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# Whitefly control in cut gerbera: is it possible to control *Trialeurodes vaporariorum* with *Encarsia formosa*?

**Oliver Berndt · Rainer Meyhöfer**

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**Abstract** We investigated the impact of inundative releases of the parasitoid, *Encarsia formosa* Gahan (Hymenoptera: Aphelinidae), for control of greenhouse whitefly, *Trialeurodes vaporariorum* (Westwood), on cut gerbera (*Gerbera jamesonii* L.) under controlled greenhouse conditions. Experimental units consisted of ten plants covered and separated from other units by gauze tents. We assessed three release rates of the aphelinid parasitoid: a 7-week experiment with a standard release rate (10 $m^{-2}$/14 days), and a subsequent 3-month trial with high (100 $m^{-2}$/week) and very high (1,000 $m^{-2}$/week) release rates. Experimental units without release of parasitoids served as control treatment. Gerbera plants were infested initially with 50–100 juvenile and 50–70 adult whiteflies in the first experiment, and in the second experiment with less than 50 juveniles per plant and 50–70 adults. Whitefly and parasitoid population density were assessed in weekly intervals using infestation and activity categories. Results show that parasitized whiteflies were present in all treatments within 2 weeks after initial release. Unfortunately, it was not possible to control whiteflies with standard release rates of *E. formosa*. Although parasitism rates slightly increased, the effect on whitefly populations was negligible. Large amounts of honeydew and growth of sooty mold fungi caused the termination of the first experiment. In a second experiment, *E. formosa* was tested at 10–100 times higher release densities. In contrast to the first experiment, whitefly densities increased steadily during the first 8 weeks, but remained constant until the end of the experiment in both treatments. Parasitism by *E. formosa* reached its maximum after 8 weeks. We discuss possible reasons for the low efficiency of *E. formosa* as a whitefly antagonist in greenhouse production of gerbera.

O. Berndt (✉) · R. Meyhöfer
Institute of Plant Diseases and Plant Protection, Leibniz University Hannover, Herrenhaeuser Street 2, 30419 Hannover, Germany
e-mail: Berndt@ipp.uni-hannover.de

R. Meyhöfer
e-mail: meyhoefer@ipp.uni-hannover.de

O. Berndt
Institute for Plant Protection in Horticulture, Federal Biological Research Centre for Agriculture and Forestry, Messeweg 11/12, 38104 Braunschweig, Germany

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## Introduction

In the last decade, biological control became a reliable environmentally friendly and economical crop protection tool for vegetable production in greenhouses. Similarly, introduction of beneficials has become ubiquitous in production of ornamental plants (van Lenteren 2000). This broad acceptance is partially due to the success obtained by exploitation of *Phytoseiulus persimilis* Athias-Henriot (Acari: Phytoseiidae) against the two spotted spider mite, *Tetranychus urticae* Koch (Acari: Tetranychidae) and the application of *Encarsia formosa* Gahan (Hymenoptera: Aphelinidae) against the greenhouse whitefly, *Trialeurodes vaporariorum* (Westwood) (Homoptera: Aleyrodidae) (Parrella et al. 1999). Referring to whiteflies *E. formosa* is among the best-studied biological control agents. It is a solitary, thelytokous endoparasitoid (i.e., obligate parthenogenetic) and each generation consists entirely of females (Doutt 1959). *Encarsia* adults attack whitefly nymphs by repeatedly inserting their ovipositor into the body of the host and feeding on hemolymph that exudes from the wound (host feeding), or by parasitizing their host via oviposition (Heinz 1996). The first introduction of *E. formosa* in 1927 (Speyer 1927) revealed the parasitoid's potential as a tool to control the greenhouse whitefly, and initiated the commercial production and application of this parasitoid. The current use of *E. formosa* in greenhouses is very well established throughout Europe (Van Driesche and Bellows 1996; Thacker 2002). Nevertheless, satisfactory whitefly control levels are lacking in a wide array of crops.

In a research project on biological and integrated control strategies in floriculture we supervised several commercial growers producing cut gerbera (*Gerbera jamesonii* L.) since 2003. In all cases, growers noted that *T. vaporariorum* was the most important pest insect on cut gerbera. Whitefly nymphs and adults cause direct damage by piercing and sucking, and excreting large amounts of honeydew that promote development of sooty mold fungi and, thus, impair photosynthesis (Byrne et al. 1990; Osborne and Landa 1992; Fransen and van Lenteren 1993; Poprawski et al. 1998).

In cooperation with commercial growers, numerous strategies were tested for controlling greenhouse whitefly using an array of beneficial species and species combinations either in succession or without applications of compatible insecticides (in preparation). Although application of *E. formosa* as a specialized natural enemy of *T. vaporariorum* is ubiquitous, all efforts to control the pest were characterized by low efficiency, high variation, and discontinuity. Therefore, we initiated standardized greenhouse experiments to investigate the overall impact of *E. formosa* on *T. vaporariorum* population development in gerbera especially in infestation hot spots and to characterize possible causes for low control efficiencies. We focused on release rates of the parasitoids, the number of releases, and release frequencies.

## Materials and methods

We examined releases of three different densities of *E. formosa* in two separate trials under controlled conditions in a greenhouse. Experiments were carried out in two greenhouse

cabins, both divided into six experimental units by gauze tents made of standard curtain cloth with a mesh width of 0.33 mm. Each gauze tent covered ten potted, 3-year-old gerbera plants covering a basal area of 5 $m^2$. We chose the gerbera cultivars 'White Spirit', 'Oilila', 'Amerika', and 'Minette' due to their high whitefly susceptibility in commercial production (pers. obs.). A standard drip system was used for irrigation and fertilization. Experiments started in April and lasted until end of September 2005. Temperatures ranged from 23 ± 2°C during day to 20 ± 2°C at night, with a mean relative humidity fluctuating between 60 ± 5% during day and 76 ± 5% at night.

Before experiments started all plants were treated with selective insecticides that were compatible with release of natural enemies (active compounds: Pymetrozin and Buprofezin) for cleaning, i.e., removal of initial pest species. However, no pesticides were applied at least 6 weeks prior to and during the experiment. At the outset of the experiment, plants were infested artificially with whiteflies collected in the greenhouse of a gerbera grower. In order to get equally infested plants, gerbera plants were kept in a separate greenhouse and incubated with about 1,000 adult whiteflies. When the infestation reached the level that was intended for the experiment, plants were transferred to the experimental units.

Parasitoids were supplied by a commercial breeder (Katz Biotech AG, Baruth, Germany) as parasitized whitefly nymphs glued to cardboard strips and were released immediately after delivery. Cards containing parasitized nymphs were attached to gerbera leaves. We took a sample of five cards from each shipment to determine the hatching rate of parasitoids. Cards were separately put in plastic vials and within 2 weeks all hatched adults were counted. Hatching rates were always higher than 97% (unpublished data). Population development of whiteflies and parasitoids was classified by weekly estimations of whitefly infestation levels and parasitism rates on each plant in each tent according to the categories described in Table 1. Therefore, we counted whiteflies, or in case of more than 100, 500, or 1,000 whiteflies being present, estimated infestation levels by counting representative areas of infested leaves. We also counted parasitized whiteflies and

**Table 1** Categories of whitefly infestation and *E. formosa* parasitism levels on cut gerbera

| Category | Whitefly infestation |
|---|---|
| 0 | No whiteflies, plant without any infestation |
| 1 | ≤10 Adult whiteflies |
| 2 | >10 Adult whiteflies and/or <50 juvenile instars, oviposition initiated |
| 3 | Numerous adult whiteflies and ≥50 ≤ 100 juvenile instars |
| 4 | Numerous adult whiteflies and >100 ≤ 500 juvenile instars, heavy honeydew production |
| 5 | Numerous adult whiteflies and >500 ≤ 1,000 juvenile instars, frequently in conjunction with fungus infestation following honeydew production, plants heavily damaged |
| 6 | Numerous adult whiteflies and >1,000 juvenile instars, plants heavily damaged and growth perspicuously retarded |
| **Category** | **Parasitism** |
| 0 | No parasitoids (neither adult nor parasitized whitefly pupae) |
| 1 | Parasitism rate ≤10% of whitefly nymphs |
| 2 | Parasitism rate >10 ≤ 50% |
| 3 | Parasitism rate >50% |

estimated the proportion of parasitized individuals in relation to unparasitized whitefly nymphs.

### First experiment—standard *E. formosa* release rates

The first experiment started in April and lasted 7 weeks until end of May. Day length ranged from 13.75 h at the beginning of the experiment to 16.25 h daylight at the end. Plants were infested with a population of 50–100 nymphs plus 50–70 adult *T. vaporariorum*. A standard rate of ten *E. formosa* per $m^{-2}$ (Standard Release) were released three times at intervals of 2 weeks, corresponding to five parasitoids per plant. This treatment was compared to an untreated control consisting of plants without an introduction of parasitoids. Treatment and control were each replicated four times in a completely randomized design.

### Second experiment—high and very high *E. formosa* release rates

The second experiment lasted from beginning of July until September (12 weeks). Plants were infested with less than 50 nymphs plus 50–70 adult *T. vaporariorum*. Day length ranged from 16.5 to 12.25 h daylight. We investigated efficiency of *E. formosa* in three treatments. In the first treatment 100 individuals (High Release) and in the second treatment 1,000 individuals of *E. formosa* per $m^{-2}$ (Very High Release) were released at weekly intervals over a 6-week period. Results were compared to population development of an untreated control. All treatments were replicated four times using a completely randomized design.

### Statistical analysis

Since whitefly population densities and parasitism rates were weekly estimated by categories, non-parametric tests were used for statistical analysis. Friedman tests were used to proof significant developments within a treatment during the experimental time. Kruskal–Wallis test was used to analyze differences among treatments at 4 week intervals, i.e., 4th, 8th, and 12th census. If Kruskal–Wallis test was significant, multiple non-parametric comparisons corrected for tied ranks (Dunn 1964) was calculated according to Zar (1984). For statistical operations we used SPSS Version 12.0 (Bühl and Zöfel 2000).

## Results

In the first experiment, plants were heavily infested with whiteflies prior to the first release of parasitoids. Within 7 weeks after the first *E. formosa* release, whitefly density increased rapidly and reached a level of more than 1,000 whiteflies per plant until the end of the experiment (Fig. 1). Whitefly population density at the end of the experiment was similar in the control and the *E. formosa* treatment (Standard Release) (Mann–Whitney $U = 1{,}2495$, $Z = 0.378$, $P = 0.706$). First parasitized whitefly nymphs were found on gerbera leaves 2 weeks after the initial release of ten *E. formosa* per $m^{-2}$ (Fig. 1). Thereafter, parasitism increased significantly from census 3 to 5 (Friedman test:

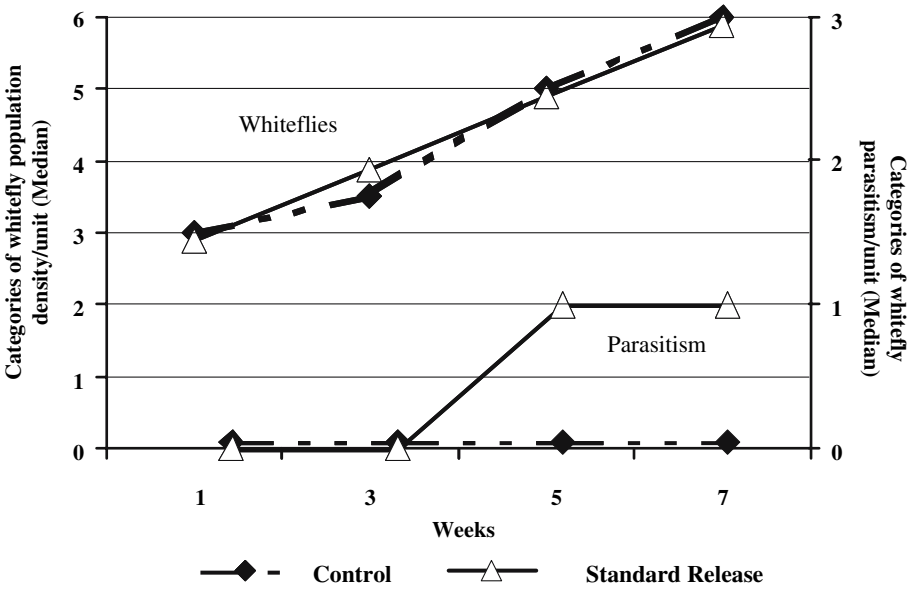


**Fig. 1** Population development of the whitefly *Trialeurodes vaporariorum* (left axis) and the parasitoid *Encarsia formosa* (right axis) on cut gerbera. Release rate of ten *Encarsia formosa* $m^{-2}$ (Standard Release) was compared to the control treatment without beneficial release. Infestation and parasitism levels are presented as median value of categories of whitefly density in the experimental units and parasitized nymphs, respectively, $N = 4$. Categories are explained in Table 1

$\chi^2 = 68.24$, $df = 3$, $P < 0.01$), but in general, parasitism rates remained at a low level, i.e., less than 10%, until the end of the experiment (Fig. 1). The experiment was terminated after 7 weeks because plants were heavily damaged by whiteflies feeding and large amounts of honeydew with subsequent growth of sooty mold fungi.

Although the initial whitefly density was considerably lower compared to the first experiment, whitefly populations in the second experiment increased steadily in the control treatment (Friedman test: $\chi^2 = 42.62$, $df = 11$, $P < 0.01$) and reached densities of more than 1,000 juvenile instars per plant within 7 weeks (Fig. 2). Until the end of the experiment the number of nymphs per plant remained at the highest infestation category (Table 1). In contrast, whitefly population density increased only slightly in the High Release treatment. In the Very High Release treatment whitefly population decreased rapidly with a slight increase in the end of the experiment. Whitefly population densities were significantly different at each census among all treatments (Table 2).

In both *Encarsia* treatments up to 10% of whitefly nymphs were already parasitized at the second census, (Fig. 3). In the High Release treatment parasitism rates increased rapidly to the highest category, i.e. more than 50% of the whitefly nymphs parasitized. In contrast, parasitism rates remained at a low level until week 8 in the Very High Release treatment. Parasitism rates were significantly different at each census among all treatments (Table 2). Until week 8 parasitism rates were significantly higher in the High Release treatment compared to the Very High Release treatment (Fig. 3, Table 2). Nevertheless, parasitism rates reached the highest category after 9 weeks even in the Very High Release treatment (Fig. 3).

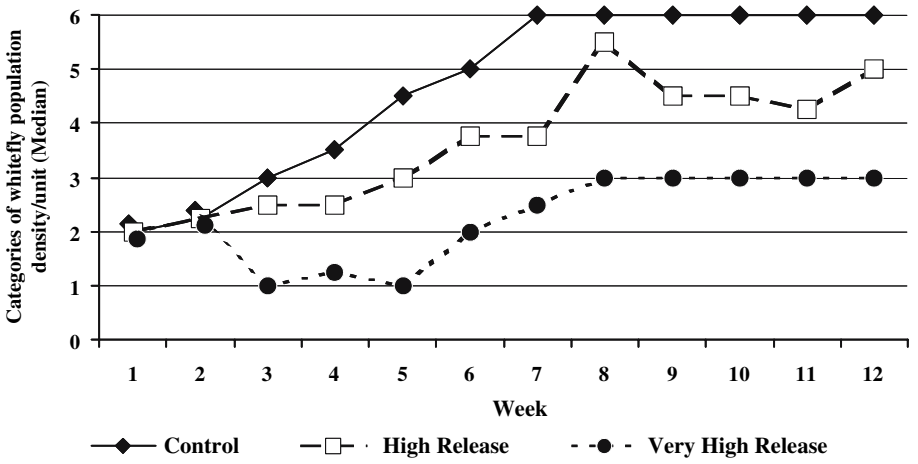


**Fig. 2** Population development of the whitefly *Trialeurodes vaporariorum* on cut gerbera. Treatments with release rates of 100 (High Release) and 1,000 *E. formosa* $m^{-2}$ (Very High Release) were compared to the population development in the control treatment without beneficial release. Infestation levels are presented as median value of categories of whitefly density in the experimental units. $N = 4$. Categories are explained in Table 1

Although no parasitoids were released in the control treatment, a few whiteflies were parasitized by *E. formosa*. This outcome was most likely the result of accidental transfers to the control treatment during census or irrigation of the experimental plants. The number of parasitoids contaminating control plants was rather low and parasitism rates never reached 10% (Fig. 3).

## Discussion

None of the tested *E. formosa* release rates led to a sufficient whitefly control. Although many whitefly nymphs were parasitized by *E. formosa* in all treatments, standard release rates of parasitoids, i.e., ten individuals per $m^{-2}$, did not result in a sustainable impact on whitefly population development (first experiment). Growth of whitefly populations was slowed down only after release of 1,000 parasitoids per $m^{-2}$ at weekly intervals (second experiment), but adequate whitefly control was again not observed.

The whitefly population density at the end of our experiments was still above a threshold which a grower would tolerate in commercial cut gerbera production. Nevertheless, the initial whitefly densities in our experiment reflect the situation in infestation hot spots, which are important for population development during the growing season. In our experiments *E. formosa* was confined to a whitefly hot spot and was not able to reduce population density below economic thresholds. Therefore, if whitefly population density in hot spots is above 40–50 nymphs per plant, on at least ten plants a curative introduction of *E. formosa* cannot be recommended.

In general, intrinsic rate of increase should be higher for the antagonist then for the pest in order to reach sufficient levels of biological control. This is true for the whitefly-*Encarsia* relation on many crops. Therefore, we expected that a successful introduction of the antagonist *E. formosa* would result in increasing parasitism rates followed by a

**Table 2** Comparison of *Trialeurodes vaporariorum* infestation (A) and *Encarsia formosa* parasitism levels (B) among the three treatments control (without antagonist release) and the two antagonist release rates High Release (100 wasps $m^{-2}$) and Very High Release (1,000 wasps $m^{-2}$) on cut gerbera

| | | Median[a] | Kruskal–Wallis test | Result of non-parametric multiple comparisons | |
|---|---|---|---|---|---|
| | | | | High release | Very high release |
| (A) Whitefly infestation | | | | | |
| 4th Census | Control | 3 (3; 4) | $\chi^2 = 7.902$, $df = 2$, $p = 0.0192$ | * | * |
| | High Release | 3 (2; 4) | | | * |
| | Very High Release | 1 (1; 2) | | | |
| 8th Census | Control | 6 (6; 6) | $\chi^2 = 9.152$, $df = 2$, $p = 0.0103$ | * | * |
| | High Release | 5 (4; 6) | | | * |
| | Very High Release | 3 (2; 4) | | | |
| 12th Census | Control | 6 (6; 6) | $\chi^2 = 9.276$, $df = 2$, $p = 0.0097$ | * | * |
| | High Release | 5 (4; 5.25) | | | * |
| | Very High Release | 3 (3; 4) | | | |
| (B) Parasitism | | | | | |
| 4th Census | Control | 0 (0; 0) | $\chi^2 = 9.042$, $df = 2$, $p = 0.0109$ | * | * |
| | High Release | 3 (1; 3) | | | * |
| | Very High Release | 1 (1; 3) | | | |
| 8th Census | Control | 1 (1; 1) | $\chi^2 = 7.420$, $df = 2$, $p = 0.0245$ | * | * |
| | High Release | 3 (2; 3) | | | * |
| | Very High Release | 2.5 (1; 3) | | | |
| 12th Census | Control | 1 (1; 1) | $\chi^2 = 7.420$, $df = 2$, $p = 0.0245$ | * | * |
| | High Release | 2 (1; 3) | | | * |
| | Very High Release | 3 (2; 3) | | | |

The table shows the median of whitefly infestation and parasitism levels in the treatments at the 4th, 8th and 12th census. If Kruskal–Wallis test was significant, multiple non-parametric comparisons corrected for tied ranks (Dunn 1964) were calculated according to Zar (1984). Asterisks in the last two columns show significant differences between treatments

[a] Median plus 1st and 3rd quartile in parentheses

considerable reduction in whitefly population densities. We did not observe such a scenario in the first experiment. The maximum whitefly density was already reached after 6 weeks of the trial.

In contrast, beneficial activity and whitefly population development fits more to our expectation in the second experiment. In both parasitoid treatments parasitism rates increased rapidly, approaching an average of 50–100% parasitism (Fig. 2). Surprisingly, parasitism rates seemed to be higher in the treatment with release rates of 100 *E. formosa* $m^{-2}$ (High Release) than in the treatment with release rates of 1,000 individuals $m^{-2}$ (Very High Release) until week 8, although whitefly densities were lowest in the treatment with the highest antagonist release rates (Fig. 3). This paradox is likely due to host feeding behavior of adult *E. formosa*, whereby females ingest hemolymph that exudes from wounds created by piercing the host with her ovipositor (Flanders 1942; Jervis and Kidd 1986; Heimpel and Collier 1996; Hoddle et al. 1998; Burger et al. 2004). Host feeding provides nutrients that enhance egg maturation and/or longevity of female parasitoids and directly contributes to a reduction in the number of whiteflies (Jervis and Kidd 1986; Heimpel and Collier 1996). In

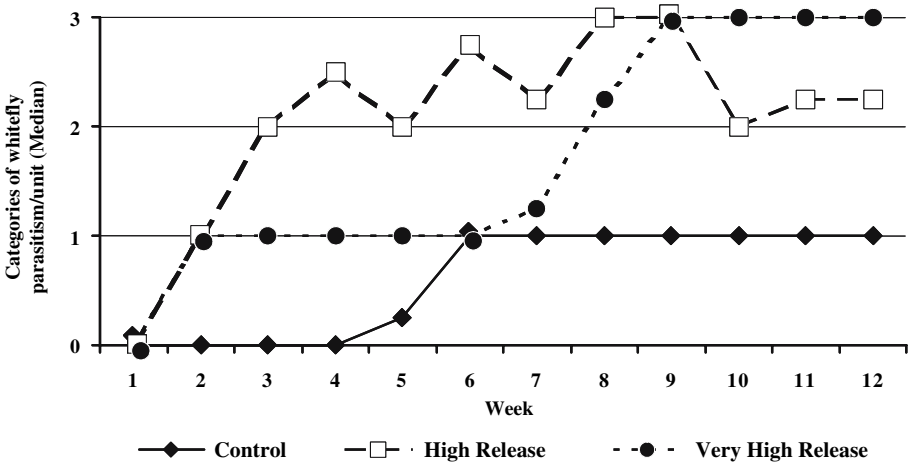


**Fig. 3** Population development of the parasitoid *Encarsia formosa* on *Trialeurodes vaporariorum* nymphs on cut gerbera. Treatments with release rates of 100 (High Release) and 1,000 *E. formosa* $m^{-2}$ (Very High Release) were compared to the population development in the control treatment without beneficial release. Parasitism levels are presented as median value of categories of parasitized whitefly nymphs in the experimental units, $N = 4$. Categories are explained in Table 1

addition, Arakawa (1987) found that *E. formosa* frequently used its ovipositor to destroy the eggs of conspecifics inside previously parasitized hosts. This may explain why an increased density of adult parasitoids did not inevitably yield higher parasitism rates, even though the number of whiteflies decreased.

Additionally, our experiments were done in closed experimental units, i.e., small tents, with uniform host distribution. Therefore, we expected that limited dispersal and short host location distances by parasitoids should be favorable for whitefly control compared to large commercial greenhouses. Nevertheless our results show that even with the particular favorable situation in our study system *E. formosa* was unable to suppress whitefly population density sufficiently. Sütterlin (2000) and Sütterlin and van Lenteren (1997, 1999, 2000) extensively investigated whitefly control in gerbera and found that the initial density of whiteflies, rate and frequency of parasitoid release, greenhouse temperature, and cultivation of susceptible cultivars strongly influence the outcome of *E. formosa* implementation as an antagonist of *T. vaporariorum*.

## Initial density of whiteflies and released parasitoids

To control a moderate infestation of *T. vaporariorum* in the greenhouse, commercial suppliers of *E. formosa* recommend a standard release rate of five parasitoids per $m^{-2}$ at weekly or biweekly intervals (Koppert Biological Systems, AD Berkel en Rodenrijs, The Netherlands, Katz Biotech AG, Baruth, Germany, Sautter & Stepper GmbH, Ammerbuch, Germany, pers. comm., see also Hassan et al. 1993; Albert et al. 2007). As a curative tool against high infestations of whitefly, Koppert Biological Systems advise a rate of nine parasitoids per $m^{-2}$ applied every week. In contrast, we applied ten *E. formosa* per $m^{-2}$ every other week in our first experiment. Although we estimated the initial whitefly infestation on our experimental plants as a quite "high infestation", it seems that the

number of introduced parasitoids was too low and the release frequency of 14 days was too long. Even though parasitoids established quickly, they were not able to suppress the whitefly population growth.

In our second experiment, we used a tenfold and hundredfold higher release rate compared to the first one. Sütterlin (2000) favored weekly releases of 4–5 parasitoids per plant (i.e., 24–30 parasitoids per $m^{-2}$) in case of an initial infestation of approximately two adult whiteflies per plant 27 days before *Encarsia* release. Given that the initial infestation level in our experiments was less than 50 juvenile whiteflies per plant, we expected a faster reduction in the whitefly population. In contrast, our results show that the whitefly population density increased over a 9-week period and remained at intermediate levels until the end of the experiment. It seems that the initial infestation level was too high for any release rate of *E. formosa* to suppress the whitefly population sufficiently. Additionally, the large number of whiteflies secreted copious amounts of honeydew. As a carbohydrate source, honeydew is exploited by parasitoids to meet their energy requirements (e.g., Viggiani 1984; Hoddle et al. 1998), but large quantities of honeydew may impede the searching efficiency of parasitoids. While foraging on a leaf, *E. formosa* starts a random search for hosts by walking and drumming with its antennae. While foraging on highly infested leaves, the parasitoid inevitably becomes contaminated with the sticky honeydew and, therefore, spends considerably more time preening (Urs Wyss, University of Kiel, Germany, pers. comm.) compared to fitness-related activities such as oviposition and host feeding. Moreover Parr et al. (1976) mentioned that excessive amounts of honeydew on leaves associated with high whitefly densities can act as an oviposition deterrent for *E. formosa*. Finally, honeydew offers an attractive medium for the growth of several species of fungi, especially sooty molds (Rabbinge et al. 1981; Bi et al. 2002). We speculate that fungal mycelia and spores could contaminate foraging parasitoids, causing preening or premature departure from patches.

## Abiotic factors

Successful whitefly control with an antagonist requires that the antagonist propagates faster than the pest. Since insect development depends on temperature, the greenhouse climate is the most important factor influencing the level of biocontrol by parasitoids. Enkegaard (1993) examined the reproduction of *E. formosa* and *T. vaporariorum* at 16, 22, and 28°C and found that the parasitoid reproduced faster than the whitefly at each temperature. According to Hoddle et al. (1998), the most appropriate temperature for successful whitefly control is 23°C. In our experiments, day temperature was adjusted to 23°C, and night temperature never fell below 20°C, ensuring reproduction and development of *E. formosa* was sufficient for whitefly control.

Several studies suggest that light intensity is a crucial factor for whitefly parasitism by *E. formosa* since the parasitoid does not forage in the dark (Hoogcarspel and Jobsen 1984). Parr et al. (1976) assumed that short day length and low light intensity might reduce the efficacy of *E. formosa*, which has later on been demonstrated by Zilahi-Balogh et al. (2005). Moreover, van Lenteren et al. (1992) showed that parasitoid dispersal was reduced at low (less than 500 lux) compared to high (greater than 8,000 lux) light intensities. Unfortunately, we did not use additional light sources nor record the light intensity in our experimental units. But although day length was not constant in our experiments, it was already at 16.5 h in the beginning of our experiments and was still at 12.25 h at the end of the second experiment, i.e., 22nd of September. Moreover, in week 9 (1st of September)

when parasitism remained static, day length was still 14 h, which normally should favor *Encarsia* activity (P. Katz, pers. comm.). Finally, in vegetable greenhouses we observed parasitism rates up to 80% until October, at a day length of approx. 10.5 h (pers. obs.). Although we cannot exclude that light quantity or quality was altered inside our gauze tents and influenced our results, it seems to be unlikely that light was a limiting factor for parasitoid efficiency in our experiments.

### Cultural factors

Sütterlin (2000) states that less susceptible cultivars would improve biological control of herbivores in gerbera. Since growers' choice of cultivars depends on the market and fashion trends, opportunities to avoid susceptible cultivars are limited. Moreover, susceptibility to herbivores, e.g., whiteflies or spider mites, seems not to be the most important selection criterion in breeding programs. Instead selection for gerbera cultivars mainly focuses on color and shape of flowers. Nevertheless, different gerbera cultivars show large differences in susceptibility to herbivores. For example, Krips et al. (1998) showed that the intrinsic rate of increase ($r_m$) for the spider mite *Tetranychus urticae* ranged from 0.088 $day^{-1}$ on cultivar Bianca to 0.242 $day^{-1}$ on cultivar Sirtaki. This variation in $r_m$ was mainly caused by differences in developmental time of the spider mites. Although most mechanism behind susceptibility of gerbera cultivars to herbivores are still unknown, one important factor for parasitoids is the leaf surface structure. Since the host encounter rate of parasitoids depends on their walking speed, every obstacle females encounter on the leaf surface reduces oviposition and host feeding rates and in consequence affects the biocontrol efficiency (van Lenteren et al. 1976; Woets and van Lenteren 1976; van Lenteren 1995). In particular, hairiness of the host plant has a strong negative impact on walking speed, activity, and foraging pattern of *E. formosa* (Hulspas-Jordaan and van Lenteren 1978; van Lenteren et al. 1996) and other small parasitoids (e.g., Babendreier et al. 2003). Sütterlin and van Lenteren (1997) demonstrated that leaf hairiness indeed influences the walking speed of *E. formosa*. They compared ten Gerbera cultivars with trichome densities from 80 to 1,000 per $cm^{-2}$ and found walking speeds of 0.2 to 0.3 mm $s^{-1}$ with no significant differences between the tested cultivars. Compared to hairless sweet pepper cultivar (0.73 mm $s^{-1}$) trichomes on Gerbera leaves reduce the parasitoid walking speed by factor 2.4–3.7. Since the gerbera cultivars of our experiments are characterized by an intermediate trichome density (approximately 150–250 trichomes $cm^{-2}$) it is likely that the negative trichome impact contributes to the low efficacy of *E. formosa* on Gerbera.

## Conclusion

The greenhouse whitefly, *T. vaporariorum*, is still a key pest in greenhouse gerbera production. While biological control of this pest in an assortment of greenhouse crops is booming (van Lenteren 1992, 1995, 2000; Wardlow and van Lenteren 1993), whitefly management in gerbera is still difficult to achieve (Sütterlin 2000).

In our experiments release of the aphelinid *E. formosa* had a minor effect on suppression of greenhouse whitefly on cut gerbera. Nevertheless, weekly release rates of 100 and 1,000 *E. formosa* per $m^{-2}$ slowed down population growth of *T. vaporariorum* substantially. Unfortunately, the resulting whitefly population density is still above the economic threshold that a grower would tolerate in commercial production of gerbera.

Therefore, we concluded that the initial whitefly population density is the most crucial factor determining the successful introduction of the antagonist *E. formosa*. In greenhouse production systems, the advised release rate of five *E. formosa* per $m^{-2}$ may result in sufficient control only if introduced preventively before any whiteflies are caught on yellow sticky traps. In practice, such low infestation levels can only be achieved if the greenhouse area is cleared, cleaned, and setup with new young plants.

Our experiments reveal the ineffectiveness of a curative release of *E. formosa* as the only antagonist to control *T. vaporariorum* in cut gerbera. Depending on greenhouse conditions, it may be reasonable to release other beneficials in combination with *E. formosa*.

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