



# Optimization of hoverfly application for biological control in horticulture

In open field production

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Degree project/Independent project • 15 credits  
Swedish University of Agricultural Sciences, SLU  
Department of Biosystems and Technology  
Hortonomprogrammet  
Alnarp 2026

# Optimization of hoverfly application for biological control in horticulture. In open field production.

*Optimering av blomfluganvändning som biologisk bekämpning inom trädgårdsodling. För frilandsodling.*

Emily Janusz Malm

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<b>Credits:</b>	15 credits
<b>Level:</b>	G2E
<b>Course title:</b>	Independent project in Biology
<b>Course code:</b>	EX0855
<b>Programme/education:</b>	Hortonomprogrammet
<b>Course coordinating dept:</b>	Department of Biosystems and Technology
<b>Place of publication:</b>	Alnarp
<b>Year of publication:</b>	2026
<b>Cover picture:</b>	Mating <i>Eupeodes corollae</i>
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<b>Keywords:</b>	<i>Eupeodes corollae</i> , aphids, banker plants, biocontrol

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## Abstract

Aphidophagous hoverflies can be used for biocontrol in greenhouses, but application in open field or high tunnels face the challenge of escaping hoverflies due to their natural migration behaviour. In this study, our goal was to develop a system to increase their loyalty to the release area. Providing enough resources could be the solution to suppress fly migration. Banker plants with alternative oviposition sites were placed in raspberry production tunnels and adult *Eupeodes corollae* Fabricius (Diptera: Syrphidae) were released on the same day or one day thereafter. The study was conducted at two raspberry (*Rubus idaeus* L.) farms in different parts of Sweden, one site in Scania and the other further north in Uppland. We saw a significant effect of the banker plant system; higher numbers of adults were observed in the banker plant treatment blocks than in controls. Oviposition rate was high and larval development was observed. The result shows that the banker plant system works to increase site loyalty and oviposition of hoverflies, but more research is needed for further optimization of the system.

*Keywords:* *Eupeodes corollae*, aphids, banker plants, biocontrol

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# 1. Introduction

Aphids are serious pests in many horticultural and agricultural crops worldwide. Without management, they can cause huge yield losses, not only by feeding but also as virus vectors. Aphids have several natural enemies, some of these are available as biocontrol products to use in Integrated Pest Management (IPM), organic cultivation as well as for home use. Conventionally, aphids have over decades primarily been controlled with chemical pesticides. Chemical pesticides not only pose risks to human and environmental health but are known to cause resistance and thereby become ineffective, therefore they should be seen as the last option in IPM. Alternative methods such as application of biological control agents are therefore to be preferred; arthropods, nematodes, bacteria and fungi are some examples. In aphid management, predators and parasitoids are both effective and available for greenhouse cultures, whilst there are still challenges for open field crops such as raspberries (McMenemy et al. 2009). In addition to the production system, the effectiveness of applied natural enemies depends on several other factors, such as aphid species, release method and environmental conditions. Adult predators and parasitoids are highly mobile and will leave in absence of aphids. To improve their persistence around the crop, secondary plants known as banker plants, can be added to provide alternative prey or hosts that help to sustain natural enemies when pest aphids are absent.

Natural enemies can be promoted by adding and/or allowing secondary plants, also known as banker plants, in the culture. Banker plant systems are primarily used in commercial greenhouse cultures, only a small percentage is used in field crops (Huang et al. 2011). The most commonly used banker plant systems either consist of a host plant infested with an alternative, non-pest prey and a natural enemy or a flowering plant providing pollen as an alternative food source (Huang et al. 2011). The first type is the focus of this study. In the case of aphids, containers of cereal plants infested with cereal specific aphids, such as *Rhopalosiphum padi* L. (Hemiptera: Aphididae), and supplied with the parasitoid *Aphidius colemani* Viereck (Hymenoptera: Braconidae) are commercially available. Not only does the system help the parasitoids survive transport, but it also gives the opportunity of preventive application while assuring survival by supplying an alternative food source and oviposition site. The banker plants are introduced into the greenhouse culture early and refreshed regularly throughout the season. The banker plant method is more cost efficient than continuous releases of adults/pupae (Huang et al. 2011; Miller et al. 2017) although both methods can be combined for optimal control. *R. padi* feed on monocotyledons, such as cereal crops, bulbs and ornamental grasses, limiting the application to non-monocotyledon crops. In cold climates, *R. padi* is host alternating,

overwintering on bird cherry, *Prunus padus* L. The banker plant method is effective in greenhouses due to the beneficial controlled climate and limited chance for the parasitoids to escape.

During their larval development, aphidophagous hoverflies (Diptera: Syrphidae) such as *Eupeodes corollae* Fabricius are important natural enemies of aphids while the adults pollinate flowers as they require floral resources, not prey. With climate changes and bee populations declining, their role as pollinators might become even more important in the future. Hoverflies populate most of the world and several species migrate long distances (Wotton et al. 2019). First individuals of *E. corollae* (Figure 1, Figure 2) usually appear in southern Sweden in May when the temperature rises and disappear in September when temperature drops. Aphids populate Sweden throughout the year; they start feeding and reproducing early spring and stay active late in autumn. Hoverflies continue to migrate more or less throughout the season (Wotton et al. 2019), to find optimal food resources and oviposition sites. *E. corollae* stay active in low temperature, ~10 °C and seem to survive down to 0 °C (Lian et al. 2022) which makes it a good candidate for applied control in Sweden, even outside of its natural season.



Figure 1. Female *Eupeodes corollae* resting on grass, at Hallongården orchard.



Figure 2. Male *Eupeodes corollae* feeding on *Bellis perennis* at Hallongården orchard.

Floral resources, pollen and nectar, are crucial for hoverfly fecundity (van Rijn et al. 2006). Hoverflies have short mouthparts and require relatively flat, open flowers to feed from such as provided by Asteraceae and Apiaceae. Planting flower strips or placing potted flowers near the crop can attract syrphids, leading to better suppression of aphids (van Rijn et al. 2006). It is important to choose plants that have a long flowering period, that are not considered weeds competing with the crop and do not require too much effort from the grower. Martínez-Uña et al. (2013) found that *Coriandrum sativum* L., *Diplotaxis tenuifolia* (L.) DC.,

*Hirschfeldia incana* (L.) Lagr.-Foss. and *Calendula arvensis* L. were the most visited amongst species in their study.

The large raspberry aphid (*Amphorophora idaei* Börner (Hemiptera: Aphididae) Figure 3) and the small raspberry aphid (*Aphis idaei* Van der Goot (Hemiptera: Aphididae), Figure 4) are the most common aphid pests in European raspberry (*Rubus idaeus* L.) orchards, *Am. idaei* being the most prevalent in the north. Other aphid species such as *Myzus persicae* Sulzer (Hemiptera: Aphididae) can also cause problems. Resistance breeding against *Am. idaei* has been largely successful, however resistant-breaking aphid biotypes have overcome all single resistance genes, only multigenic, partial resistance remains (Birch et al. 2004).



Figure 3. Large raspberry aphid, apteros *Amphorophora idaei* birthing (influentialpoints.com 2014).



Figure 4. Small raspberry aphid, apteros *Aphis idaei* (influentialpoints.com 2023).

*E. corollae* larvae (Figure 5) are polyphagous, eating small lepidopteran larvae as well as aphids (Jiang et al. 2022). Aphidophagous hoverflies use a combination of olfactory, visual and sensory cues to find oviposition sites (Almohamad et al. 2009). The predatory hoverfly larvae however depend on their mother's ability to detect and locate aphid infested plants for oviposition. Few studies previously investigated oviposition cues in hoverflies but the knowledge on the specificity and diversity of such compounds is limited.



Figure 5. *E. corollae* larva, possibly 3<sup>rd</sup> instar. On oat leaf at Hallongården orchard.

The chemical ecology group previously established an oviposition assay and confirmed *E. corollae* responds to the green peach aphid *Myzus persicae*. In this project we want to build on previous results by conducting additional assays to test aphid colony growth on potential banker plants, hoverfly oviposition, and develop a banker plant system for application in open fruit production systems. Even though *E. corollae* is a promising biocontrol agent against aphids, there is a demand for developing methods to improve long-term effectiveness. We tested if a banker plant system can be used to increase loyalty and eventually sustain a growing colony.

## 2. Methods and Materials

### 2.1 Hoverflies

Pupae of *Eupeodes corollae* were obtained from Biobasiq (Biobest Group). First arrival at week 10, the colony was then kept in a climate-controlled room at  $20 \pm 2$  °C, 70 % RH and L16:D8 photoperiod, kept on a diet of pollen, 3 % sugar water solution and water. 750 pupae for the field experiment arrived 8 days before release. Once emerged, the adults were divided into 15 cages (size 30x30x30 cm) and allowed to mate.

### 2.2 Cereal aphids

A colony of *Rhopalosiphum padi* (Figure 6) were obtained in week 3, from V. Nincovic at Sveriges Lantbruksuniversitet (SLU) Ultuna. The aphids were transferred to wheat *Triticum aestivum* L. ‘Brons’ in a climate chamber at 23 °C, 60 % RH and L16:D8 photoperiod under full spectrum LED. A second batch of aphids arrived 2 weeks prior to field experiment, transferred to 80 containers of oat in the greenhouse.



Figure 6. Bird cherry-oat aphid, apteros *Rhopalosiphum padi* (*influentialpoints.com, n.d.*).

### 2.3 Cereals

Wheat, *Triticum aestivum* ‘Brons’, were grown from seed in a climate chamber (L16:D8) under full spectrum LED at 23 °C, 60 % RH. Containers 11x11 cm, substrate SW Horto yrkesplantjord. For aphid rearing, 6 containers were sown, 14 seeds each, later 4 new containers per week with 16 seeds each. For production of

banker plants; 20 containers/week with 6 g seeds each in 1.5 l (Ø14 cm) containers.

Oat, *Avena sativa* L. 'Belinda' for aphid rearing; grown from seed in a climate chamber (L16:D8) under full spectrum LED at 23 °C, 60 % RH. 16 seeds each in 3 containers. As banker plants; 20 containers/week with 5 g seed each in 1.5 l (Ø14 cm) containers.

Cereals were sown weekly, wheat starting the first week, oat starting week 5. Small batches in the first 5 weeks were grown in the climate chamber. From week 6 the new batches were placed in a greenhouse.

## 2.4 Aphid rearing

The aphid colony was maintained by transferring aphid covered leaves from older plants to 2 weeks old wheat plants during the first 5 weeks.

At week 6 the first aphid colony growth test was initiated by placing 3 aphids each in 10 oat containers and 9 wheat containers. The plants of each container covered in perforated bags, secured with a rubber band and tape around the container. These 10 containers were placed in the climate chamber.

At week 9, 9 days old wheat and oat plants were prepared for the second aphid colony growth test. In each container, some plants were cut, reducing the number of plants to 60 per container, divided into 3 sections with 20 plants each. The containers were then placed in Bugdorms (size 40x40x70 cm), and aphid colonies were added.

Banker plants for the field experiment were sown in week 12. Infested with aphids in week 13.

## 2.5 Oviposition assay

First and second oviposition assays were performed in week 15. 3 mated females were randomly selected, each transferred to a cage (size 45x45x45 cm) containing one container each of oat and wheat, 8 plants in each. The day before, plants were infested with >50 aphids per plant. Pollen, water and sugar water was provided in petri dishes (Figure 7). The cages were placed in a climate chamber at 23 °C, 65 % RH, 16L:8D (Figure 8). After 24h eggs were counted. One female in each assay failed to oviposit. These females were observed to have narrow abdomen, so for the following assay plumper females were selected.



Figure 7. Cage setup for oviposition assay, *E. corollae*, oat and wheat infested with *R. padi*, feeding dish.



Figure 8. Climate chamber setup for *E. corollae* oviposition assay. Cages evenly placed under full spectrum LED for 24h.

A third oviposition assay was performed in week 13 with sexed and separated hoverflies delivered in week 12, emerged 6-8 days before the assay.

## 2.6 Field experiment Hallongården

*Rubus idaeus* 'Glen Ample' were grown at Hallongården (Bodarpsvägen 144, 231 94 Trelleborg. 55.43588144252733, 13.067271727148196) in poly high tunnels. The experiment was performed in 2 tunnels 80 m long with 3 rows of raspberries in each. The groundcover in the paths between rows was grass with varying degree of wild native plants. A third tunnel, in between the treatment tunnels was used as control, not containing banker plants.

Each raspberry tunnel at Hallongården has 2 paths that each was divided into 8 blocks 7 meters long and 3 meters wide, alternating treatments and controls. The blocks were separated by a buffer area of 2 m. Each replicate consisted of 2 parallel blocks, one in each path. At the north end, a buffer zone of 5 m, at the south end a buffer of 7 m (map in Appendix 1). A third tunnel in between was used as control.

The raspberries were planted in mid-March. The following week, we prepared the ground for sowing of the in-ground banker plant strips; the existing grass was broken up, then we laid new soil on top in strips 15 cm wide, approximately 6 cm

thick and 7 m long in the centre of each treatment block. *Calendula* was sown in sections of 1 m in the middle of each treatment block. Oat was sown 3 m on either side of the *Calendula* (Figure 9a and b).

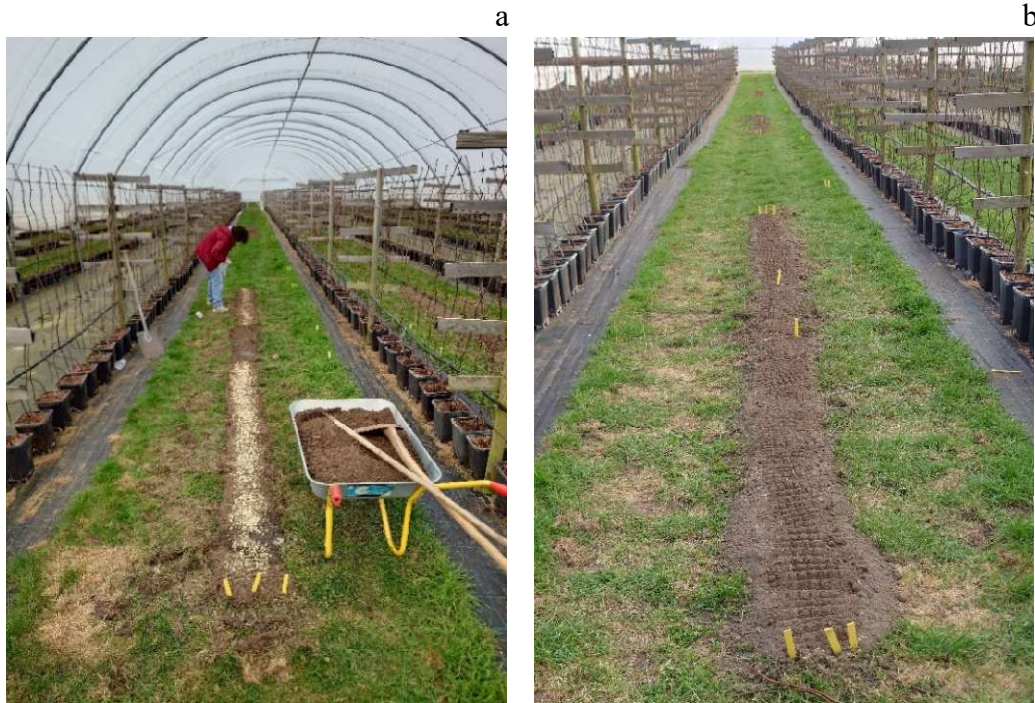


Figure 9. Preparations of treatment block in Hallongården orchard. Sowing oat and *Calendula*, on the right the second block of the same replicate can be seen a), blocks after covering the seeds b).

The grass was not cut in either of these three tunnels, which provided natural food sources from wildflowers, see examples in Appendix 2. To regulate temperature, the south and north sides of the tunnels could be closed or open in varying degrees.

In week 17 the banker plants were placed (day 1), 5 per treatment block, 2 in each 3 m oat section and 1 in the *Calendula* section (Figure 10a and b). Temperature loggers were placed in each tunnel and just outside to the north. The temperature and humidity were logged every 30 minutes.

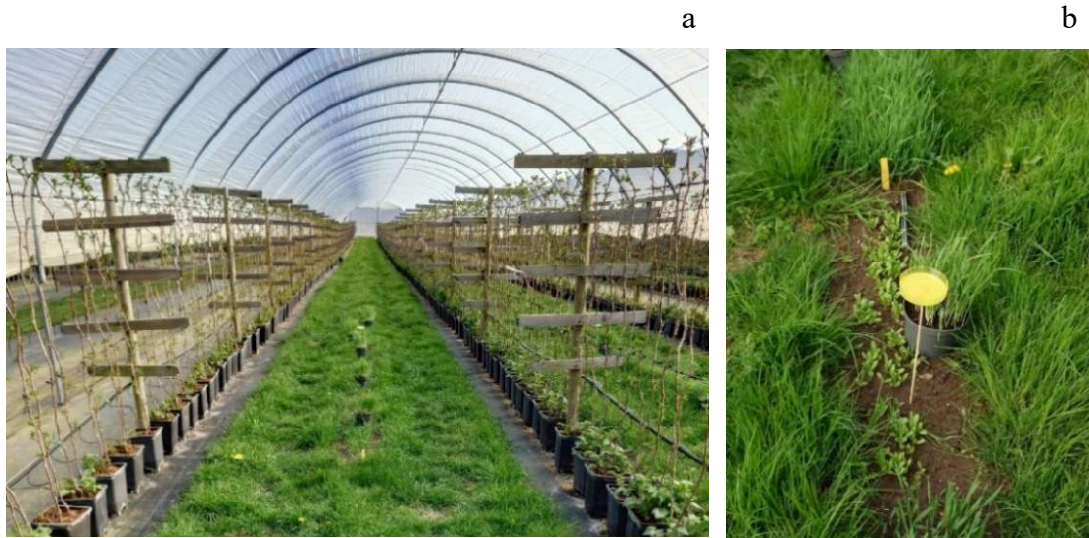


Figure 10. A treatment block in Hallongården orchard a) and field feeding station in middle of treatment block with an elevated petri-dish for pollen feeding b).

The next day (day 2) feeding stations were prepared, then the hoverflies released dynamically throughout each tunnel starting at 10 am. 5 cages of approximately 50 hoverflies each, in total 250 hoverflies per tunnel. Immediately after finished release, a transect walk was done to observe and establish counting parameters. The *Calendulas* did not flower at the start of the experiment. Feeding stations with sugar water and pollen therefore were provided. The first counting of adults in treatment and control blocks was performed between 11 am and 2 pm.

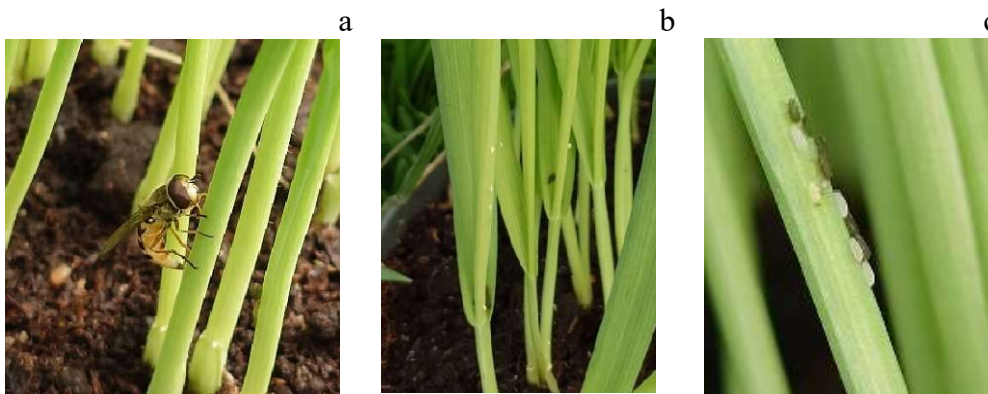


Figure 11 *E. corollae* on banker plant in Hallongården orchard, female ovipositing a), eggs on banker plant b), eggs and first-instar larva c).

The counting procedure for the experiment was set up as:

1. Counting adults, 2.5 minutes in each block; flying, resting, feeding and ovipositing (Figure 11a).
2. Counting eggs on banker plants, 1 minute per plant (Figure 11b).
3. From day 7: The first larvae had hatched (Figure 11c) and were included in the counting.

Counting was documented using an app; Multi Counter by YILMAZ.

*Amphorophora idaei* overwinter as eggs near the base of raspberry canes and are already present upon planting in spring. The first generation can hatch as early as March depending on weather (McMenemy et al. 2009). At Hallongården, no eggs were observed during planting in March.

## 2.7 Field experiment Ulvagubben

Another part of the study was performed at Ulvagubben, Ulva kvarn, 755 93 Uppsala (59.91142802255376, 17.583858482732683), started 3 weeks later due to seasonal difference. Experiment was performed in 2 tunnels with *Rubus idaeus* 'Violet' and 'Glen Ample'. Tunnels 90 m long with 3 rows of raspberries. A third tunnel was used as control. The ground was covered in the tunnels, with white or black plastic film.

Each tunnel was divided into 4 blocks, each containing 4 containers of oat infested with aphids (Figure 12). On day 1 the containers were placed on top of the substrate in the raspberry containers, one of the watering spikes moved to the oat. In each tunnel, 16 containers of oat. For the control tunnel, the oat was not aphid infested.

300 hoverflies were released in each tunnel. The first count performed on day 2, the second count on day 3.

On day 1 other beneficials were released as well, as part of the orchard's normal pest control; *Aphidius colemani*, *Aphidius ervi* Haliday, *Aphelinus abdominalis* Dalman (Hymenoptera: Aphelinidae) and *Ephedrus cerasicola* Stary (Hymenoptera: Braconidae).



*Figure 12. Setup of treatment block at Ulvagubben orchard. Banker plant containers of oat placed on the substrate in the raspberry containers. For treatment tunnels, the oat was infested with aphids, for the control tunnel the banker plants had no aphid infestation.*

## 2.8 Statistical analysis

All data was analysed in R (version 4.6.0). Ggplot2 (v. 4.2) was used for visualization.

To test on which host plant supported aphid population growth better we compared the number of aphids on oat and wheat using a Mann-Whitney test from stats package.

For the oviposition assay the Shapiro-Wilk test was used to test for normal distribution, as it is powerful for small datasets and using counts opposed to continuous values. To test for significance, the Wilcoxon test was used from stats package.

For the adults counted in field experiment, test of normality was performed with Shapiro-Wilks test for normal distribution. Generalised linear model (GLM) and DHARMA package (v0.4.7) was used for test fit of negative binomial distribution to the observed data. If ( $p < 0.05$ ) then negative binomial model is the best fit. Treatment and day of observation was used as covariates.

## 3. Results

### 3.1 Aphid colony growth test

In the aphid colony growth test, there was no significant difference in the number of aphids on wheat and oat plants after 15 days ( $p > 0.05$ ).

### 3.2 Oviposition assay

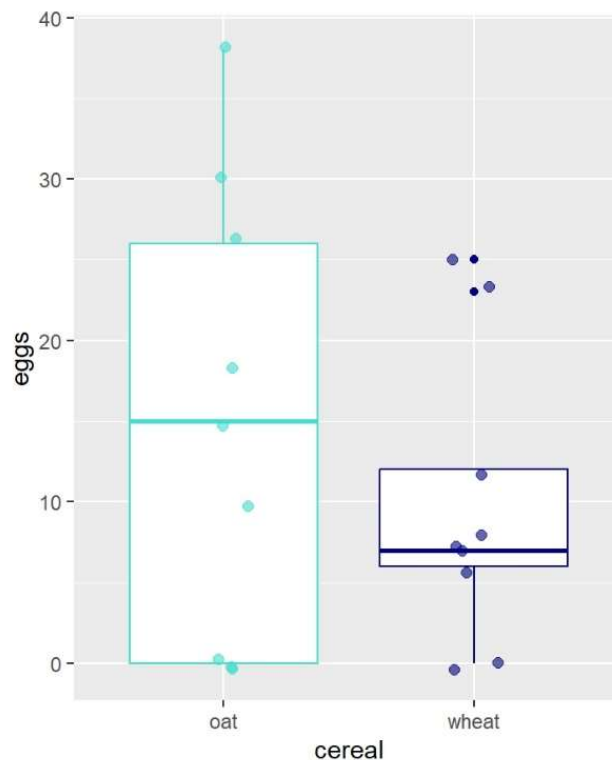


Figure 13. Distribution of *E. corollae* eggs in oviposition assays. Colour and x-axis show cereal type, and y-axis shows number of eggs. The lower and upper lines of the box frames 50 % of the values (lowest and highest 25 % are outside the box), and the inner line is the median. The whiskers show the minimum and maximum counts. Each dot is an individual count. For wheat, the smaller dots at 23 and 25 are outliers.

To determine whether the eggs were normal distributed, Shapiro-Wilk test was performed. The result was  $p > 0.05$ , meaning that we cannot confirm that there is not a normal distribution. However, since the dataset is so small and consisting of counts, it is still indicative to perform the Wilcoxon signed-rank test. This gave  $p > 0.05$ , showing no significant difference between plant of preference for oviposition (Figure 13). Figure 14 shows oat at the end of assay 1.



Figure 14. Aphid infestation level for oviposition assays, and *E. corollae* eggs (white) after the 24h assay.

### 3.3 Hallongården field experiment

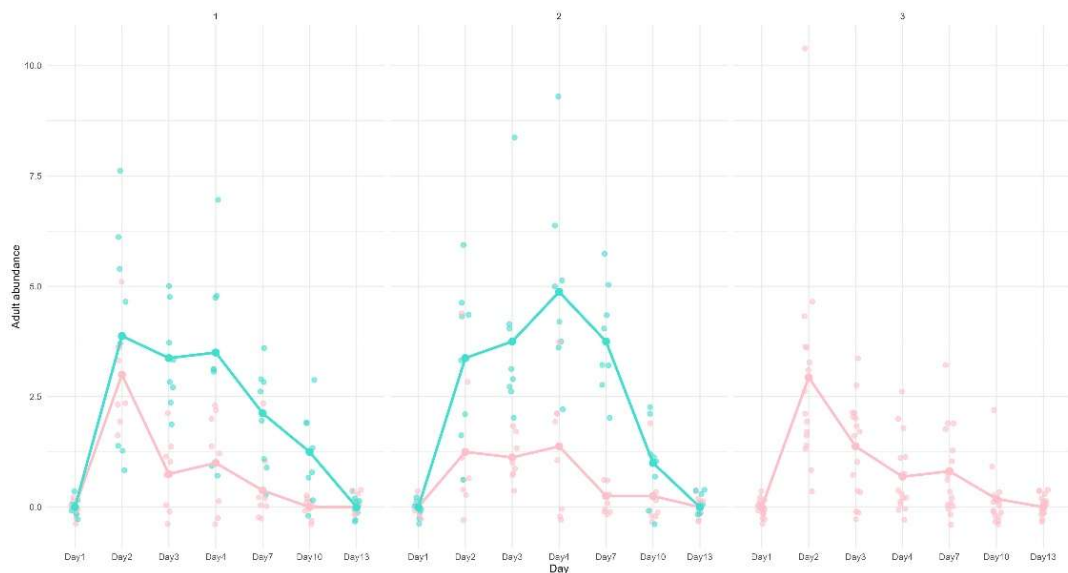


Figure 15. The number of adult *E. corollae* counted in each tunnel in Hallongården field experiment and mean (line) per sample day. The adults were counted while walking through the blocks and searching for flying and sitting adults. Each dot shows the sum for each replicate i.e. the sum of 2 parallel blocks. Tunnel 1(left) treatment blocks (blue) and control blocks(pink), 2(middle) treatment blocks (blue) and control blocks(pink) and 3 (right) tunnel without banker plants, only control blocks. X-axis shows sample days, y-axis shows count.

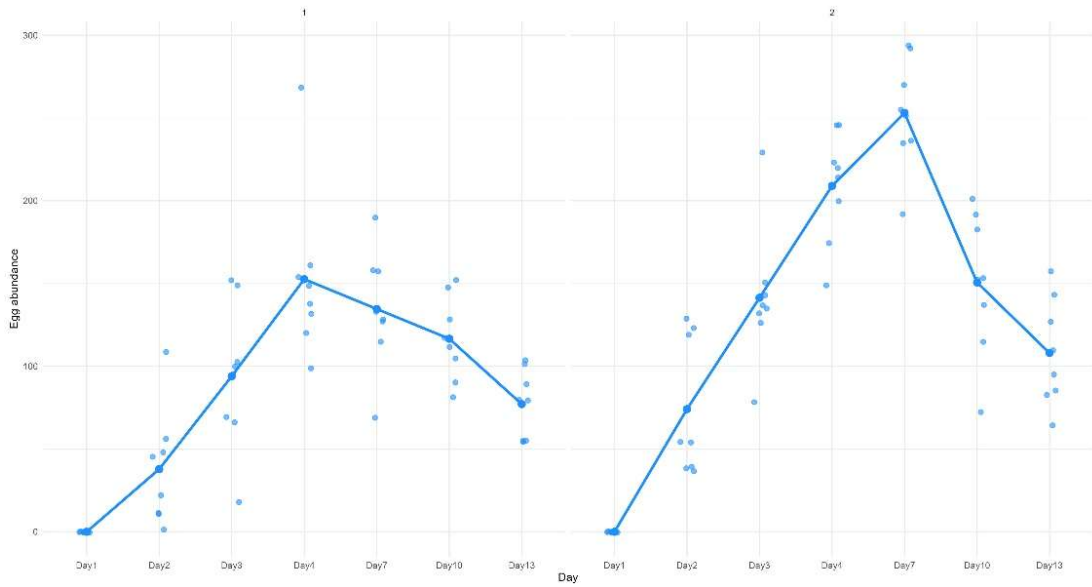


Figure 16. The counted number of *E. corollae* eggs on banker plants in Hallongården field experiment. Eggs were counted by inspecting banker plants individually. The number of eggs for each replicate (dots), is the sum of the 2 paired treatment blocks (each block containing five potted banker plants, i.e. 10 banker plants per replicate). Counts are shown separately for tunnel 1 (left) and tunnel 2 (right). Line shows mean for each sample day. X-axis shows sample days, y-axis shows count.

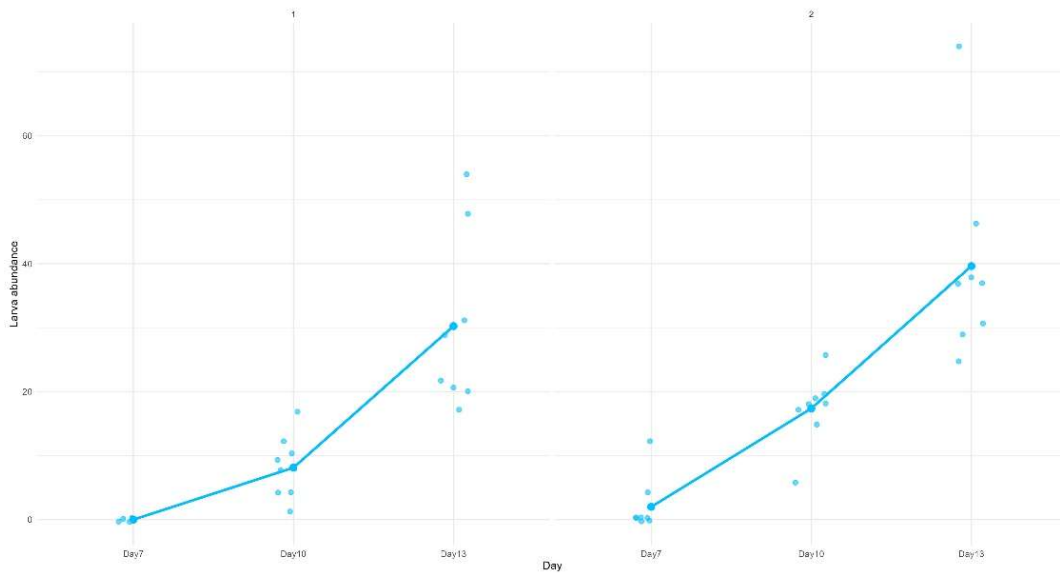


Figure 17. The counted number of *E. corollae* larvae on banker plants in Hallongården field experiment. The larvae were counted by inspecting banker plant individually. The number of larvae for each replicate (dots), is the sum of the 2 paired treatment blocks (each block containing five potted banker plants, i.e. 10 banker plants per replicate). Counts shown separately for tunnel 1 (left) and tunnel 2 (right). Line shows mean for each sample day. X-axis shows sample days, y-axis shows count.

Adult hoverflies were observed in all tunnels, until day 13 (Figure 15). Eggs were present at the first count, 4h after release on day 2, increasing during subsequent days in amount until peak at day 4 for tunnel 1 and day 7 for tunnel 2 (Figure 16). Larvae were first observed on day 7, count and mean in Figure 17. No adult hoverflies were observed before release. After day 4, the number of observed adults started to decline. After day 13 no adults were counted.

Based on GLM and Shapiro-Wilk test ( $p = <0.001$ ) we used a negative binomial model. Banker plant presence in block vs. absence, and day of observation had significant effect ( $p = <0.001$ ) on the count of adults.

We observed that the spread of aphids from the banker plants in containers to the oat strip sown in the ground was limited; still eggs and larvae on the strip were observed but not counted (Figure 18, Figure 19). Ants guarding the aphids were present from day 1 and spread throughout the duration of the experiment. Despite all the ants, development of hoverfly larvae was observed. See different development stages and larvae eating aphids in Figure 20.



*Figure 18. E. corollae eggs on oat strip in Hallongården orchard.*



*Figure 19. Small E. corollae larva on oat strip in Hallongården orchard.*

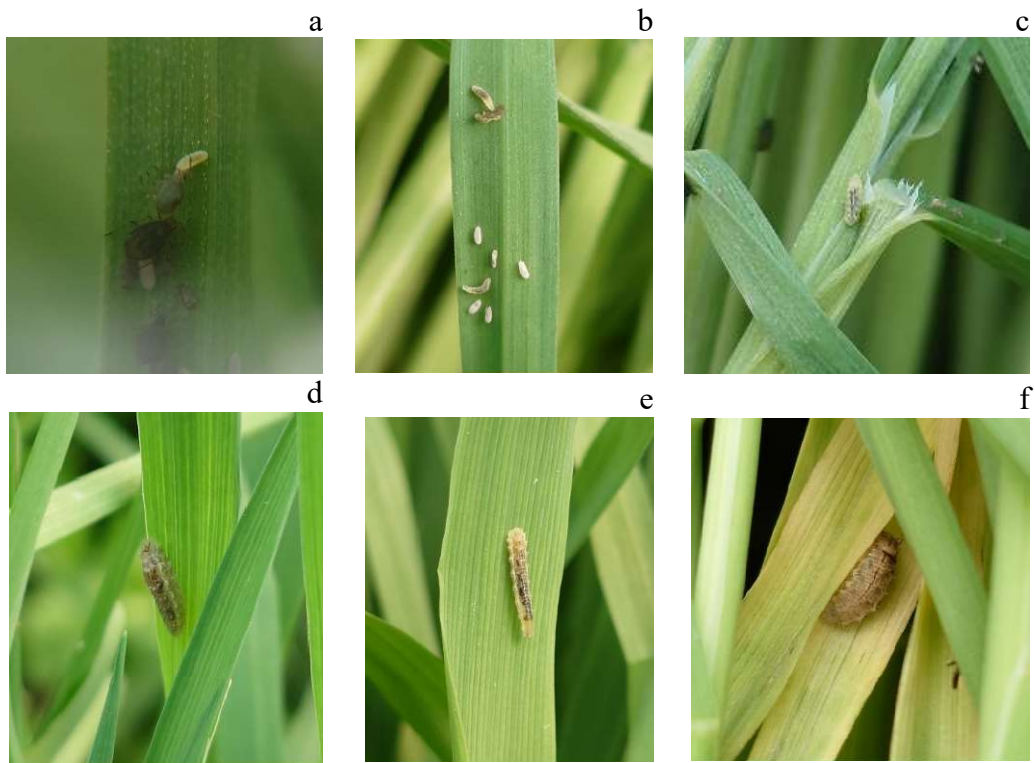


Figure 20. Larval development stages of *E. corollae* on oat banker plants in Hallongården orchard a-f).

During the first week of the experiment, a few individuals of other hoverfly species was observed as well. We were unable to precisely identify them but got a photo of one (Figure 21). On day 17 some observations of adult, unidentified hoverflies were made (Figure 22a-b). By then the expected lifetime of the released *E. corollae* were exceeded. In studies such as Lillo et al. (2021) and Li & Wu (2023) the adult stage lasted 11-24 days in lab conditions.

Throughout the experiment other natural enemies like lady beetle *Coccinella septempunctata* and parasitic wasps, as well as aphid mummies, were also observed. By the end of the experiment, no aphid infestation of the raspberry plants had been observed.



Figure 21. Possibly *Sphaerophoria* sp. On grass in raspberry tunnel at Hallongården orchard.



a



b

Figure 22. Other hoverflies observed in raspberry tunnels at Hallongården orchard. Hoverfly belonging to *Syrphus* genus a) and individual similar to *Scaeva pyrastris* b).

### 3.4 Ulvagubben field experiment

On the first 3 days, the temperature was below 10°C. The flies were difficult to release as they stayed quite inactive. On the first 2 counts, only few adults were observed, mainly sitting on leaves ( Figure 23), no eggs were observed. A third count will be conducted on day 15 (not included here).



Figure 23. *E. corollae* resting on raspberry leaf in Ulvagubben orchard.

## 4. Discussion

*Eupeodes corollae* larvae are known to be polyphagous and are able to complete their life cycle on different aphid species, including *R. padi* (Jiang et al. 2022; 2024), making it well suited for these experiments. *R. padi* are used in commercially available banker plant systems due to their low risk of infesting non-cereal crops. Figure 13

The oviposition experiment showed that *E. corollae* readily oviposits near *R. padi* on both cereals, wheat and oat. In a 24h period, oviposition rate was comparable to Jiang et al. (2022) and in one of our assays (data not included) a single female oviposited 155 times (photo in Appendix 3). Further testing could show if this was an outlier or can occur more regularly. Gonzalez et al. (2023) showed that *Eupeodes americanus* prefers to oviposit on plants with less trichomes if available which should be taken into consideration when pairing a banker plant to a value crop.

The population growth of *R. padi* did not show significant difference on the tested cereal cultivars. We tested if *E. corollae* have preference for *R. padi* on either of the cereal cultivars. The oviposition assays did not show any significant difference (Figure 13). Accordingly, we considered that either one would be a suitable banker plant. We observed a slight tendency for preference, although non-significant, for ovipositing near aphids on oat, which was selected as banker plant systems for the tunnel experiments.

The result of the field experiment at Hallongården shows great promise for a future commercial product. Despite fluctuating temperatures (see Appendix 4) loyalty and survival of the hoverflies shows that *E. corollae* can be applied before the natural immigrating flies arrive. As seen in Figure 15, the retention of adults in the field was significantly higher in blocks with banker plants compared to both control blocks in the same tunnel and the control tunnel where banker plants were not present. It also indicates that the presence of banker plants has a local effect. For future implementation, the optimal distance between banker plants needs to be established to obtain an even distribution of hoverflies throughout the field. The lower infestation rate of some banker plants is likely to have affected the result, although this shows that even a moderate aphid infestation is enough to maintain *E. corollae* in the tunnel.

We verified that the released adult *E. corollae* oviposited on banker plants (Figure 11). The abundance of eggs on the potted banker plants (Figure 16) started to increase from the day of release and continued to increase until adult abundance started to decline. We observed an increasing number of *E. corollae* larvae from

day 7 which were also developing in size (Figure 17, Figure 20). This shows that larvae survived in the cultivation tunnels despite occasionally low and high temperatures (Appendix 4). Extreme temperatures (min. 1,7 °C, max. 38,4 °C) in cultivation tunnels (see Appendix 4) could have had a negative impact on adult survival, being outside the temperature optimum of *E. corollae* adults (Biobest Group NV 2020) but further evaluation is needed to verify this trend (Lian et al. 2022). The presence of ants could also have influenced the abundance of *E. corollae* larvae. Several ant species are known to protect aphids (Rodríguez-Gasol et al. 2020) and can remove eggs and larva of aphid natural enemies from guarded plants. Despite their presence, egg abundance was increasing over time and development of hoverfly larvae was recognizable (Figure 17, Figure 20). The most mature larvae observed were close to pupation, indicating that the lifecycle was close to completion. Temperature affects the rate of development, as does diet (Jiang et al. 2022) making it difficult to calculate time for pupation and emergence of adults. Egg mortality is usually high and conspecific larvae occasionally feed on eggs if aphid availability is low (Li & Wu 2023). By the end of the experiment, adult hoverflies had reached the end of their expected life time (Lillo et al. 2021). Under the controlled optimal conditions in Lillo et al. (2021), the mean adult longevity was  $23.81 \pm 1.143$  days, the mean pre-adult stage lasted  $13.70 \pm 0.078$  days. At sample day 13, the adults in this experiment had emerged 20-23 days prior.

As we could not distinguish between the immigrating individuals and the offspring of released adults, any observation of adult *E. corollae* after this period could not be included in the count.

Upon experiment start, the aphid infestation on the banker plants was relatively low. A higher infestation rate could have sped up the spread of *R. padi* to the oat strip and possibly led to a higher count of hoverfly eggs and survival of larvae. A larger original aphid colony would also have provided the possibility of manually transferring aphids to the strip. A larger aphid infestation increase the amount of released volatile compounds (Almohamad et al. 2009), which could lead to even better adult loyalty, increased oviposition, larva survival and eventually building a colony through new generations.

To the best of our knowledge, this study is the first of its kind to achieve retention of the released hoverflies outside of greenhouse environments and, with some adaptations, this banker plant system could be effective in open production in colder climates. More research is needed however to optimize banker plant density and evaluate the effect of application on aphid infestation levels on raspberries and fruit yield.

Pineda & Ángeles Marcos-García (2008) had a similar setup to ours; partially open plastic greenhouses, although blocks were separated with fine mesh. Barley was sown in the ground in early season and later infested with *Rhopalosiphum maidis* Fitch (Hemiptera: Aphididae). Later 1-day old *Episyrphus balteatus* DeGeer (Diptera: Syrphidae) were released. They did not observe any *E. balteatus* offspring (e.g. eggs and larvae) but instead several local species including *E. corollae*. The main pollen source in that study was the crop sweet pepper, *Capsicum annuum* L..

The presence of other hoverflies indicates that the banker plants not only retain the released hoverflies but also attracted species present in the orchard (see Figure 21Figure 22). This finding is similar to Pineda & Ángeles Marcos-García (2008). During the experiment we also observed other naturally occurring predators such as lacewings and ladybeetles. This can indicate increased predatory pressure by other species and that the system could become self-sustaining once started in spring. In greenhouse cultivation, banker plant systems work with very few plants per area (Pineda & Ángeles Marcos-García 2008), as dispersion is limited.

Studies on how to attract hoverflies have been conducted, investigating which flowers syrphids visit most frequently in various geographical locations. Several plant species of Asteraceae and Apiaceae meet hoverfly feeding criteria (Almohamad et al. 2009; Martínez-Uña et al. 2013; Grosso et al. 2025). Branquart et al. (2000) studied which wildflowers hoverflies visit in western Europe, finding that species belonging to the *Ranunculus* (Ranunculaceae) and *Pastinaca* (Apiaceae) genus were the most attractive.

The retention of hoverfly adults in both cultivation tunnels where banker plants are present and not, could have been influenced in this study by availability of floral resources, this could be tested in a future experiment. We observed hoverflies feeding on several native wildflowers in this study, see examples in Appendix 2 (not including either *Lamium*). In a future study, early flowering plants, selected for phenotype suitable for hoverflies' short mouthparts, can be sown in the field to provide floral resources. Allowing the local wildflowers to grow in and near the field increases abundance of nectar and pollen sources while providing a wider range of nutrients. *Calendula* are highly suitable for hoverflies (Martínez-Uña et al. 2013) and cold resistant varieties are available. Due to the timeframe and cold early spring conditions on the field, the *C. officinalis* we had grown in the greenhouse did not reach flowering stage. For future experiments, a production time in greenhouse of minimum 10 weeks would be desirable. Since one of the aims for this study was to introduce hoverflies before their natural occurrence, requirements for selected flowers include tolerating the low spring temperatures when transferred to the field. A general field observation we made

was that blocks with more flowers had more adult hoverflies and, for treatments, also a higher oviposition rate. Further analysis is needed though to statistically evaluate this observation.

In raspberry orchards, parasitoid wasp applications have shown relatively low efficiency (McMenemy et al. 2009). The parasitic wasp, *Aphidius ervi* can parasitize *Amphorophora idaei*. Each female parasitic wasp can lay more than 300 eggs in four to five days (Cloyd 2024); each egg is inserted into a single aphid, which is then consumed from within. The effect on aphid population however was shown to be variable (McMenemy et al. 2009) . Hoverflies could provide a promising complementary method to this application since each larva can eat hundreds of aphids (Lillo et al. 2021), up to 1000 (Biobest Group NV 2020). Hoverflies fecundity depends on their diet (Li & Wu 2023), but studies have shown that females can lay over 800 eggs in their life (Biobest Group NV 2020).

World-wide, few banker plant systems are available for open field applications, some studies have been published, such as Zheng et al. (2017). A few studies on banker plants for syrphids have been conducted (Pineda & Ángeles Marcos-García 2008; Gonzalez et al. 2023).

Since a larger amount of banker plants are needed in open field, start up in spring could be more expensive and require bigger initial effort than in greenhouses. The system has potential to be more cost-efficient and require less maintenance over time by having banker plants and flowers incorporated in the crop system. Another possible advantage, since hoverflies are avid pollinators, is that yield could increase. Testing that could be part of future studies.

Overall, our results demonstrate that banker plant systems using *E. corollae* and *R. padi* have strong potential for biological control in tunnel-grown raspberries, providing a basis for sustainable pest management strategies in open and semi-open cultivation systems in the future.

# Acknowledgements

I want to thank my supervisors Paul Becher and Anna Laura Erdei for all of their invaluable support. And thank you to Adam Flöhr for helping with statistical preparations.

I also want to thank the raspberry farms for participating and assisting us when needed:

- Johan Biersjö at Hallongården (Bodarpsvägen 144, 231 94 Trelleborg)
- Ivan Vysochanskyi and Fredrik Hörenius at Ulvagubben, (Ulva kvarn, 755 93 Uppsala)

And thank you to Kabbarps trädgård for donating 64 *Coriandrum sativum* plants.

Funding from The Swedish Board of Agriculture for the project

*Optimization of Hoverfly application for biocontrol in horticulture (2024-3098)*

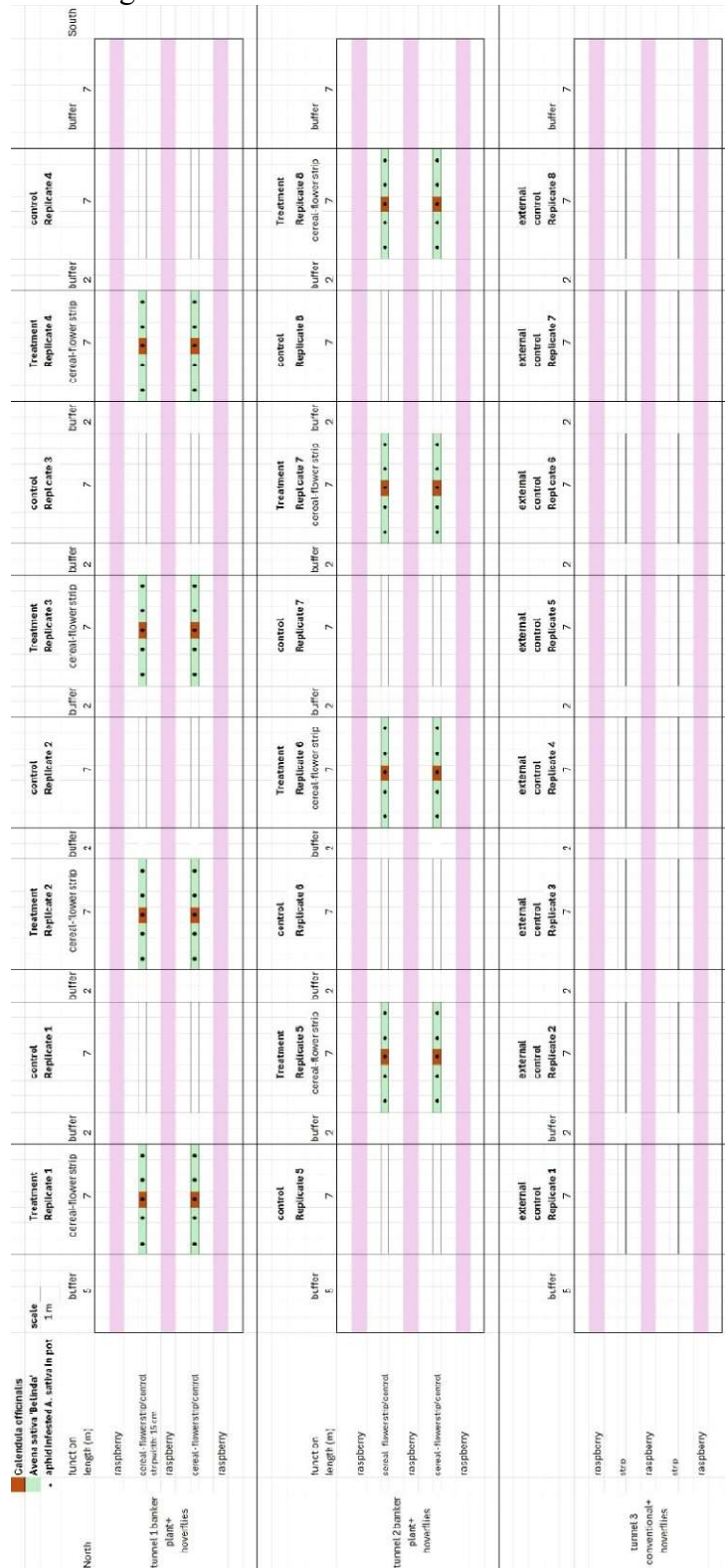
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# Appendix 1

## Tunnel layout Hallongården.



## Appendix 2



*Stellaria media*



*Bellis perennis*



*Cardamine hirsuta*



*Veronica persica*



*Veronica polita*



*Veronica sp.*



*Lamium purpureum*



*Lamium amplexicaule*



*Geranium molle*



*Taraxacum sp.*

Examples of flowering plants observed in the tunnels at Hallongården orchard.

## Appendix 3



Oat leaf, front and back, with 37 eggs.

# Appendix 4

*Table 1 Temperature data for sampling days at Hallongården*

tunnel 1				
date	sampling_mean_temp	period_mean_temp	period_min_temp	period_max_temp
2026.04.21	<b>23,752 °C</b>	<b>8,885 °C</b>	<b>3,25085</b>	<b>28,82215</b>
2026.04.22	<b>31,345 °C</b>	<b>10,239 °C</b>	<b>2,731 °C</b>	<b>32,766 °C</b>
2026.04.23	<b>32,799 °C</b>	<b>16,181 °C</b>	<b>5,870 °C</b>	<b>38,404 °C</b>
2026.04.24	<b>31,198 °C</b>	<b>13,782 °C</b>	<b>4,062 °C</b>	<b>36,831 °C</b>
2026.04.27	<b>27,327 °C</b>	<b>14,069 °C</b>	<b>1,490 °C</b>	<b>37,211 °C</b>
2026.04.30	<b>29,625 °C</b>	<b>14,92 °C</b>	<b>1,65 °C</b>	<b>35,81 °C</b>
2026.05.04	<b>24,18 °C</b>	<b>18,85 °C</b>	<b>4,43 °C</b>	<b>39,15 °C</b>

tunnel 3				
	sampling_mean_temp	period_mean_temp	period_min_temp	period_max_temp
2026.04.21	<b>22,994 °C</b>	<b>8,537 °C</b>	<b>3,05632</b>	<b>27,97762</b>
2026.04.22	<b>28,670 °C</b>	<b>10,164 °C</b>	<b>2,488 °C</b>	<b>31,161 °C</b>
2026.04.23	<b>29,739 °C</b>	<b>15,570 °C</b>	<b>5,788 °C</b>	<b>35,724 °C</b>
2026.04.24	<b>28,689 °C</b>	<b>13,014 °C</b>	<b>4,001 °C</b>	<b>29,743 °C</b>
2026.04.27	<b>24,908 °C</b>	<b>13,424 °C</b>	<b>1,558 °C</b>	<b>32,113 °C</b>
2026.04.30	<b>26,059 °C</b>	<b>14,11 °C</b>	<b>1,91 °C</b>	<b>32,86 °C</b>
2026.05.04	<b>22,16 °C</b>	<b>17,81 °C</b>	<b>4,49 °C</b>	<b>35,95 °C</b>

tunnel 2				
	sampling_mean_temp	period_mean_temp	period_min_temp	period_max_temp
2026.04.21	<b>22,204 °C</b>	<b>8,346 °C</b>	<b>2,82543</b>	<b>26,50986</b>
2026.04.22	<b>29,395 °C</b>	<b>10,314 °C</b>	<b>2,495 °C</b>	<b>30,939 °C</b>
2026.04.23	<b>30,385 °C</b>	<b>15,974 °C</b>	<b>5,830 °C</b>	<b>36,880 °C</b>
2026.04.24	<b>28,986 °C</b>	<b>13,695 °C</b>	<b>4,121 °C</b>	<b>33,026 °C</b>
2026.04.27	<b>26,611 °C</b>	<b>13,927 °C</b>	<b>1,563 °C</b>	<b>35,542 °C</b>
2026.04.30	<b>26,973 °C</b>	<b>14,87 °C</b>	<b>2,01 °C</b>	<b>35,68 °C</b>
2026.05.04	<b>23,56 °C</b>	<b>18,37 °C</b>	<b>4,56 °C</b>	<b>39,81 °C</b>

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