experimental location (nearest city), field size (ha), sowing date, the number of *C. sulcicollis* and *P. chrysocephala* collected in yellow pan traps in autumn (average number of individuals per trap and week, with the total number of individuals within parenthesis), the insecticide application date in autumn (corresponding to BBCH 13–15), the accumulated number of *C. pallidactylus* collected in yellow pan traps in spring (average number of individuals per trap and week, with the total number of individuals within parenthesis), date when the threshold of 50 individuals of *C. pallidacylus* per pan trap and week was achieved (corresponding to the existing thresholds of 20–30 individuals per pan trap and three days, Williams, 2010), the insecticide application date in spring (corresponding to BBCH 59–65) and harvest date for each experiment. The precrop was winter wheat in all fields. All fields were ploughed prior to sowing of the oilseed rape, except the field in Norrköping 2023–2024, where reduced tillage with shallow cultivation of the soil was practised. Further details about the trap catches, including weekly numbers, are available in Table S1–2.

Year	Site	Field size (ha)	Sowing date	Cultivar	*C. sulcicollis*	*P. chrysocephala*	Application date autumn	*C. pallidactylus*	Threshold achieved	Application date spring	Harvest date
2022–2023	Norrköping	22	20-Aug	Atora	51 (1334)	1.8 (47)	13-Oct	188 (1693)	24-Apr	16-May	12-Aug
2022–2023	Linköping	15	13-Aug	DK Expat	31 (871)	2.4 (68)	13-Oct	12 (108)	15-May	16-May	8-Aug
2023–2024	Norrköping	25	16-Aug	DK Expansion	50 (792)	0.2 (3)	10-Oct	168 (1174)	15-Apr	13-May	7-Aug
2023–2024	Linköping	3	19-Aug	Helypse	91 (1462)	0.8 (13)	27-Sep	77 (536)	6-May	21-May	15-Aug
2023–2024	Vadstena	10	23-Aug	Explicit	384 (4608)	8.4 (101)	28-Sep	49 (344)	6-May	21-May	31-Jul

measurements and insect sampling (3 m width, all measurements and samples were taken at least 1 m from the plot edge), and the other half left undisturbed for harvesting (3 m width).

Locations for the field experiments were chosen in the autumn of each year based on high confirmed pest pressure from *C. sulcicollis*, which was monitored by the Plant Protection Centre of the Swedish Board of Agriculture and crop consultants with yellow pan traps (diameter = 25.5 cm) in winter oilseed rape fields in the county. Two (autumn) and one (spring) yellow pan traps, respectively, filled with water and soap solution were used per field. Pan traps were placed in one untreated monitoring plot in each of the five fields, 30 m in length and 24 m in width, at the field edge. The only exception was in Vadstena 2023–2024, where the untreated plot was placed next to the trial area, approximately 48 m from the field edge. The distance between the untreated monitoring plot and the trial area varied between 24 and 80 m. In autumn, the pan traps were emptied and refilled weekly between the end of August and until late in October (Table S1), covering the flight activity period of *C. sulcicollis* and *P. chrysocephala*. In all experimental locations, pest pressure from *C. sulcicollis* far exceeded that of cabbage stem flea beetle (Table 1), indicating that any effects of insecticide treatment in the autumn are mainly due to control of *C. sulcicollis*. Expected pest pressure from *C. pallidactylus* was also considered when choosing experimental locations, prioritising locations where abundance of this species had been high in previous seasons. In spring, the pan traps were emptied and refilled weekly from early April to late May or early June (Table S2), covering the flight period of *C. pallidactylus*. The timing of insecticide application was based on monitoring of weekly trap catches. In the autumn, application was done in late September or early October (Table 1), when trap catches of immigrating *C. sulcicollis* had culminated (i.e., weekly trap catches declining). Selecting the application date in spring was more complex due to a delayed appearance of female *C. pallidactylus* compared to males in the field and a prolonged egg-laying period (Seidenglanz et al., 2009, 2022). Following the findings of Seidenglanz et al. (2009), but without performing any sex determinations or dissections to search for eggs in females, the spring application of insecticides against *C. pallidactylus* was performed with a delay after a threshold of >50 *C. pallidatylus* individuals (corresponding to 20–30 individuals per three days, Williams, 2010) had been collected in the yellow pan trap over one week (Table 1). The delay was to allow time for colonisation of females and initiation of egg-laying, and varied slightly between experiments, but was generally longer when thresholds were achieved early in the season (Table 1), based on an assumption that colonisation of females, activity and initiation of egg-laying would progress slower early in the season.

2.2. Stem weevil injury assessments

Stem injury was assessed twice, once mid-May (May 17 in 2023, May 14–15 in 2024) at crop stage BBCH (Biologische Bundesanstalt für Land- und Forstwirtschaft, Bundessortenamt und CHemishe Industrie) 59–61 (early flowering, Lancashire et al., 1991), and once in June (June 11–12 in 2023, June 28 in 2024, BBCH 69–75; pod development). The first assessment was close to the estimated onset of egg-laying by *C. pallidactylus* when the spring insecticide application were conducted. Injury assessed at this time point should therefore mainly be attributed to *C. sulcicollis* and no effects of the insecticide treatments conducted in spring on stem injury were expected at this time point. The second assessment reflects combined stem injury from both *C. sulcicollis* and *C. pallidactylus*.

At each injury assessment, we dug up 20 randomly selected oilseed rape plants per plot. Stems were cut open and the length of the stem with insect-caused injuries was measured. We also classified the injury in classes from 1 to 4 (Gustafsson, 1991), which represented plants with no injury (rating 1), light (2: slight tunnelling, most of the stem intact, a few larvae present at most), medium (3: severe discoloration with several larvae, but vascular tissue still intact) and severe injury (4: severe injury reaching vascular tissue), respectively. Due to a degree of subjectivity involved in the injury rating, assessors collectively inspected plants prior to the assessment occasions to calibrate the ratings among assessors, and the same assessor always rated all plants from a complete block of treatments for stem injury.

2.3. Pollen beetle and pod midge injury assessments

As the insecticide treatment in spring might affect pollen beetle and indirectly also brassica pod midge through effects on the cabbage seedpod weevil (*C. obstrictus* Marsham, Hausmann, 2021), we assessed injury by pollen beetle and brassica pod midge in late June or early July (June 28 in 2023, July 1–3 2024, BBCH 75) when the crop was turning in colour from green to yellow. We selected ten plants from each plot. In each plant, we selected three shoots; one in the lower, middle and upper part of the plant, respectively. On each shoot, we counted the number of podless stalks caused by pollen beetles (Seimandi-Corda et al., 2021), the number of distorted and discoloured pods injured by brassica pod midge (Hausmann, 2021) as well as the number of intact pods. Select injured pods were also opened to confirm the presence of brassica pod midge larvae. We calculated the proportion of pods injured by pollen beetles as the number of podless stalks divided by the sum of all three categories (podless stalks, injured by brassica pod midge or intact). The proportion of pods injured by brassica pod midge was calculated as injured pods divided by the sum of injured and intact pods (i.e. not including podless stalks, as they do not provide any pods for brassica pod midge).

2.4. Stem weevil emergence

We monitored the emergence of the new generation of stem mining weevils from June 19 to July 24 in 2023 and from June 17–19 to July 22–24 in 2024 with emergence traps (from BBCH 71–75 to BBCH 80–83, depending on the field). We placed one emergence trap in each plot. The emergence traps consisted of a metal ring (diameter 35 cm, height 30 cm) that was buried approximately 10 cm into the soil. The emergence traps covering 0.096 m^2 each were set up with one or two oilseed rape plants inside that were cut at the base. The rings were covered with a fine mesh that was secured with a strap. Photos of the emergence traps are available in Boetzl et al. (2025). We placed one yellow sticky trap horizontally on wooden skewers inside each emergence trap. Yellow sticky traps were replaced weekly for five weeks until the emergence traps were removed due to harvest of the fields. Eleven weekly trap catches (2.4 %) were lost due to wildlife damage and lodging of the crop. Beetle emergence was calculated as emerged individuals per day across all available samples per plot.

2.5. Crop yield and oil content

A 9 m by 2 m area in the centre of each harvest plot was harvested with an experimental thresher near the time of commercial harvest of the field. A sample of seeds from each harvested plot was rinsed and analysed for water and oil content using near-infrared transmittance (AgriLab, Uppsala, Sweden). We analysed oil content as this is an economically important yield quality parameter (Lundin et al., 2020), which could be affected by insect pests (Brown et al., 1999). All yields were standardised to kg ha^{-1} of rinsed seed with 9 % water content. We excluded yield data from the experiment in Linköping harvested in 2024 from analyses, as this experiment suffered from lodging and seed shattering due to local rainstorms.

2.6. Statistical analyses

All analyses were performed in R 4.4.1 (R Development Core Team, 2024) using generalised linear mixed models (package 'glmmTMB', version 1.1.9–9000, Brooks et al., 2017). Response variables were stem injury length during early flowering and during pod development, respectively ('early stem injury length' and 'late stem injury length', length in cm), stem injury severity during early flowering and during pod development, respectively ('early stem injury severity' and 'late stem injury severity', injury severity rating 1–4), podless stalks due to pollen beetles (percent), pods affected by the brassica pod midge (percent), *C. sulcicollis* emergence (number per trap and day), *C. pallidactylus* emergence (number per trap and day), crop yield (kg ha^{-1}) and oil content (percent). All response variables that were assessed per plant (stem, pollen beetle and brassica pod midge injuries) were averaged per plot before analyses. All models contained insecticide treatment (factor, five levels), year (factor, two levels) and the interaction between treatment and year as fixed effects, and site and block nested within site as random intercept. We simplified the models by removing the interaction term between treatment and year whenever it was not statistically significant (all models except the one for oil content). We chose residual distributions that resulted in the best model fits, gamma distributions for the averaged non-integer count data and beta regressions for the percentage data, and we additionally specified hurdle models in some cases (specified in Table 2), to account for zeros in the data that are outside of the boundaries of the chosen residual distributions. Model fits were checked for under- and overdispersion and suitability of chosen residual distributions using the DHARMa package (version 0.4.6, Hartig, 2022) and no violation of the model assumptions were detected. Estimated marginal means were calculated using the 'emmeans' package (version 1.10.3, Lenth, 2022), statistical test results were obtained using type II sums of squares Wald chi-square tests with the command 'Anova' (package 'car', version 3.1-2, Fox and Weisberg, 2019) and conditional R^2 values with the command 'performance' (package 'performance', version 0.12.2, Lüdecke et al., 2021).

3. Results

3.1. Stem injury

Early stem injury length was on average 50.9 % and 54.9 % lower in the treatments with Nexide in autumn, and both Nexide in autumn and Mavrik in spring, compared to the untreated control while stem injury length in the other insecticide treatments did not differ significantly from the control (Fig. 2a, Table 2). Stem injury length increased almost 10-fold or 26.6 cm from the early to the late assessment across all treatments. Late stem injury length ranged between 27.8 cm and 29.8 cm and was not significantly affected by insecticide treatment (Table 2).

Early stem injury severity was on average 0.24 and 0.23 injury classes lower in the treatments with Nexide in autumn, and both Nexide in autumn and Mavrik in spring, compared to the untreated control, while stem injury severity in the other insecticide treatments did not differ significantly from the control (Fig. 2b, Table 2). Early stem injury severity was additionally on average 0.69 injury classes lower in 2024 than in 2023 (Table 2). Stem injury severity increased by on average by 0.83 injury classes from the early to the late assessment across all treatments. Late stem injury severity ranged between 2.40 and 2.43 and was not significantly affected by insecticide treatment, but was on average 0.55 injury classes lower in 2024 than in 2023 (Table 2).

Table 2
Results of statistical test analyses with the effect of insecticide treatment and year on the early and late stem injury length and severity by stem mining weevils, pollen beetle (*B. aeneus*) and brassica pod midge injury (*D. brassicae*), blue stem weevil (*C. sulcicollis*) and cabbage stem weevil (*C. pallidactylus*) emergence, and crop yield and oil content. Shown are residual distributions (gamma or beta regression), degrees of freedom (df, numerator and denominator) and Chi-square ($\chi2$), p and conditional R^2 values (calculated using the package performance (version 0.12.29; marginal R^2 values are currently not implemented for beta regression or gamma distributions). For model specifications, see section 2.6. Statistically significant p values (<0.05) are indicated in bold and trends (0.05<p < 0.10) in italics.[1] hurdle models, to account for zeros in data (see section 2.6).

Response variable	Residual distribution	R^2_c	Treatment			Year		
			df	$\chi2$	p	df	$\chi2$	p
Early stem injury length	Gamma[1]	0.58	4, 86	24.86	**< 0.001**	1, 86	2.23	0.135
Early stem injury severity	Gamma	0.88	4, 86	47.56	**< 0.001**	1, 86	6.16	**0.013**
Late stem injury length	Gamma	0.57	4, 86	2.57	0.632	1, 86	0.14	0.707
Late stem injury severity	Gamma	0.86	4, 86	1.15	0.886	1, 86	25.03	**< 0.001**
Pollen beetle injury	Beta regression	0.92	4, 86	5.58	0.233	1, 86	14.94	**< 0.001**
Brassica pod midge injury	Beta regression	0.99	4, 86	8.69	*0.069*	1, 86	1.26	0.261
C. sulcicollis emergence	Gamma[1]	0.44	4, 86	3.04	0.551	1, 86	20.85	**< 0.001**
C. pallidactylus emergence	Gamma[1]	0.31	4, 86	1.42	0.841	1, 86	1.89	0.170
Crop yield	Gamma	0.74	4, 66	22.04	**< 0.001**	1, 66	0.167	0.683
Oil content	Beta regression	0.99	4, 65	4.04	0.401	1, 65	4.70	**0.030**

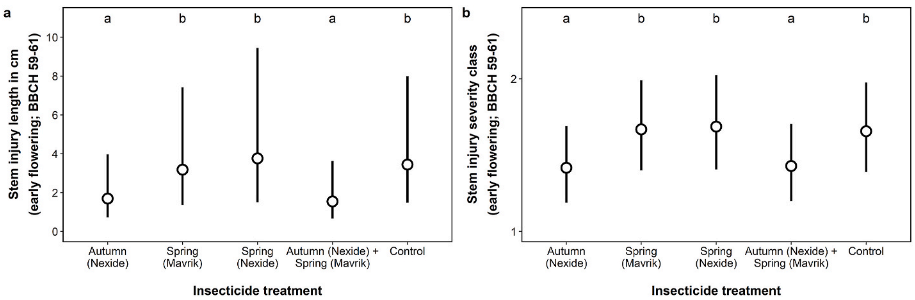

Fig. 2. (a) Early stem injury length (cm), and (b) early stem injury severity (class 1–4. see section 2.2) depending on insecticide treatment: insecticide treatment in autumn with Nexide (gamma-cyhalothrin, 3.6 g ha^{-1}), insecticide treatment in spring with Mavrik (tau-fluvalinate, 48 g ha^{-1}), insecticide treatment in spring with Nexide (gamma-cyhalothrin, 3.6 g ha^{-1}), insecticide treatment both in autumn with Nexide (gamma-cyhalothrin, 3.6 g ha^{-1}) and spring with Mavrik (tau-fluvalinate, 48 g ha^{-1}), or untreated control. Shown are model-estimated marginal means (points) with 95 % confidence intervals (black error bars). Different letters denote treatments that are significantly different from each other ($p < 0.05$) based on pairwise contrasts with Tukey correction.

3.2. Pollen beetle and brassica pod midge

The average percent podless stalks caused by pollen beetles ranged from 18.3 % to 20.7 % and were not affected by insecticide treatment (Table 2). The percent of podless stalks caused by pollen beetles was 51.3 % lower in 2023 compared to 2024 (Table 2). The percent pods injured by brassica pod midge tended to be affected by insecticide treatment (Table 2), which was driven by lower injury in the treatment with Nexide in spring compared to treatments with applications of Nexide in autumn, although treatments means were similar and ranged from 16.7 % to 18.9 %.

3.3. Stem weevil emergence

In total, 434 *C. sulcicollis* and 2009 *C. pallidactylus* were collected in the emergence traps. The number of *C. sulcicollis* and *C. pallidactylus* emerging per trap and day ranged between 0.14-0.20 and 0.58–0.74 individuals, respectively and was not affected by insecticide treatment, however on average 64.0 % less *C. sulcicollis* emerged in 2024 compared to 2023 (Table 2).

3.4. Crop yield and oil content

All insecticide treatments except Nexide in spring increased yields by on average 185–245 kg ha^{-1} (corresponding to 7.6 %–9.9 %, Fig. 3a, Table 2). Oil content was the only variable which was affected by an interaction between insecticide treatment and year ($F_{df} = 11.40_{3,65}$, $p = 0.010$). The treatment only affected oil content in 2024, with higher oil content in the treatment with both Nexide in autumn and Mavrik in spring compared to the treatment with Nexide in autumn, whereas there was no effect of the insecticide treatment on oil content in 2023 (Fig. 3b, Table 2). Oil content in 2024 was also on average 3.4 percentage points higher than in 2023 (Table 2).

4. Discussion

In five field experiments conducted over two cropping seasons, we showed that insecticide treatment in autumn, but not spring, reduced stem injury length and severity caused by stem mining Ceutorhynchus weevils. Crop injury by pollen beetle and brassica pod midge was not affected by the treatments. Emergence traps successfully captured the new generation of *C. sulcicollis* and *C. pallidactylus*, but insecticide treatment did not affect the number of emerged weevils. Insecticide treatments generally increased oilseed rape yield with only a limited effect on the oil content.

Our results from the early-season stem injury assessments confirm earlier findings of reduction in injury or number of emerging larvae of *C. sulcicollis* following insecticide treatment (Gustafsson, 1991; Sulg et al., 2022). In our case, insecticide treatment in autumn reduced stem injury, but only early in the season. Insecticide treatment in autumn also increased yield by on average 9 %, or 230 kg ha^{-1}, which is clearly sufficient to make the treatment profitable under a range of economic conditions regarding costs for the insecticide treatment and price for oilseed rape (see e.g. Lundin, 2020). The experimental sites were intentionally selected to have high numbers of *C. sulcicollis* in order to determine an upper level for possible yield loss to this species. While we therefore can conclude that insecticide treatment targeting *C. sulcicollis* in autumn can be economically motivated under the conditions of the experiments with high pest pressure, our experiments were not designed to develop thresholds for insecticide treatments. To that end, further

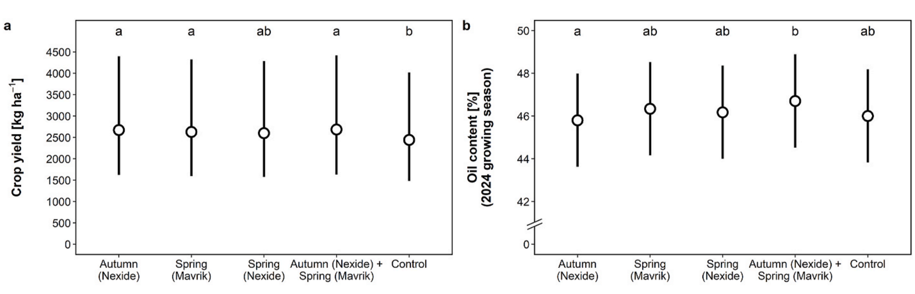

Fig. 3. (a) Crop yield (kg ha^{1}) and (b) oil content (percent) depending on insecticide treatment: insecticide treatment in autumn with Nexide (gamma-cyhalothrin, 3.6 g ha^{-1}), insecticide treatment in spring with Mavrik (tau-fluvalinate, 48 g ha^{-1}), insecticide treatment in spring with Nexide (gamma-cyhalothrin, 3.6 g ha^{-1}), insecticide treatment both in autumn with Nexide (gamma-cyhalothrin, 3.6 g ha^{-1}) and spring with Mavrik (tau-fluvalinate, 48 g ha^{-1}), or untreated control. Panel (a) shows average values across both years, whereas panel (b) shows data from 2024 only, as oil content only was affected by treatment in this year (see section 3.4). Points show model-estimated marginal means and error bars 95 % confidence intervals. Different letters denote treatments that are significantly different from each other ($p < 0.05$) based on pairwise contrasts with Tukey correction.

experimentation with a similar design but with more variable levels of *C. sulcicollis* pest pressure would be needed. Until such data is available, and considering that the median for cumulative number of *C. sulcicollis* caught in two yellow pan traps was 1334 individuals, we suggest that a cumulative catch of ca. 500 *C. sulcicollis* in two yellow pan traps in the colonisation period during autumn (in our study area from mid-September to mid-October) could act as a rule of thumb that sets a lower limit for insecticide treatment.

Contrary to our expectation, insecticide treatment in spring did not affect late-season stem injury. The early-season differences in stem injury, with lower injury after insecticide treatment in autumn, had also disappeared by the time of the late injury assessment. One interpretation of these results, where the least injured plants gained more injury between the two assessments, is that *C. pallidactylus* selectively attacked plants with less injury by *C. sulcicollis*. This would be in contrast with the finding that *C. pallidactylus* preferred to oviposit in oilseed rape plants already occupied by *C. napi* (Dechert and Ulber, 2004), but in line with the finding that *C. pallidactylus* was spatially dissociated with another stem mining pest, the cabbage stem flea beetle (Ferguson et al., 2006). Emergence of the new generation of both *Ceutorhynchus* species were similar in all treatments, but this could be an artefact of traps covering a low sampling area in each plot (0.1 m^2). The number of larvae per plant, and thereby likely also emergence, varied considerably within a plot. Larger or multiple emergence traps might be needed to better capture this heterogeneity and assess the true emerging densities.

A puzzling result is that the insecticide treatment in spring with Mavrik increased crop yield, without affecting any of the injury assessments on neither stems nor pods. Injury by pollen beetle and brassica pod midge to the pods were not clearly affected by the insecticide treatment, which was expected as they mostly caused limited injuries and the most efficient timing for insecticide treatment against these pests is earlier (bud stage) and later in the spring (from mid-flowering onwards), respectively (Brandes et al., 2018; Hausmann et al., 2021). One potential explanation as to why the insecticide treatment in spring increased yield without any detectable effect on crop injury is that the insecticide treatment in spring delayed stem injury growth, and thereby also reduced the negative effect of stem injury on yield, rather than affecting the final level of injury to the stems. The fact that insecticide treatment in spring did not provide any additional yield gain if combined with an insecticide treatment in autumn, further speaks for complex compensatory relationships between early and late-season stem injuries (see also Gagic et al., 2016). We measured stem injury caused by *C. pallidactylus* only once, three to five weeks after the insecticide application in spring, and a time-series with several assessments of stem injury following the applications would be needed to examine this further. Another possibility is that the increased yield following the insecticide treatment in spring reflects a joint response to injury by several insect pests including *C. pallidactylus*, pollen beetle and brassica pod midge, and potentially also secondary pests that were not quantified, although no such pests were observed. The experiments were also limited to investigating a single time point for the insecticide application in autumn and spring, respectively, and especially in spring when the optimal time point for application is more complex to determine (Seidenglanz et al., 2009) the role of timing of the application needs further examination. In particular, earlier applications in spring warrants further study, as it is possible to our insecticide treatments were conducted too late to substantially reduce larval injury from *C. pallidactylus*. While pyrethroid resistance is known to occur in some populations of *C. pallidactylus* in Europe (Daum et al., 2024), no such resistance has been reported or suspected in our study area. Pyrethroid resistance is therefore likely not explaining the limited effect of the treatments in spring on *C. pallidactylus*. The more complex results from our experiments regarding insecticide treatment in spring targeting *C. pallidactylus* hinder us from providing clear pest management recommendations for this species. It would be valuable to conduct further experiments focusing on insecticide treatment in spring in fields with *C. pallidactylus* as the dominating stem mining pest species.

Our field experiments shed light on the potential of *C. sulcicollis* as a pest species that can reduce crop yields and be economically motivated to treat for with insecticides when occurring in high numbers. Our results for insecticide treatment in spring targeting *C. pallidactylus* were inconclusive, with yield increases without any detectable effects on crop injury, calling for further research into the underlying causes. The cabbage stem flea beetle is an additional major insect pest of winter oilseed rape (Ortega-Ramos et al., 2022) which is benefiting from climate change (Emery et al., 2023) and becoming more abundant in growing areas further north in Sweden that already have high numbers of *C. sulcicollis*. Unless competition between the two species that occupy a similar ecological niche will counteract overall increased pest pressure, pest management strategies in these areas need to be developed to take into account two pest species that colonise the winter oilseed rape crop at different time points in the autumn. Due to pest pressure from multiple insect species, insecticide resistance and decreasing availability of insecticides (Zheng et al., 2020; Daum et al., 2024) there is in general a great need to develop pest management strategies in oilseed rape. Considering the potential for multiple insect pests to exceed economic thresholds and a limitation in the total number of insecticide applications that can be done in an oilseed rape crop, strategies are needed that can reduce the dependency on chemical insecticides and increase use efficiency for the few insecticides that remain available.

CRediT authorship contribution statement

Ola Lundin: Writing – original draft, Validation, Supervision, Resources, Project administration, Methodology, Investigation, Funding acquisition, Data curation, Conceptualization. **Rebecka Alaton:** Writing – review & editing, Investigation, Data curation. **Lovisa Eriksson:** Writing – review & editing, Resources, Methodology, Investigation, Conceptualization. **Fabian A. Boetzl:** Writing – original draft, Visualization, Supervision, Investigation, Formal analysis.

Declaration of competing interest

The authors declare the following financial interests/personal relationships which may be considered as potential competing interests: Ola Lundin reports financial support was provided by Stiftelsen Svensk Oljeväxtforskning. If there are other authors, they declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Acknowledgements

We thank the Plant Protection Centre of the Swedish Board of Agriculture in Linköping for providing time and resources to the project, the Rural Economy and Agricultural Society that managed and harvested the experiments and the farmers that hosted them. We are grateful to Alf Djurberg, Anders Arvidsson, Alessandra Munari, Bafraw Karimi, Emile Amans, Jop van der Wel, Léna Beaudet, Lovisa Hansson, Sandra Lillsjö Kronblad, Pia Ottosson and Sarah Schajer for their help in the field and laboratory. Chloé Raderschall is thanked for providing comments on the manuscript. We are grateful to Felix Riegel for providing the photograph of *C. pallidactylus*. Funding: This work was supported by Stiftelsen Svensk Oljeväxtforskning, which is a research foundation instituted by the Swedish Seed and Oilseed Growers Association.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.cropro.2025.107286.

Data availability

Data available via the Swedish National Data Service: https://doi.org/10.5878/wqsg-qn25

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