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Spring Abundance, Migration Patterns and Damaging Period of *Aleyrodes proletella* in the Czech Republic

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Abstract: The cabbage whitefly has become an important pest on brassica vegetables in Central Europe. It does not destroy the affected plants, but the product becomes unmarketable, causing considerable economic losses. The pest is also difficult to control due to its way of life and because it develops resistance to some of the active components of insecticides. In organic farming systems, insecticides are strictly restricted, but neither predators nor whitefly parasitoids are able to keep the pest at a tolerable level. It is, therefore, necessary to become familiar with the whitefly's life cycle and habits, including mass migration from winter hosts to vegetables. We inspected 44 rapeseed fields across the republic in the period 2014–2021 in order to find the connection between the presence of oilseed rape fields near vegetable growing areas (VGAs) and the abundance of the overwintering cabbage whiteflies. We also conducted regular weekly monitoring of whitefly occurrence in the main cultivation area of the Czech Republic (Polabí) with the aim of specifying critical data important for the successful control of this pest. We found that the cabbage whitefly incidences were many times higher in rapeseed fields close to VGAs compared to areas where the crops are not adjacent. The average number of whiteflies was 0.59 individuals per plant in VGA-1 (oilseed rape grown inside this area or up to 1 km far), 0.052 in VGA-2 (distance 3–10 km from vegetable fields) and 0.014 in VGA-3 (more than 20 km). In the extremely warm year 2016, the difference was up to sixty times. The first CW eggs laid on cruciferous vegetables were usually found around 20 May. The period of mass migration of CW adults to cruciferous vegetables was between 6 June and 2 August. At this time, vegetables are most vulnerable to damage. Successful control of the cabbage whitefly requires the use of fabric netting, combined with an insecticide as needed and trap plants as needed; the latter have to be destroyed before adult whiteflies hatch—typically in early July.

Keywords: *Aleyrodes proletella*; brassica crops; oilseed rape; ecology; migration; cabbage whitefly; Czech Republic

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1. Introduction

The cabbage whitefly (CW) *Aleyrodes proletella* L. (Hemiptera: Aleyrodidae) is an oligophagous species causing economic losses to brassica vegetables. It is a native species of the Palearctic realm but has also spread to other continents, where it has the invasive species status. It is currently present on all the continents except Antarctica [1]; for example, its occurrence has been reported in Angola, Australia [2], India, the United States, Mexico, Brazil, China [3] and New Zealand [4]. It was regarded as a minor pest in Europe, so little research has focused on this species in the past [5], but its importance as a pest has increased considerably in recent decades [6–13]. Den Belder et al. [14] stated that *Aleyrodes proletella* is slowly spreading from Central to Western Europe and has recently become a serious pest in commercial brassica fields in the Netherlands.

The CW spreading is probably associated with an increase in winter rapeseed (*B. napus* L.) cultivation areas. Askoul et al. [15] examined the effects of various host plants on the reproductive parameters of *A. proletella*, such as fertility, survival rate and preoviposition period, and all of the parameters were significantly the best in winter rapeseed. In the UK, for example, the oilseed rape cultivation area increased only in the mid-1970s; brassicas as vegetables clearly dominated until then [16]. In the Czech Republic, the size of the rapeseed growing areas was under 50 thousand hectares until the end of the 1970s. After the 1990s, there was a jump shift when the cultivation area skyrocketed to 350 thousand ha. After 2000, the area decreased to 250 thousand ha, and there was another shift to about 340 thousand ha in 2007 in connection with EU directives on organic additives in diesel fuel. The rapeseed growing area was between 350 and 420 thousand hectares in 2010–2020 [17]. The oilseed rape area grew by 20% from the Czech Republic's ascension to the EU (1 May 2004) to 1 May 2016, and the total increase has even been 283.9% since 1989 [18].

In the Czech Republic, CW had no pest status in the past [19]. Until the beginning of the 21st century, no significant damage to crops existed in the Czech Republic. The first damage was recorded around 2008 in the southeastern part of the Czech Republic (Moravia region), where the climate is warmer. In the Polabí region, with a high concentration of vegetable fields, the damage occurred 1–2 years later (depending on location). Since 2012, *A. proletella* has been a regular pest on cruciferous vegetables in all lowland regions of the Czech Republic [20] and is also abundant in all oilseed rape fields.

Winter rapeseed provides a suitable shelter for the cabbage whitefly during the winter as well as a food source for the period when no vegetables grow in the fields. Its widespread cultivation results in so-called green bridges and, along with milder winters, has a critical influence on the current success rate of the cabbage whitefly [14,16]. CW does virtually no harm to rapeseed, but it creates numerous colonies there [13], from which the adults migrate en masse to vegetable fields in the course of June [16], where they pose a major problem. It has been noted that CW has two morphs with different specific flight capabilities [21]. While one of them can spread over a range of several hundred meters, the other migrates from origins up to several kilometres distant. The migrating morph (around 5 km) appears to be much more important in colonising vegetable fields than the local one (200–1000 m) [22]. Typically, the cabbage whitefly life cycle from egg (laid after wintering) to adult is completed within 3–6 weeks, depending on the temperature [13,23]. The number of generations that the whiteflies can achieve differs depending on the geographic location. While there tend to be 3–5 generations in the UK [24], there may be up to 10 generations under ideal conditions in Southern Europe [11].

Infested plants are characterised by the presence of CW or later by the appearance of honeydew; sap sucking has little effect on the crops, so no retarded or dead plants due to CW sucking have been observed, and no colour changes are visible on the leaves. After the registration of insecticides containing the active ingredient spirotetramat in 2008 and other effective insecticides such as spinosyns or cyantraniliprole [25], CW was a problem only in a small part of less intensively sprayed fields, but especially in organic vegetable production. A recent study by Müller et al. [26] detected field resistance to ketonenol insecticides in some CW populations in Belgium and Germany with cross-resistance to spirotetramat and spiromesifen, indicating an increased risk that insecticide protection against CW may become less reliable and the situation may worsen.

To draw an appropriate sensitive crop protection strategy, it is important to know the CW population trends. Critical data include knowledge of when whitefly populations peak on rapeseed and when they migrate to vegetables [5]. The objective of this investigation was to obtain a better understanding of cabbage whitefly migration and population development on sites selected based on their proximity to vegetable growing areas, validate the biological data for the Czech Republic and help complete missing information about the pest.

2. Materials and Methods

2.1. Spring Abundance of Whiteflies on Oilseed Rape

The survey of the spring abundance of whiteflies was carried out in March or early April in 2014, 2016–2018 and 2021, up to a plant height of 40 cm. The assessment of the fields each year was carried out within a few days. The date was different each year depending on the weather, but the plants were always in the same phenophase.

Forty-four oilseed rape fields across the Czech Republic (Central Europe, 48°39′–50°59′ N, 12°19′–18°29′ E) were inspected for the presence of *A. proletella* (Figure 1). Nine selected sampling sites were located in (1) a vegetable growing area (VGA-1) with oilseed rape grown inside this area or up to 1 km away; twenty-two sites were (2) close to VGA at 3–10 km (VGA-2); and thirteen sites were considered controls with (3) no proximity of VGA at more than 20 km (VGA-3). At each site, ten oilseed rape plants with four repetitions were inspected, and numbers of adults, eggs and nymphs were recorded.

Figure 1. Schematic map of locations of investigated winter rapeseed fields in European context.

The location of the rapeseed fields changed a little from year to year due to crop rotation, but their distance was always within 2 km. The altitude of the sites ranged from 150 to 200 m a.s.l. for (1), 166 to 350 m a.s.l. for (2) and 175 to 530 m a.s.l. for (3). Mean temperatures in the Czech Republic for a given year and deviations from the long-term normal are summarised for selected months in Table 1.

Table 1. Mean temperatures and deviations from the long-term normal for the Czech Republic. Data taken from CHMI [27].

Mean Temperatures and Deviations from the Long-Term Normal for the Czech Republic	January	February	March	April	Annual	Year
Temperature	0.5	2.1	6.2	9.8	9.4	2014
Deviation	2.5	3	3.3	1.9	1.5	
Temperature	−1.4	3	3.3	7.7	8.7	2016
Deviation	0.6	3.9	0.4	−0.2	0.8	

Table 1. *Cont.*

Mean Temperatures and Deviations from the Long-Term Normal for the Czech Republic	January	February	March	April	Annual	Year
Temperature	–5.6	1.1	5.9	6.9	8.6	2017
Deviation	–3.6	2	3.4	–1	1.1	
Temperature	1.8	–3.5	0.8	12.7	9.6	2018
Deviation	3.8	–2.6	–2.1	4.8	1.7	
Temperature	–1.1	–0.8	2.6	5.4	8	2021
Deviation	0.3	–0.4	-0.6	–3.1	–0.3	

2.2. Monitoring of Whiteflies, Their Natural Enemies and Migration Period of Whiteflies

Regular monitoring of cruciferous vegetables was carried out from April to October 2018–2023 as a service for the growers and the Vegetable Union of Bohemia and Moravia (Czech Republic) to prepare a weekly report with the current occurrence of pests, their natural enemies and recommendations for crop protection. During the monitoring of vegetable pests, the first occurrence of adults, eggs and nymphs, as well as the first hatching of whitefly adults from the puparia on cruciferous vegetables, was recorded. The onset of mass migration from oilseed rape was estimated as the presence of more than five adult whiteflies per vegetable plant on at least 90% of the plants in the field.

The fields in the "Polabí" region were inspected once a week. Polabí is an area along the Elbe River where vegetable cultivation predominates. It has the highest concentration of vegetable fields in the Czech Republic. Three sites were monitored: the vicinity of Litoměřice (GPS: 50.5221728 N, 14.1204472 E), Obříství (GPS: 50.3071008 N, 14.4655750 E) and Semice (GPS: 50.1527447 N, 14.8755667 E) with numerous fields with different cruciferous vegetables (cabbage, kale, cauliflower, kohlrabi, etc.). A visual examination of plants was performed. In each site, three to five fields were inspected, depending on year and season. Therefore, a minimum of 40 plants per field was visually inspected in four different places of the field, and the abundance of pests and natural enemies was recorded.

From April to June, all life stages of CW were recorded; however, in this work, we mainly mention the first occurrences of whitefly stages in rapeseed and vegetables. After the mass migration had started, the number of adults was only estimated (increasing/decreasing from week to week) because after the beginning of mass migration, growers started spraying insecticides against CW adults regularly until harvest, and the abundance of adults thus depended more on the spray programme than on migration. All of the monitored fields were used for vegetable production, so no untreated control was available. Monitoring of CW larvae continued until the first adults developed on cruciferous vegetables. This is important because, from this period, cruciferous vegetables are an important source of CW for new vegetable plantings.

Predators of CW were recorded during visual examination of vegetable plants from the first occurrence of CW until the end of October. Hymenopteran parasitoids were examined only from puparia. Leaves with puparia of CW were collected from all three sites (more than 100 puparia on each site) at least twice per season; afterward, the leaves were placed in a plastic cup with mesh on the top and stored in laboratory conditions (23 ± 3 °C) until adults of CW or parasitoids hatched.

2.3. Data Analysis

The "spring abundance" data were statistically analysed with R version 4.3.1 [28]. The count data (numbers of adult whiteflies per plant) were fitted with a negative binomial family using the "glmmTMB" package model [29]. The proximity to VGA (1 = yes, 2 = between, 3 = no) and the year were set as the explanatory variables. Repetition was taken as a random effect. Residual plots from the package "DHARMa" [30] and AIC values were used to select the best model, which was chosen to calculate the variance analysis table (ANOVA function). Tukey's post hoc test ("emmeans" package) was applied for multiple comparisons [31]. The "multcomp" package was used to assign letters to indicate significant differences [32]. A total of 8400 observations were made.

3. Results

3.1. Spring Abundance of Whiteflies on Oilseed Rape

Observation of the first laid eggs on rapeseed was recorded at the beginning of March, specifically on 4 March 2014 in Mochov–VGA 1, when the plants were mostly 10–15 cm high. CW always lay fewer than 10 eggs per clutch initially. The first grey coloration of the eggs, indicating impending hatching, and more than 10 eggs per clutch were observed in mid-March, but usually in early April, when the plants reached a height of more than 20 cm. This period roughly corresponded to the beginning of apricot blossom.

The numbers of CW adults were significantly different on the sampled sites depending on their proximity to vegetable growing areas ($\chi^2{}_2 = 905.77$, $p < 0.001$). The effect of the year was also significant ($\chi^2{}_4 = 136.53$, $p < 0.001$). The highest number of CW individuals was found on oilseed rape plants in VGA-1 in all the sampling years. More details are shown in Table 2. No overwintering whitefly nymphs and puparia were found on the oilseed rape during our survey.

Table 2. Mean numbers of CW adults per plant (mean ± SE) per year over all experimental sites.

Mean Number of *Aleyrodes proletella* Adults in Rape Fields per Plant in Early Spring during the Survey. Different Letters Mark Significant Differences in CW Numbers between Vegetable Growing Areas (VGAs)			
Year	**In VGA**	**Close to VGA**	**Far from VGA**
2014	0.76 ± 0.08 ^{c}	0.06 ± 0.01 ^{b}	0.02 ± 0.01 ^{a}
2016	1.28 ± 0.12 ^{c}	0.05 ± 0.01 ^{b}	0.02 ± 0.01 ^{a}
2017	0.09 ± 0.02 ^{b}	0.02 ± 0.00 ^{a}	0.01 ± 0.00 ^{a}
2018	0.49 ± 0.06 ^{c}	0.07 ± 0.01 ^{b}	0.01 ± 0.00 ^{a}
2021	0.33 ± 0.04 ^{c}	0.06 ± 0.01 ^{b}	0.01 ± 0.0 ^{a}

3.2. Monitoring of Whiteflies, Their Natural Enemies and Migration Period of Whiteflies

The first adults of the generation, which developed on oilseed rape and herbs, usually appeared and laid eggs in cruciferous vegetable around 20 May (Figure 2). Due to cold temperatures in the spring of 2021 and 2023, the occurrence was delayed until early June.

The number of migrating adults gradually increases, and as the oilseed rape dries, a mass migration occurs. The beginning of the mass migration to cruciferous vegetables was usually around 10 June; in 2021, it was postponed until the second half of June. Intense storms at the beginning of July 2021 killed most of the adults in the vegetables, so a significant increase in damage appeared later that year—from the end of July/beginning of August. Mass migration can be recognised by a sudden increase in the number of individuals on brassica plants. Adults can be observed during mass migration and also in other crops (e.g., celery, zucchini) in some years. Mass migration from oilseed rape usually lasted until the beginning of July; in 2021–2023, it was postponed until the end of July/beginning of August due to the late harvest. The rapeseed plants were still green at the beginning of July. The end of the mass migration to cruciferous vegetables is gradual, and it corresponds with the end of the rapeseed harvest in the surrounding fields. During July, individuals hatched from the rapeseed in uplands may also probably migrate to vegetables, up to tens of kilometres. The next generations overlap, and they develop on vegetables and partly on newly germinated rapeseed oil plants on the harvested fields. The main autumn migration from vegetables to new oilseed rape fields in the Czech Republic usually appears around mid-October, but in 2022 it happened at the beginning of September before an unusually long cold and rainy period from 17 September to 13 October appeared.

During our survey of the occurrence of natural enemies of CW in Czech fields since 2011, no significant predator or parasitoid was observed. The dominant syrphid species was *Episyrphus balteatus*. Coccinellidae and other predators were usually low in numbers. *Encarsia tricolor* was recorded on unsprayed vegetables only in 2011.

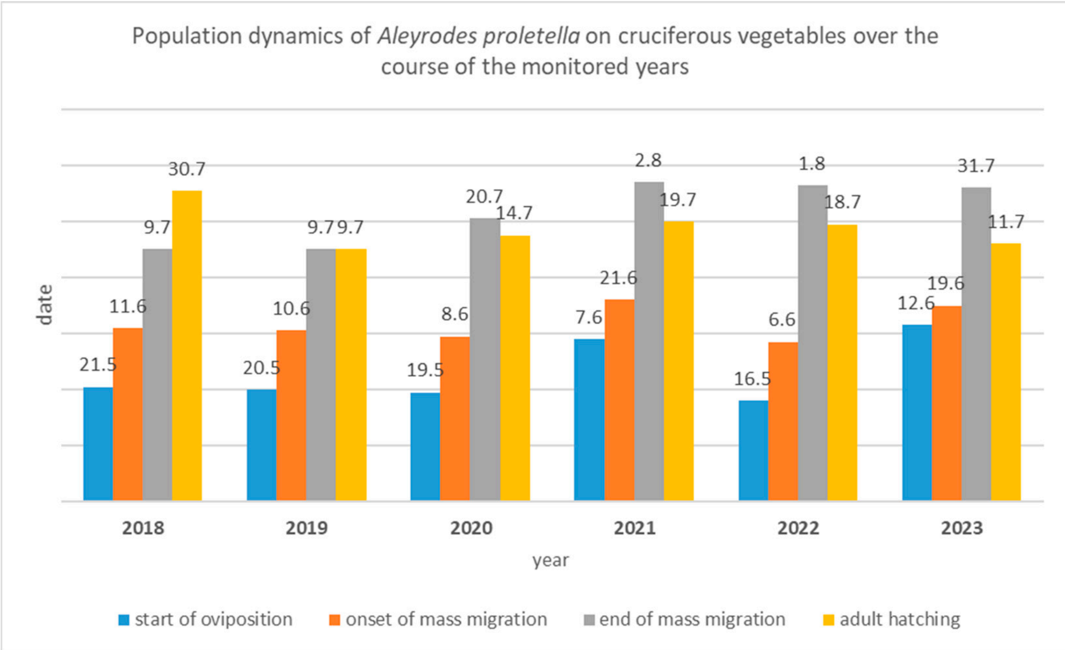

Figure 2. Population dynamics of *Aleyrodes proletella* on cruciferous vegetables over the course of the monitored years.

4. Discussion

Richter and Hirthe [13] reported that overwintering *A. proletella* adults in Germany began ovipositing on oilseed rape, notably at the end of April, and dispersed to new host plants in June. In our case, the first eggs laid on rapeseed were found at the beginning of March 2014, which was a little earlier, but this might have been an effect of different weather. More eggs are usually laid at the end of March or the beginning of April. Also, in contrast to the observations of Iheagwam [21] in southern England, we found no fourth-instar larvae on overwintering rapeseed in March/April. On the contrary, the author states that during winter, there are often many of them, which is due to different winter temperatures in both regions. Because there are no cruciferous vegetables left in the field from autumn to spring in the Czech Republic, we assume that the first generation of CW develops mainly on winter oilseed rape and wild plants (March–May). The second CW generation then develops on rapeseed and partly on wild herbs and vegetables (May–July). The number of generations is generally dependent on the geographic region (temperature) and may also overlap [24]. Therefore, it is not easy to determine the exact order.

Whitefly migration occurs for several reasons–plant death, drying up, or overcrowding–more than six adults per approx. 6.5 cm^2 [33]. Iheagwam [21] also stated that the high density of larvae slows down the development. In our case, the trigger was probably the ripening of rapeseed when the plants were still green but no longer provided favourable conditions for the development of the next CW generation. This was also stated by Richter and Hirthe [13]. Our findings are similar to the results of Richter and Hirthe [13]. Between the years 2014 and 2021, the average number of whiteflies per 10 plants varied between 1 and 13 individuals on winter rapeseed. Let us say that the average number was five individuals per 10 plants in normal years, whilst 2016 and 2017 were exceptionally warm and cold, respectively. This means that CW numbers in the spring did not grow substantially from 2009 to 2011.

Migration and damage rates depend on the weather. During a cold and rainy period in June and July, the mass migration is often interrupted for one or two weeks. Also, intensive rain can reduce the CW population in vegetables. Cruciferous vegetable damage usually occurs from the end of June or the beginning of July. Autumn migration from vegetables to overwintering sites takes place during September/October. In some years, mass migration can actually be observed during warm October days, when adults can be found even in city centres (e.g., in the centre of Prague), far away from the fields. Prague city centre is at least 7 km from the nearest field.

We assume that less than 1% of CW adults are killed by predators (mainly syrphid larvae). Syrphid larvae prefer to feed on cabbage aphids (*Brevicoryne brassicae*); only after eating all the aphids do they start feeding on CW adults. Other predators were usually low in numbers, probably due to frequent spraying with broad-spectrum pyrethroids and better migration capability. Unlike syrphid larvae, they can fly to other nearby crops after aphid predation. In neighbouring Germany, mainly *Encarsia tricolor* parasitises CW nymphs [34,35]. This species was recorded on unsprayed vegetables in the Czech Republic only in 201120. Since then, no additional CW parasitoids (adults or parasitic whitefly nymphs) have been observed, even in fields without pesticide application. Interestingly, the mass occurrence of CW did not lead to an increase in the activity of predators or parasitoids, and this rich food source remained unused.

The first cruciferous vegetables are planted in March, and, depending on the weather, they are covered with netting until mid/late April. Field edges are especially vulnerable to whitefly infestation [5]. The mesh is very effective protection of young plants against colonisation by overwintering CW females. To some extent, it is also possible to use systemic insecticides. With contact insecticides, it is necessary to wet the underside of the leaves well using droplegs [36]. Trap plants can be used to reduce the pest population [37]. On the other hand, trap plants can also be a source of CW, so it is necessary to know when the first adults of the generation who are developing cruciferous vegetables usually appear. According to our observation, it is usually in the first half of July. Remains of cruciferous vegetables on harvested fields can be a habitat for CW and other pests if they are not removed. For this reason, it is necessary to remove post-harvest residues immediately after harvest from the beginning of July and carefully plough them into the soil without leaving plant remains on the surface because adults would hatch from puparia even on dead leaves. The landing behaviour of whiteflies can also be reduced by using reflective and contrast-minimising foils [38]; this method should also be included in integrated and organic farming systems.

The present findings can contribute to whitefly management, especially in organic farming, where the use of pesticides is limited. Suitable means of CW control appear to be (1) a netting system at the right time (before the mass migration), which can be combined with the application of insecticides if necessary, (2) the use of trap plants that can be destroyed by ploughing in shortly before new adults hatch. Several studies [35,39], including the present one, have shown that successful whitefly control cannot be based on naturally occurring predators and parasitoids because their contribution is not sufficient. Laurenz and Mayhöfer [35] tested the implementation of banker plants with *Aleyrodes lonicerae* as an alternative host for natural enemies. Due to the high labour costs, we do not foresee outdoor use of this method.

5. Conclusions

Oilseed rape is a source of CW for surrounding fields with cruciferous vegetables. The first adults migrate from oilseed rape to cruciferous vegetables at the end of May, and a mass migration usually begins between the beginning of June and the beginning of July. Migration to overwintering sites takes place in September–October, and a mass migration usually takes place in October. No significant reduction in CW population by parasitoids or predators was observed in any of the monitored areas.

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