Evaluation of *Euseius gallicus* as a biological control agent of western flower thrips and greenhouse whitefly in rose

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ABSTRACT

*Euseius gallicus* is a new phytoseiid species recently described from southern France that has shown potential as a biocontrol agent for thrips and whitefly in rose, if pollen is supplied as an additional food source. To investigate if the use of *E. gallicus* provides improved thrips and whitefly control, we conducted laboratory experiments examining the biology of *E. gallicus* and a semi-field experiment comparing the biological control efficiency of *E. gallicus* with that of *Amblydromalus limonicus* and *Amblyseius swirskii*, two phytoseiid species commonly used for biological control of thrips and whitefly in roses. *Euseius gallicus* had high oviposition rates on *Typha latifolia* pollen (3.9 eggs/day) and on young whitefly eggs (3.6 eggs/day). Oviposition on first instar *Frankliniella occidentalis* larvae was lower (1.5 eggs/day). *Euseius gallicus* predated 2.6 first instar thrips larvae per day; however, predation of thrips larvae was nearly zero when *T. latifolia* pollen was offered as a supplementary food source. *Euseius gallicus* females did not enter diapause under short-day conditions, and juvenile development was completed at 13°C. When released in combination with *T. latifolia* pollen on roses in the semi-field trial, *E. gallicus* developed the largest population of the predatory mites tested; however, despite reducing the whitefly population, it had no control effect on the thrips population.

Key words: Phytoseiidae, Thripidae, Aleyrodidae, predation, alternative food

INTRODUCTION

Greenhouse whitefly, *Trialeurodes vaporariorum* (Gennadius), and western flower thrips, *Frankliniella occidentalis* (Pergande), are major pests of greenhouse roses. The generalist predatory mite species *Amblyseius swirskii* Athias-Henriot, *Amblydromalus limonicus* (Garman & McGregor), and *Transeius montdorensis* (Schicha) are currently used as biological control agents of both pests (Bolckmans et al. 2005; Knapp et al. 2013; Medd and GreatRex 2014; Steiner et al. 2003). Some growers also use *Neoseiulus cucumeris* (Oudemans) for western flower...
thrips control, and the whitefly parasitoids Encarsia formosa Gahan and Eretmocerus eremicus Rose & Zolnerowicht are important components of whitefly biocontrol (Van Lenteren 2012). However, biological control of both pests remains difficult in roses for several reasons (Heinz et al. 2004). As roses are sold for their aesthetic value, the level of damage that can be tolerated is much lower than in vegetables. Furthermore, roses are not suitable plants for certain biocontrol agents; for instance Orius spp. cannot lay eggs in the woody plant parts (Chow et al. 2008; Heinz et al. 2004) and any suitable oviposition sites (softer stems of flowers) are harvested, which removes a potential new generation of predators from the greenhouse (Messelink et al. 2014). Roses also lack domatia, which are refuges in the plant for natural enemies (Walter 1996). On sweet pepper, which has domatia and provides pollen during flowering as supplementary food for predatory mites and Orius spp., biological control of thrips and whiteflies works excellently (Abdala-Roberts et al. 2014; Calvo et al. 2012).

Due to low tolerance levels for thrips and whitefly in ornamental crops, it remains difficult to maintain a constant population of predatory mites that is sufficiently high to control these pests. Therefore, predatory mites need to be released at regular intervals or other strategies need to be developed to maintain predator populations in the greenhouse. Providing supplementary food is one such potential strategy (Messelink et al. 2014).

Euseius gallicus Kreiter & Tixier is a phytoseiid species recently described from southern France (Tixier et al. 2010). It has also been recorded from Tunisia, Belgium, Germany, the Netherlands, and Turkey (Döker et al. 2014; Kreiter et al. 2010). Unlike the phytoseiid species mentioned above, which are classified as generalist predators of small insects and mites (type III), Euseius species are pollen-feeding generalist predators (type IV) (McMurtry and Croft 1997). Type III phytoseiids also feed on pollen but prefer, or show better performance, on insect or mite prey. Type IV predatory mites have their highest reproductive capacity when feeding on pollen, and populations in the field often increase significantly when the crop or the surrounding vegetation is flowering (McMurtry et al. 2013).

Recently, E. gallicus has shown potential as a biocontrol agent for western flower thrips and whiteflies in roses when Typha sp. (cattail) pollen is supplied as an additional food source (Biobest 2013; Wackers 2013). However, no data on the performance of E. gallicus on thrips or whiteflies are available.

Provision of pollen as a supplementary food source can improve biological control of whiteflies and thrips by type III phytoseiids (Nomikou et al. 2010; van Rijn and Sabelis 1993), and control works excellently in crops where pollen is naturally available (Calvo et al. 2012). The population of Euseius species can grow faster than the population of type III phytoseiids when pollen is provided as a food source. Adar et al. (2014) reported that a Euseius scutalis (Athias-Henriot) population increased tenfold when pollen was supplied, whereas an A. swirskii population increased only twofold. On avocado, the provision of pollen has been shown to increase populations of E. scutalis and improve control of the persea mite Oligonychus perseae Tuttle, Baker and Abbatiiello in the laboratory and in the field (Maoz et al. 2011).

The objectives of the present study were to (1) investigate selected biological parameters of E. gallicus in the laboratory, (2) check if E. gallicus applied in combination with pollen can improve thrips and whitefly control on rose compared with regular releases of A. limonicus and A.
swirskii, and (3) compare single release of *E. gallicus*, *A. swirskii*, or *A. limonicus* plus pollen application with regular releases of *A. limonicus* and *A. swirskii* without pollen application, which is a strategy currently used by many rose growers in the Netherlands.

**MATERIALS AND METHODS**

*Mites, insects, and pollen*

*Euseius gallicus* was collected from horse chestnut and linden trees in Saorge (43°59.347’ N, 07°33.099’ E) and La Brique (44°03.745’ N, 07°36.535’ E) in southern France in 2013. After collection, the mites were reared in a climate-controlled room at 25°C, 75% relative humidity, under a L16:D8 light regime on reversed sweet pepper leaves placed on water-soaked cotton wool. The culture was fed *T. latifolia* pollen. *Amblyseius limonicus* and *A. swirskii* originated from the commercial mass rearing at Koppert Biological Systems, Berkel en Rodenrijs, The Netherlands and were either directly used in experiments or maintained in the laboratory under similar conditions as *E. gallicus*. *Trialeurodes vaporariorum* was reared on tobacco plants in a greenhouse and *F. occidentalis* was reared in the laboratory on bean pods. *Typha latifolia* pollen was collected in the Netherlands and stored at −18°C for approximately 2 years before it was used in the experiments.

**Oviposition rate on thrips, whiteflies, and pollen, and predation rate on thrips**

The oviposition rate of *E. gallicus* was determined on pollen of *T. latifolia*, first instar larvae of *F. occidentalis*, newly laid eggs (age, 0-24 h) of *T. vaporariorum*, and a combination of *T. latifolia* pollen and first instar *F. occidentalis* larvae. Predation was examined on first instar western flower thrips larvae in the presence or absence of *T. latifolia* pollen. Since cucumber is a good host plant for both pests, predation and oviposition rates were determined on cucumber leaf disks (diameter, 2.7 cm) placed upside down on a layer of 1% agar in small, ventilated plastic cups. Cattail pollen was dusted on the leaf disks with a small brush. To obtain leaf disks with *T. vaporariorum* eggs, larger cucumber leaf disks (diameter, 7.3 cm) were put on 1% agar in petri dishes and infested with 50 adult whiteflies one day before the start of the experiment. The leaf disks for the oviposition trial were cut from these disks. All leaf disks contained an excess amount of whitefly eggs. For the predation and oviposition experiments with *F. occidentalis*, 12 just-hatched first instar *F. occidentalis* larvae were transferred to the leaf disks with a fine brush. Thereafter, fresh cattail pollen was dusted with a small brush on the leaf disks used for the combination treatment. A female of *E. gallicus* reared on cattail pollen that had been laying eggs for two days after maturation was placed on each leaf disk. The cups were kept in a climate-controlled room at L16:D8, 25°C, and 75% relative humidity. In all treatments, the predators were transferred each day to fresh leaf disks with food for four days. The numbers of eggs laid and thrips larvae killed were recorded daily. The data for the first day were omitted from the calculations to minimize the effects of the rearing diet (i.e., pollen).

**Juvenile development and oviposition rate on pollen at 13°C and 25°C**

This experiment was performed on reversed sweet pepper leaves placed on water-soaked
cotton wool in plastic trays. Cultures with egg-laying females of *E. gallicus* were placed in different climate-controlled cabinets at 13°C or 25°C, 16L:8D, and 75% relative humidity. Since 25°C is a temperature that has been used in similar experiments with predatory mites (e.g., Leman and Messelink 2014; Park et al. 2011), the present results can easily be compared with published data; 13°C was chosen because there is demand from the greenhouse sector in the Netherlands for predatory mites that perform at low temperatures. Eggs of both cultures, collected 0 to 24 h after deposition (52 at 13°C and 100 at 25°C), were placed on the leaves, provided with *T. latifolia* pollen every other day, and kept at 13°C or 25°C. The development of the mites was assessed daily until egg-laying females had developed. The oviposition rate was determined on 25 small sweet pepper leaf disks (diameter, 2.7 cm) placed upside down on a layer of 1% agar in small, ventilated plastic cups. Single young gravid females were placed on each leaf disk together with ample amounts of cattail pollen, 15 females from the culture at 13°C and 10 females from the culture at 25°C, and placed back under the same climate conditions in which they had developed. Eggs were counted three times in a period of 7 days.

**Diapause**

Six sweet pepper leaf disks (diameter, 7.3 cm) were placed upside down on a layer of 1% agar in Petri dishes. Eggs of *E. gallicus*, collected 0 to 24 h after deposition, were placed on the leaf disks and provided with fresh pollen of cattail and iceplant (*Mesembryanthemum* sp.) every second day. Iceplant pollen contains beta-carotene. In the absence of beta-carotene in their diet, some phytoseiid mite species do not respond to photoperiod (Overmeer et al. 1989). The Petri dishes were closed with lids containing gauze for ventilation (diameter, 5.0 cm; mesh, 90 µm). Two petri-dishes were kept under a short daylight regime of L8:D16 at 18°C, two petri-dishes under a short daylight regime of L9:15D at 17°C, and two petri-dishes under a long daylight regime of L16:8D at 18°C as controls in different climate cabinets at 75% relative humidity until the first ovipositing females had developed in the control regime. The newly emerged females mated with males on the same leaf disks. Thereafter, the females were removed and placed individually on small sweet pepper leaf disks (diameter, 2.7 cm) placed upside down on 1% agar in small, ventilated cups and fed with pollen of cattail and iceplant. They were kept under the same conditions as during their juvenile development and were examined three times a week for egg laying.

**Semi-field experiment**

**Experimental setup**

A semi-field experiment with 6 treatments and 3 replications was carried out in 18 cages (each 0.9 m²) in an experimental greenhouse of Koppert B.V. in Berkel en Rodenrijs, the Netherlands, between January and March 2014. Temperature and relative humidity were recorded every 30 minutes with a data logger placed within the rose canopy in one of the cages. The mean temperature and relative humidity during the experiment were 21.7°C and 62.9%. Lamps above the cages provided extra light to ensure a photoperiod of L16:D8. Each cage contained 10 potted rose plants (var. Sweet Jumilia) with 2 to 3 branches, each with approximately 10 leaves at the start of the experiment. The strategy of releasing *E. gallicus*, *A. swirskii*, or *A. limonicus* once
and supplying them with *T. latifolia* pollen as an additional food source was compared with a strategy to release *A. swirskii* or *A. limonicus* repeatedly at regular intervals, which is currently used by many Dutch rose growers. The application rates for pests, predatory mites, and pollen per treatment are shown in Table 1, and the detailed release schedule is shown in Table 2. In total, 125 adult *T. vaporariorum* were released in each cage starting three days before predatory mite release (day −3). There was slight contamination with *F. occidentalis* in all cages at the beginning of the experiment (Fig. 1). As the *F. occidentalis* population did not increase as expected, 25 adult female *F. occidentalis* were released in each cage on day 18. In the cages supplied with pollen, 50 adult (1-3 days old) female *E. gallicus*, *A. swirskii*, or *A. limonicus* from laboratory colonies were released. The *E. gallicus* colony was the same as that used for the laboratory trials, whereas the colonies of *A. swirskii* and *A. limonicus* were started with commercial products from Koppert Biological Systems. In each cage where phytoseiid mites were released only once, 0.05 g *T. latifolia* pollen was sprinkled over the plant canopy with a brush every two weeks. In the cages with repeated releases of *A. swirskii* and *A. limonicus*, commercial products were used, i.e., a mix of juvenile and adult stages plus prey mites (astigmatid mites that are used as prey in the mass-rearing). *Amblydromalus limonicus* was released at half the rate of *A. swirskii* (Table 1) because earlier experiments had shown that *A. limovicus* is a more effective biocontrol agent of thrips and whitefly than *A. swirskii* (Hoogerbrugge et al. 2011; Knapp et al. 2013). In the untreated control cages, only the pests were released.

In addition to the phytoseiid mites released for thrips and whitefly control, 110 *Phytoseiulus persimilis* Athias-Henriot were released per cage 10 days before the start of the experiment and

Table 1. Overview of application rates of pests, predatory mites, and pollen in the semi-field experiment.

| Treatment | Phytoseiid mite species | Phytoseiid mites per cage | *T. vaporariorum* per cage | *F. occidentalis* per cage | *T. latifolia* pollen per cage (g) |
|-----------|-------------------------|---------------------------|---------------------------|---------------------------|----------------------------------|
| T1 (A. swirskii + pollen) | *A. swirskii* | 50♀️ | 125 | 25♀️ | 5 × 0.05$^1$ |
| T2 (A. limonicus + pollen) | *A. limovicus* | 50♀️ | 125 | 25♀️ | 5 × 0.05$^1$ |
| T3 (E. gallicus + pollen) | *E. gallicus* | 50♀️ | 125 | 25♀️ | 5 × 0.05$^1$ |
| T4 (A. swirskii weekly) | *A. swirskii* | 10 × 100$^1$ | 125 | 25♀️ | — |
| T5 (A. limonicus weekly) | *A. limovicus* | 10 × 50$^1$ | 125 | 25♀️ | — |
| T6 (Untreated control) | — | — | 125 | 25♀️ | — |

1 100 or 50 individuals (adults and juveniles) weekly for 10 weeks
2 0.05 g every two weeks for 10 weeks

Table 2. Application schedule for pests, predatory mites, and pollen in the semi-field experiment.

| Treatment | Release | Days after start |
|-----------|---------|-----------------|
| All       | *T. vaporariorum* | 50 | 50 | 25 |
| All       | *F. occidentalis* | 25 |
| T1        | *A. swirskii* | 50 |
| T2        | *A. limonicus* | 50 |
| T3        | *E. gallicus* | 50 |
| T4        | *A. swirskii* (mix) | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 |
| T5        | *A. limonicus* (mix) | 50 | 50 | 50 | 50 | 50 | 50 | 50 | 50 |
| T1, T2, T3 | *T. latifolia* pollen | 0.05 | 0.05 | 0.05 | 0.05 | 0.05 | 0.05 | 0.05 | 0.05 |
Fig. 1 Population development of phytoseiid mites (A), whiteflies (B), and thrips (C) in the cage experiment.
220 per cage on day 46 to control the naturally occurring two-spotted spider mite *Tetranychus urticae* Koch. No other beneficial insects or mites were released in the cages. All plants were treated with Rocket (active ingredient, 150 g/L triflumizole) four days before the start of the experiment to control rose powdery mildew (*Podosphaera pannosa* (Wallr.) de Bary).

**Sampling**

The development of the whitefly population was assessed at weekly intervals for 8 weeks, and the thrips and phytoseiid populations were assessed at weekly intervals for 10 weeks starting from the day of the first phytoseiid mite release. In the first 8 weeks, 25 leaflets were picked randomly from each cage per observation and taken to the laboratory. The number of eggs and mobile stages of *E. gallicus*, *A. swirskii*, and *A. limonicus*, eggs and larvae of *T. vaporariorum*, and mobile stages of *F. occidentalis* were recorded separately per leaflet by using a stereomicroscope. During the last two observations, 50 leaflets were picked per cage and washed three times with hot water and soap over a 90-µm sieve. The numbers of phytoseiid mites and thrips on the sieve were assessed by using a stereomicroscope. Whiteflies cannot be recorded with this method as the eggs and nymphs cannot be washed of the leaves. Adult female phytoseiid mites were collected from the sieves for identification to check for contamination between treatments.

**Statistics**

The oviposition rates of *E. gallicus* on different food sources were not normally distributed and were therefore analyzed by using Mood’s median test, which is non-parametric. Multiple comparisons were performed by checking the overlap of the confidence intervals calculated with Mood’s median test. The predation rate of *E. gallicus* on thrips in the presence or absence of pollen was analyzed by using the Mann–Whitney *U* test.

For the greenhouse experiment, cumulative insect days (CID) for the mean number of *T. vaporariorum* and *F. occidentalis* per leaflet, and cumulative mite days (CMD) for the mean number of *E. gallicus*, *A. swirskii*, and *A. limonicus* per leaflet, were calculated by using the following equation:

\[
\sum_t \left[ \frac{x_i + x_{i+1}}{2} \right]^* t
\]

where \( x_i \) is the number of insects or mites at sampling date *t*, \( x_{i+1} \) is the number of insects or mites at sampling date \( i+1 \), and *t* is the number of days between the sampling dates (Park and Lee 2005), and analyzed by using one-way analysis of variance (ANOVA). Mean separation was performed with Tukey’s test. All statistical analyses were conducted with Minitab 17 (Minitab Inc., Coventry, United Kingdom).

**RESULTS**

*Oviposition rate of E. gallicus on thrips, whiteflies, and pollen, and predation rate on thrips*
Oviposition rate was significantly \((P=0.002)\) higher on pollen and whiteflies than on thrips. When \(F.\ occidentalis\) was offered as prey in combination with pollen, oviposition rate was similar to the rate with pollen only. In the absence of pollen, \(E.\ gallicus\) killed 2.6 thrips larvae per day, whereas only one thrips larva was killed by the 10 females tested in the presence of \(Typha\) pollen (Table 3).

**Juvenile development and oviposition rate of \(E.\ gallicus\) at 13°C and 25°C**

\(E.\ gallicus\) developed into egg-laying females and laid eggs at 13°C; however, juvenile mortality was higher than at 25°C. Developmental time was more than four times longer at 13°C than at 25°C, and oviposition was 1.1 eggs per day at 13°C (Table 4).

**Diapause**

The \(E.\ gallicus\) population tested was non-diapausing under short day-light regimes at 17°C to 18°C. All female mites laid eggs under both short- and long-day conditions (Table 5).

**Semi-field experiment**

\(E.\ gallicus\) established and developed better on the rose plants than did \(A.\ limonicus\) and

| Food source                      | N  | Eggs/female/day ± s.e. | Thrips killed/female/day ± s.e. |
|---------------------------------|----|------------------------|---------------------------------|
| \(T.\ latifolia\) pollen        | 10 | 3.85 ± 0.17a          | n/a                             |
| \(F.\ occidentalis\)            | 10 | 1.53 ± 0.24b          | 2.60 ± 0.51a²                   |
| \(F.\ occidentalis and T. latifolia pollen\) | 10 | 3.85 ± 0.09a         | 0.03 ± 0.03b                    |
| \(T.\ vaporariorum\)            | 10 | 3.63 ± 0.12a          | n/a                             |

1 Means followed by the same letter are not significantly different (Mood’s median test, \(P<0.05\))
2 Means followed by the same letter are not significantly different (Mann–Whitney U test, \(P<0.05\))

\(N = \) number of females; \(s.e. = \) standard error

| Temperature | Eggs tested | Development time (egg–egg laying female) | Juvenile mortality | Females tested | Eggs/female/day ± s.e. |
|-------------|-------------|------------------------------------------|--------------------|----------------|------------------------|
| 13°C        | 52          | 22 days                                  | 12%                | 15             | 1.1 ± 0.05             |
| 25°C        | 100         | 5 days                                   | 4%                 | 10             | 3.9 ± 0.14             |

\(s.e. = \) standard error

| Light regime | Temperature (°C) | Number of females | Diapause (%) |
|--------------|------------------|-------------------|--------------|
| L8:16D      | 18               | 24                | 0            |
| L9:15D      | 17               | 24                | 0            |
| L16:8D      | 18               | 36                | 0            |
A. swirskii, resulting in 2.5-times more CMD for E. gallicus than for A. limonicus when both mites were released only once at the beginning of the experiment and fed with Typha pollen. At one week after release, the E. gallicus population had already reached one mite per leaflet, whereas A. limonicus took six weeks to reach this density and A. swirskii remained below this density throughout the experiment (Figure 1A). The A. limonicus population developed better when released once and fed with Typha pollen compared with weekly releases, whereas for A. swirskii the difference was minimal and not statistically significant (Table 6). Between-cage contamination of the phytoseiid species was minimal with only two E. gallicus found in one of the A. swirskii cages during the final assessment and two phytoseiid mites found in one of the control cages during the experiment.

Despite the repeated releases, T. vaporariorum did not establish well. In the untreated control, the density of whitefly immatures peaked at five per leaflet on day 49, but declined again the week after (Figure 1C). The variation in whitefly densities was high and CID was not significantly lower in either of the A. swirskii treatments (weekly releases or single release plus pollen) compared with the control. Amblyseius limonicus and E. gallicus releases resulted in a significant level of whitefly control compared with the untreated control (Table 6).

Frankliniella occidentalis was released only once, but established better than T. vaporariorum, i.e., the thrips population slowly increased over time in the untreated control and in the A. swirskii plus pollen treatment (Figure 1B). In the A. swirskii and E. gallicus treatments supplied with pollen, the thrips population was similar to that of the untreated control. The weekly releases of A. swirskii and both A. limonicus treatments (i.e., weekly releases or single-release plus pollen) resulted in a 63% reduction in CID compared with the untreated control (Table 6).

DISCUSSION

In the laboratory experiment, E. gallicus laid a high number of eggs on pollen and T. vaporariorum. High oviposition rates on pollen have been reported for other Euseius species (Bouras and Papadoulis 2005; Broufas and Koveos 2000; Fouly et al. 2013) and are typical for type IV predatory mites (McMurtry et al. 2013). The egg-laying capacity of A. swirskii and A. limonicus on pollen is lower with about 2 eggs per day for A. swirskii feeding on T. latifolia pollen (Park et al. 2011) and for A. limonicus feeding on iceplant pollen (McMurtry and Scriven 1965). The oviposition rate of E. gallicus on 0- to 24-h-old T. vaporariorum eggs (3.6 eggs/day)

| Treatment | Cumulative phytoseiid days | Cumulative thrips days | Cumulative whitefly days |
|-----------|---------------------------|-----------------------|-------------------------|
| T1 (A. swirskii + pollen) | 23.4 ± 3.81c | 9.4 ± 2.26a | 45.2 ± 14.67ab |
| T2 (A. limonicus + pollen) | 63.5 ± 6.45b | 2.7 ± 0.76b | 12.8 ± 3.03b |
| T3 (E. gallicus + pollen) | 164.1 ± 25.54a | 8.7 ± 2.36a | 39.2 ± 3.97b |
| T4 (A. swirskii weekly) | 24.4 ± 2.73c | 2.9 ± 0.93b | 53.3 ± 3.40ab |
| T5 (A. limonicus weekly) | 19.3 ± 1.40c | 1.4 ± 0.63b | 33.8 ± 11.67b |
| T6 (Untreated control) | 0.2 ± 0.09d | 8.5 ± 3.30a | 100.8 ± 22.07a |

1 Means followed by the same letter within a column are not significantly different (Tukey’s test, P < 0.05)
is similar to that of *A. limonicus* (3.7 eggs/day) (Van Houten et al. 2008). *Amblyseius swirskii* lays only 2.3 eggs per day with greenhouse whitefly eggs as prey (Bolckmans et al. 2005). On thrips, both *A. limonicus* (3.1 eggs/day) and *A. swirskii* (2.1 eggs/day) laid more eggs than did *E. gallicus* (1.5 eggs/day). The predation rate of these species on first instar *F. occidentalis* larvae is also much higher than the predation rate of *E. gallicus* at 4.9 larvae per day for *A. swirskii* and 6.8 larvae per day for *A. limonicus* (Bolckmans et al. 2005; Van Houten et al. 2008). The predation rate (2.6 first instar larvae/day) and oviposition rate (1.5 eggs/day) of *E. gallicus* on thrips is similar to that of the type II predatory mite *Neoseiulus californicus* (McGregor), which is a broadly specific spider mite predator (McMurtry et al. 2013; Van Baal et al. 2007). *Frankliniella occidentalis* larvae, therefore, seem to be a less favorable food source for *E. gallicus* than cattail pollen and greenhouse whitefly eggs.

In our laboratory experiments, *E. gallicus* nearly completely ceased to prey on *F. occidentalis* larvae when *T. latifolia* pollen was provided as an alternative food source. Negative effects of the presence of pollen on thrips predation have also been reported for *A. swirskii* and *A. limonicus*, but were less pronounced. For *A. swirskii*, the reduction was about 50% (Leman and Messelink 2014); for *A. limonicus*, Vangansbeke et al. (2014) reported a reduction of 30% whereas Leman and Messelink (2014) did not find any reduction.

The development time from egg to egg laying of *E. gallicus* at 25°C on pollen (5 days) was much shorter than that of *A. swirskii* (11.8 days) (Lee and Gillespie 2011) and slightly shorter than that of *A. limonicus* (6 days) (Steiner et al. 2003). In contrast to *E. gallicus* and *A. limonicus* (Knapp et al. 2013), *A. swirskii* did not develop at 13°C. Similarly to *A. swirskii* (Bolckmans et al. 2005) and *A. limonicus* (Van Houten et al. 1995a), the tested population of *E. gallicus* did not enter diapause. This is important for the success of biological control in greenhouses under winter conditions (Van Houten et al. 1995b).

In the semi-field experiment, the *E. gallicus* population reacted much stronger to the pollen supplements than did the two other species. This is in line with results obtained for other *Euseius* species and with our own laboratory results. On potted pepper plants supplied with pollen on twine, *E. scutalis* developed much higher populations than did *A. swirskii* (Adar et al. 2014). In an experiment comparing *Euseius ovalis* (Evans), *A. swirskii*, and *A. limonicus* supplemented with pollen for the control of *T. vaporariorum* on roses, *E. ovalis* reached the highest population (Hoogerbrugge et al. 2011). Pollen supplements substantially increased the abundance of *E. scutalis* on avocado and on citrus, and the abundance of *Euseius stipulatus* (Athias-Henriot) on citrus (Maoz et al. 2011, 2014; Pina et al. 2012).

Despite the high *E. gallicus* density, thrips control was not effective. This might have been caused by the strong preference of this pollen-feeding species for pollen compared to thrips. In addition, *F. occidentalis* also feeds on pollen, and pollen feeding can enhance its population growth rate (Hulshof et al. 2003; Leman and Messelink 2014). Van Rijn et al. (2002) and Leman and Messelink (2014) showed that pollen feeding by thrips has no negative effect on biological control of thrips by *Iphiseius degenerans* (Berlese) on cucumber and by *A. swirskii* on chrysanthemum. However, it has also been suggested that biological control is improved in the long term through an increase in predator equilibrium densities via apparent competition (Holt 1977). These effects may differ depending on the plant–predatory mite combination.
Unlike the thrips population, the whitefly population was significantly lower than in the control when *E. gallicus* was released. The level of control was similar to that seen with the two treatments with *A. limonicus* (Table 6), which is known to be a good biocontrol agent for *T. vaporariorum* in roses (Hoogerbrugge et al. 2011; Knapp et al. 2013).

Why whitefly control with *E. gallicus* was better than thrips control remains to be investigated. We have not examined the prey preference of *E. gallicus* between pollen and whitefly eggs; however, in contrast to thrips larvae, which are mobile and express anti-predator behavior (Vangansbeke et al. 2014), whitefly eggs cannot defend themselves and may therefore be an easier prey for *E. gallicus*.

Based on the results of the laboratory experiments, *E. gallicus* may be a suitable biocontrol agent for whiteflies, but not for thrips control. This was confirmed in the semi-field experiment where *E. gallicus* supplemented with pollen reduced the whitefly population but not the thrips population compared with untreated controls. When comparing regular releases of *A. limonicus* and *A. swirskii* with single releases combined with supplementary pollen feeding, there were no differences in thrips control with *A. limonicus* or in whitefly control for both species, whereas regular releases of *A. swirskii* resulted in better thrips control than did single releases plus pollen (Table 6).

The present results need to be confirmed in further experiments because both pest populations, but especially the whiteflies, did not develop very well in the untreated controls compared with in other experiments (e.g., Hoogerbrugge et al. 2011; Knapp et al. 2013). Furthermore, the duration of the experiment, initial predator–prey ratios, predatory mite species, plant species, and method of supplementary food application may have influenced the results of the experiment (Leman and Messelink 2014). Therefore, application of pollen to crops as supplementary food to improve biological control should be treated with caution, and further experiments are necessary to design more efficient and robust strategies.

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