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Release rates for control of *Bemisia tabaci* (Homoptera: Aleyrodidae) biotype "Q" with *Eretmocerus mundus* (Hymenoptera: Aphelinidae) in greenhouse tomato and pepper

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Abstract

Tomato and sweet pepper are the principal crops grown in protected culture on the southern coast of Spain. Augmentative biological control based on the parasitoid *Eretmocerus mundus* Mercet promises to be a useful component to manage *Bemisia tabaci*, the key pest of these and other horticultural crops. The present studies were undertaken with the objective of evaluating control obtained with different release rates under simulated commercial conditions. Experiments were conducted in an air-conditioned plastic greenhouse located on the southern Spanish coast during the two main horticultural cropping seasons of the region (fall-winter and spring). Host plant (tomato and sweet pepper) constituted the main plots and release rate of *E. mundus* (0, 1.5 and 6 m^{-2}) the subplots in split plot design with four replicates. No other management practices were used against whitefly. Whitefly populations in fall reached over 80 nymphs/100 cm^2 leaf surface in pepper and twice this in tomato. Nevertheless, control using the high release rate in fall exceeded 90% in both crops, with no differences between rates in pepper, although the high rate was significantly better in tomato. Whitefly populations on pepper in spring reached densities five times greater than in fall, and yet control equalled or exceeded 95% with the high rate. Adult whiteflies on tomato were reduced by 92% in response to the high rate in spring, but nymphs were only reduced 69%. These experiments suggested that, although higher rates may be required in tomato to achieve the same level of control as in pepper, good suppression of *B. tabaci* could be achieved in both crops under most conditions using *E. mundus* without recourse to insecticides.

Keywords: Whitefly; Augmentative release; Biological control; Protected agriculture

1. Introduction

Pepper and tomato are the chief greenhouse crops on the southern (Mediterranean) Spanish coast. Together these crops occupied 22,565 ha and produced 1686 kt of product during 1998 in Almería and Murcia provinces (INE, 2002). These and other horticultural crops destined for markets in Northern Europe and elsewhere are planted in late summer or early fall to be harvested from late fall through spring. A second crop may also be planted in late winter to be harvested in late spring and early summer. The key pest of these crops in recent times has been the whitefly *Bemisia tabaci* (Gennadius) (Homoptera: Aleyrodidae) that causes direct damage to both crops due to removal of plant sap and deposition of honeydew that serves as a substrate for sooty mold. Even more damaging are the virus diseases vectored by this pest, particularly in tomato where it readily

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transmits the geminivirus tomato yellow leaf curl (TYLCV) (SIFA, 2004). Cultural practices in Spain also lend themselves to whitefly and virus problems, with overlapping crop cycles, and enclosed pest populations that favor rapid selection against susceptibility to pesticides. Resistance to imidacloprid and other neonicotinoids has been documented (Cahill et al., 1996; Elbert and Nauen, 2000). The threat of TYLCV and the decreasing effectiveness of insecticides have spurred the development of tolerant cultivars that now constitute a large portion of tomato varieties planted in the region. These together with screening of vents and doorways to exclude pest entry create a compatible greenhouse environment for augmentative biological control (Stansly et al., 2004, 2005).

The parasitic wasp *Eretmocerus mundus* Mercet (Hymenoptera: Aphelinidae) stands out among potential biological control agents of *B. tabaci* for its reproductive and competitive potential on this host (Greenberg et al., 2002; López, 2002; Stansly et al., 2002; Urbaneja et al., 2003; Urbaneja and Stansly, 2004), and its adaptation to environmental conditions in its native Mediterranean region (Calvo et al., 2002; Urbaneja et al., 2002; Téllez et al., 2003). Like its congeners, *E. mundus* is a strict primary parasitoid that oviposits underneath the nymphal whitefly host (Gerling and Fried, 2000). Upon hatching, the first instar larva penetrates the host vector and completes development as an internal parasite. Prior to 2002, *E. mundus* was not commercially available in Spain and a North American species, *Eretmocerus eremicus* Rose and Zolnerowich, reared on greenhouse whitefly *Trialeurodes vaporiarorum* (Westwood) (Homoptera: Aleyrodidae), was used instead. Studies conducted following commercial releases of *E. eremicus* in greenhouses of Murcia and Almería showed that the indigenous *E. mundus* coming spontaneously from outside was recovered from *B. tabaci* in tomato and pepper in progressively greater proportions until it totally displaced *E. eremicus* (Van der Blom, 2002). This finding spurred development of commercial production of *E. mundus* in Spain and elsewhere.

Release rates for natural enemies in greenhouses are generally expressed in numbers per unit area, just as are application rates for spray materials. Release rates for *E. mundus* were initially set to those recommended for *E. eremicus* (www.koppert.nl) of 1.5–3 wasps m^{-2}/week as a preventative treatment and 3–9 wasp m^{-2}/week as curative treatments. These rates largely contrasted with those tested for control of *B. tabaci* with *E. eremicus* in poinsettia by Hoddle and Van Driesche (1999), and Van Driesche et al. (1999, 2001a) that were set at 1–5 wasps per plant per week, equating to 10.6–53.2 wasps m^{-2}/week depending on plant population.

Evaluations in Spain were conducted under commercial conditions using a weekly release rate of 3 wasps m^{-2} in tomato during the fall season (Stansly et al., 2004) but only a mean 0.46 wasps m^{-2}/week over an average of 9.4 weeks in pepper during the spring season (Stansly et al., 2005). These different rates reflected differences in perceived risk from whitefly in the crops, seasons, and localities tested. While results were largely satisfactory, these rates could hardly be considered generally applicable for several reasons: (1) different rates were not evaluated, (2) influx of *E. mundus* from wild populations in the field was not controlled.

In preventing influx of *E. mundus* from outside, many pests were also excluded, although intrusion of some smaller species might be expected. We planned to deal with these through biological control or other compatible management practices. Thus, *Frankliniella occidentalis* (Pergande), the western flower thrips, would be controlled in pepper with the mite *Neoseiulus* (*Amblyseius*) *cucumeris* (Oudemans) and the minute pirate bug, *Orius laevigatus* (Fieber) (Monserrat et al., 1998). *Phytoseiulus persimilis* Anthias-Henriot would be released to control two-spotted spidermite *Tetranychus urticae* Koch (Acari: Tetranychidae) in pepper or tomato. The selective acaracide bromopropylate would be applied in the event of an infestation of the tomato russet mite *Aculops lycopersici* (Massee) (Acari: Eriophyidae). None of these actions would be expected to impact whiteflies or *E. mundus* with the possible exception of *O. laevigatus* that can prey on *B. tabaci* nymphs in the absence of preferred thrips prey (Gerling et al., 2001; Montserrat et al., 2000). However, we considered this a less disruptive option than insecticide to control thrips.

The present experiments were designed to avoid earlier shortcomings by evaluating specific release rates in both tomato and pepper isolated from outside populations of natural enemies. The two rates tested, 1.5 and 6 wasps m^{-2}/week, were chosen to bracket the most commonly used rate of 3 wasps m^{-2}/week. In addition, typical patterns of whitefly infestation and likely timing of natural enemy release were simulated. All these measures were designed with objective of identifying optimal release rates for whitefly control under realistic greenhouse conditions where a biologically based pest management system was being employed.

2. Materials and methods

2.1. Compartmentalized greenhouse

Experiments were conducted in a 40 × 10-m air inflated double layered polyethylene covered Quonset-style greenhouse located at the Koppert Biological Systems S.A. facilities in Águilas (Murcia, Spain). The greenhouse was provided with pad and fan cooling and diesel heating and divided into 36 compartments 4 × 2 × 3.5 m (l × w × h) of which 24 were used for the present experiment, 12 on each side of a central corridor.

Compartment walls and ceilings were constructed of "anti-thrips" polyethylene screening with 220 × 331 μm interstices supported by heavy guy wires connected to the greenhouse superstructure. Floors were lined with woven 2-mm thick polyethylene ground cloth. Access to the greenhouse was gained through a double, zippered doorway with an additional zippered doorway leading to each compartment from the corridor. Each compartment was provided with a separate duct from the air-conditioning system. Temperature and relative humidity were monitored in four of the compartments with HOBO H8 RH/Temp Loggers (Onset Computer Company, Bourne, MA, USA).

2.2. Ambient conditions

Temperatures dropped 10° over the fall season from a mean 28 °C in week 35 to 18 °C in week 50 (Fig. 1A). Range about the mean was approximately 15 °C early season, narrowing to 10 °C late season. Mean relative humidity (%) rose from the high 60s early season to the high 70s mid season as temperatures fell, then descended again toward the end of the season as the use of artificial heating increased for an overall mean ± SE of 60.9 ± 1.7 (max 88.2 ± 2.0, min 27.3 ± 0.7). Temperatures remained close to 25 °C during the spring crop, rising 2° or 3° over the season (Fig. 1B) while mean relative humidity rose approximately 20% giving mean of 72.1 ± 1.1 (max 92.2 ± 1.2, min 40.1 ± 1.4).

2.3. Cultural and pest management practices

Seeds of tomato *Lycopersicum esculentum* L. 'Saskia' tolerant to TYLCV and TSWV and sweet pepper *Capsicum annuum* L. 'Spiro' tolerant to TSWV (Seminis Vegetable Seeds Europe Enkhuizen, The Netherlands) were planted into 5.4 cm^2 peat moss root cubes and later transplanted into composted coconut fiber in 6.3 L black polyethylene flowerpots. Transplant dates were 10 September 2001 and 15 March 2002 for the two experiments, respectively. Ten flowerpots were arranged in two rows in each screened compartment to give a density of 1.25 plants m^{-2}. Standard integrated pest management and horticultural practices for protected tomato and pepper in Spain were followed throughout the crop cycle (Monserrat et al., 1998). Each pot was supplied with a drip emitter delivering 2 L/h through which water and fertilizer were supplied as required. Plants were trained to 2 (tomato) or 3 (pepper) stems supported by strings attached to an overhead wire.

One blue and one yellow double-sided sticky trap 18 × 25 cm (Hombio BVBA, Sint-Katelijne Waver, Bel-

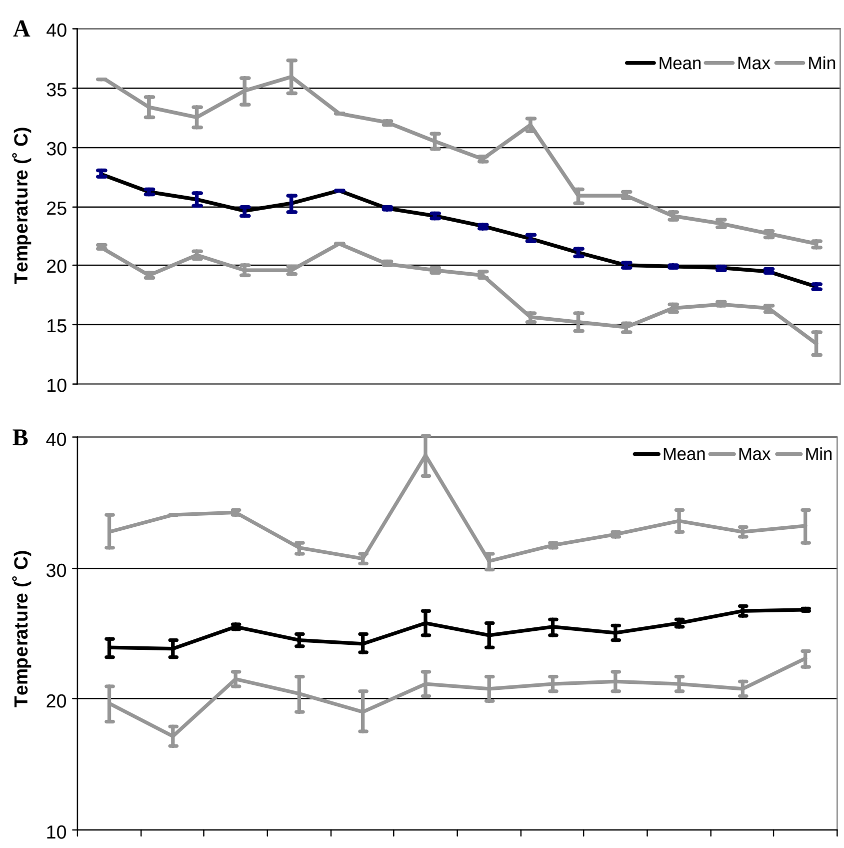

Fig. 1. (A) Mean (standard error) temperature in greenhouse, fall, 2001. (B) Mean (standard error) temperature in greenhouse, spring, 2002.

gium) was hung in each compartment at canopy level to capture flying insects. Traps were removed when parasitoid releases commenced. The first crop was treated once prior to transplanting with lufenuron (Match Syngenta Agro S.A., Madrid) 40 ml/hl to control western flower thrips. Tomatoes in both seasons were treated once with bromopropylate (Neoron, Syngenta, Madrid) at 15 ml/hl to control the tomato russet mite. Two weeks after transplanting, a sachet containing 1000 *N. cucumeris* (THRIPEX-PLUS; Koppert Biological Systems, Berkel en Rodenrijs Holland) *was* hung on each pepper plant for thrips control. One and 2 weeks later *O. laevigatus* (Fieber) (THRIPOR-L; Koppert Biological Systems, Berkel en Rodenrijs Holland) was released at a rate of 1 per pepper plant again for thrips control. *P. persimilis* (SPIDEX; Koppert Biological Systems, Berkel en Rodenrijs Holland) was released once in mid-December at 2000 per cage in two cages of tomato to control two-spotted spidermite.

2.4. Whiteflies and parasitoids

Bemisia tabaci adults originated from a production colony originally obtained locally and identified by PCR as biotype "Q" (J.L. Cenís, CIDA La Alberca. Murcia, SP, personal communication). *E. mundus* used in the studies were from colonies originally collected from multiple locations in the provinces of Murcia and Almería and maintained on *B. tabaci* at the Koppert facility in Águilas. Emergence from pupae used in the study was estimated at 70% so numbers were adjusted upward 30% in compensation.

2.5. Experimental design

Two factors were evaluated, crop and release rate, in a split plot design with four replications. There were four main plots of both tomato and pepper, each divided into three subplots, each in a cage designated at random for 1 of 3 release rates: 0, 1.5, and 6 *E. mundus* m^{-2}/week. Whiteflies for infestation were cooled momentarily in a refrigerator at 10 °C and counted out for release at a rate of 48 females per cage, a number calculated to provide one female per leaf. For the first experiment, whiteflies were released all at once on 27 September to simulate a frequent pattern during this period of massive whitefly migration from senescing summer crops. In contrast, whiteflies were released over three consecutive weeks beginning 4th April during the second experiment to simulate gradual entry more typical of the cool season. *E. mundus* was released weekly at the indicated rate for 6 weeks in pepper and for 11 and 9 weeks in tomato for the fall and spring crops, respectively. The release periods were prolonged in tomato because control took longer to achieve based on subsequent monitoring. Initial releases were made on 11 October and 25 April, respectively, 2 weeks after whitefly release. This interval was chosen to simulate a typical situation for a crop advisor, allowing a week for detection of the pest and another week to obtain and release the desired natural enemy. The appropriate number (16 and 48 per cage for the 1.5 and 6 m^{-2} treatments, respectively) of *E. mundus* pupae (inside their whitefly host) were counted out and left to emerge in 4-cm diameter petri dishes placed on the soil surface of a central pot. Care was taken to always enter control cages first, followed by low release rate cages and finally high release rate cages to minimize risk of cross contamination by parasitoids.

2.6. Evaluation

Plants were monitored weekly for 12 weeks in fall and 11 weeks in spring, beginning 1 October and 18 April, respectively. For the first (fall) experiment, three leaves were sampled from each of eight plants in each cage. One leaf was selected at random from the upper, middle, and bottom third of the plant. All whitefly stages and parasitized 4th instars were noted on each leaf using a 10×-hand lens. Relative incidence of parasitized whiteflies in the fall trial was expressed as the number of parasitized 4th instars/number of all instars. Leaf area was estimated at 451 cm^2 for tomato and 169 cm^2 for pepper by cutting out and weighing photocopies 20 leaves. These figures were used to convert whiteflies per leaf to whiteflies per 100 cm^2.

Based on information from the fall trial, a more efficient but comparable sampling scheme was devised for the second trial. Counts of adult whiteflies were made from six leaves selected at random from the middle strata of six tomato plants or from the 3rd node of six separate plants in each cage. In addition, leaf disks of 38.5 cm^2 area were cut with a sharpened section of pipe from six leaves selected randomly at the same level from six different plants. Leaf discs were examined under a stereoscopic microscope and all the following counted: whitefly eggs, nymphs by instar, exuviae from parasitized and unparasitized whiteflies, and parasitized nymphs. Early stages of parasitism in 4th instars were recognized by displaced mycetomes and later stages by the presence of the parasitoid pupa. Relative incidence of parasitism was expressed again as number 4th instars parasitized/number of all stages (for comparison with the fall experiment) and also as number of parasitized 4th instars/number of all 4th instars.

2.7. Analysis

Cumulative whitefly days were calculated for each sample location (plot, plant, and stratum) by multiplying the number of whiteflies observed each sample day by the number of days between sampling periods (7).

Whitefly days were subjected to one-way analysis of variance with mean separation using LSD in the event of a significant F ($P < 0.05$) (SAS, 2004); The arc sine square root transformation was used on proportions of parasitized whiteflies before analysis to stabilize error variance (Gomez and Gomez, 1984), although untransformed data are given in tables and figures. Degree of whitefly suppression obtained by parasitoid treatments was expressed using the formula $100 \times (1 - \text{treated}/\text{control})$.

3. Results

The maximum whitefly population density on control plants in cages receiving no *E. mundus* were twice as high on tomato as on pepper during the fall season (Figs. 2, 3). Whitefly adults on untreated pepper peaked at over 8 per 100 cm^2 leaf surface on the 10th week, falling to about half that value during the subsequent 2 weeks (Fig. 2A). In contrast, fewer than 1 adult per 100 cm^2 was observed throughout the season on plants in cages receiving either 1.5 or 6 m^{-2} *E. mundus* per week for 6 weeks. Numbers of nymphs on pepper rose to a high of almost 80 per 100 cm^2 compared to 10 or less on treated plants (Fig. 2B). Adult population reductions exceeding 90% were observed by the 8th and 9th week for the high and low rate, respectively, and by the 9th and 11th week for nymphs.

Whitefly adults on tomato reached more than 17 per 100 cm^2 on untreated plants compared to less than 1 per 100 cm^2 on plants in cages receiving 6 m^{-2} *E. mundus* per week for 11 weeks (Fig. 3A). Numbers of adults on plants in cages receiving 1.5 m^{-2} *E. mundus* were intermediate. A similar pattern was observed for nymphs, with the mean surpassing 160 per 100 cm^2 compared to less then 20 with no increase for the last 5 weeks in response to the high release rate (Fig. 3B). Whitefly populations on plants receiving the low release rate were intermediate. Populations of both adults and nymphs were reduced more than 95% by the 9th week in response to the high release rate, but never more than 69 and 54% for adults and nymphs, respectively, by the low rate.

Interactions between plant type and release rate were significant ($P < 0.001$) for both adult days and nymph days accumulated during the 12 weeks of the trial ($F = 18.2$ and 6.0, $P < 0.0001$ and 0.0026, respectively,

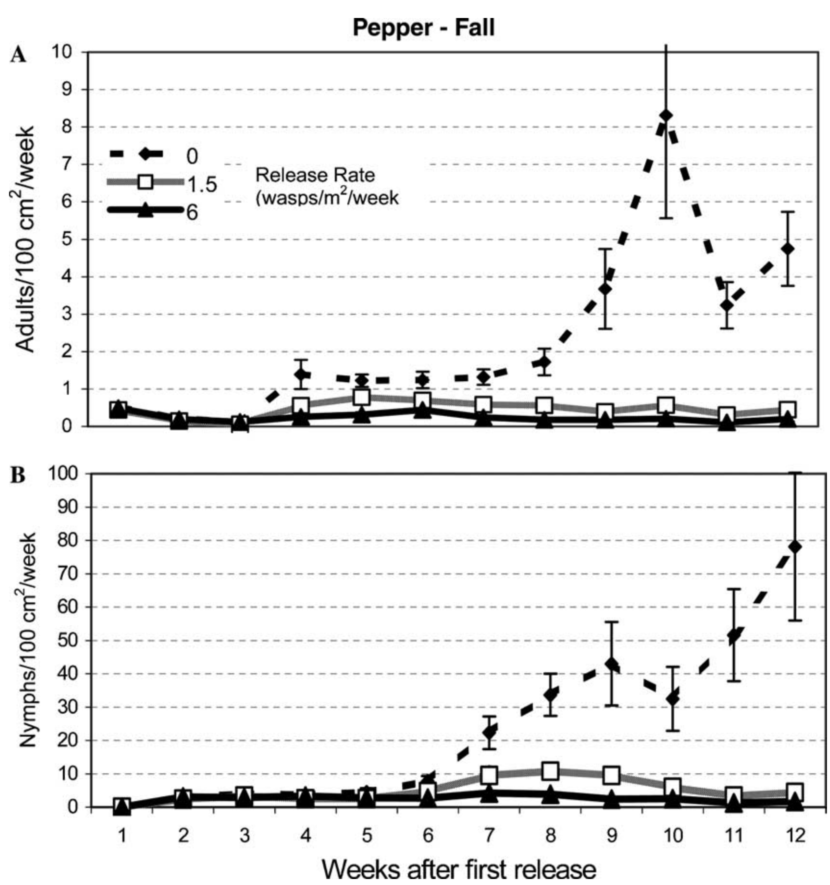

Fig. 2. (A) Mean (standard error) whitefly adults on pepper in cages receiving 0, 1.5, and 6 *E. mundus* per week for 6 weeks, fall 2001. (B) Mean (standard error) whitefly nymphs on pepper in receiving 0, 1.5, and 6 *E. mundus* per week for 6 weeks, fall 2001.

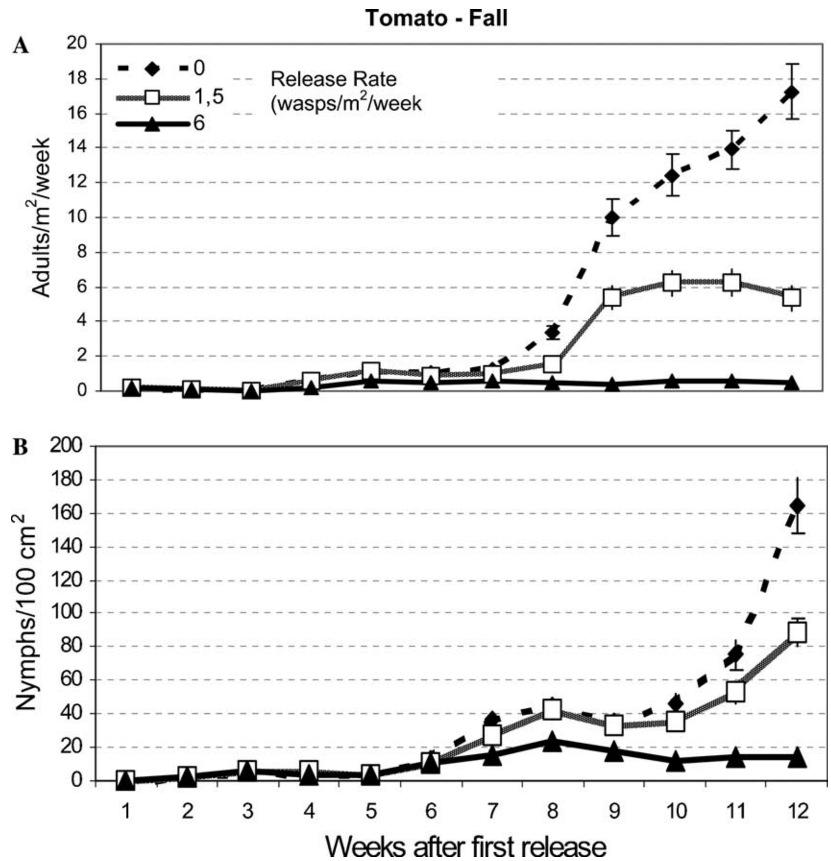

Fig. 3. (A) Mean (standard error) whitefly adults on tomato in cages receiving 0, 1.5, and 6 *E. mundus* per week for 11 weeks, fall 2001. (B) Mean (standard error) whitefly nymphs on tomato in receiving 0, 1.5, and 6 *E. mundus* per week for 11 weeks, fall 2001.

df = 2558). Therefore, crop effects were analyzed separately for each release rate and the effect of rate tested separately for each crop.

Significantly more whitefly days were accumulated in fall on tomato than on pepper for both adults and nymphs at all release rates including the control (Table 1). However, there were no significant differences between crops in parasitism rates. In pepper, significantly more whitefly days were observed on control plants than on plants subject to either release rate, with no differences between the 1.5 and 6 wasps m^{-2}/week rates. Nevertheless, incidence of parasitism was significantly different between these two rates. Reduction of whitefly days in treated pepper compared to the untreated population reached 83 and 90% (adults) and 94–98% (nymphs) for the two release rates, respectively. This contrasted with the situation in tomato where whitefly days were reduced by 90% or more in response to the high rate, but only by 67 and 63% for adults and nymphs, respectively, in response to the low rate. Again, incidence of parasitism was significantly different among all release rates. Reduction in whitefly days in response to the high rate was still 92 and 88% for adults and nymphs, respectively, compared to only 51 and 41% for the low rate.

Table 1
Whitefly days and percent parasitism of 4th instars with respect to all nymphal stages in fall compared between crops by release rate and among rates for each crop

Crop	Fall Release rate (wasps m^{-2}/week)		
	0	1.5	6
Adult days			
Pepper	175.6 ± 32.3bA	35.5 ± 3.5bB	18 ± 1.6bB
Tomato	367.2 ± 21.4aA	180.5 ± 12.3aB	30.3 ± 1.8aC
Nymph days			
Pepper	453.9 ± 124.1bA	26.8 ± 2.4bB	10.5 ± 1.0bB
Tomato	840.2 ± 79.5aA	496.1 ± 43.5aB	99 ± 11.8aC
Parasitism (%)			
Pepper	0.46 ± 0.24aC	10.6 ± 2.2aB	24.9 ± 3.7aA
Tomato	0.05 ± 0.03aC	5.9 ± 0.8aB	13.3 ± 1.5aA

Means in columns (of two crops) followed by the same small letter or means in rows (of three rates) followed by the same capital letter are not significantly different (LSD, $P < 0.05$).

3.1. Spring trial

This time whitefly populations were greater on pepper than tomato, exceeding fall populations on pepper by a factor of 4 (Figs. 4 and 5). Up to 300 nymphs per

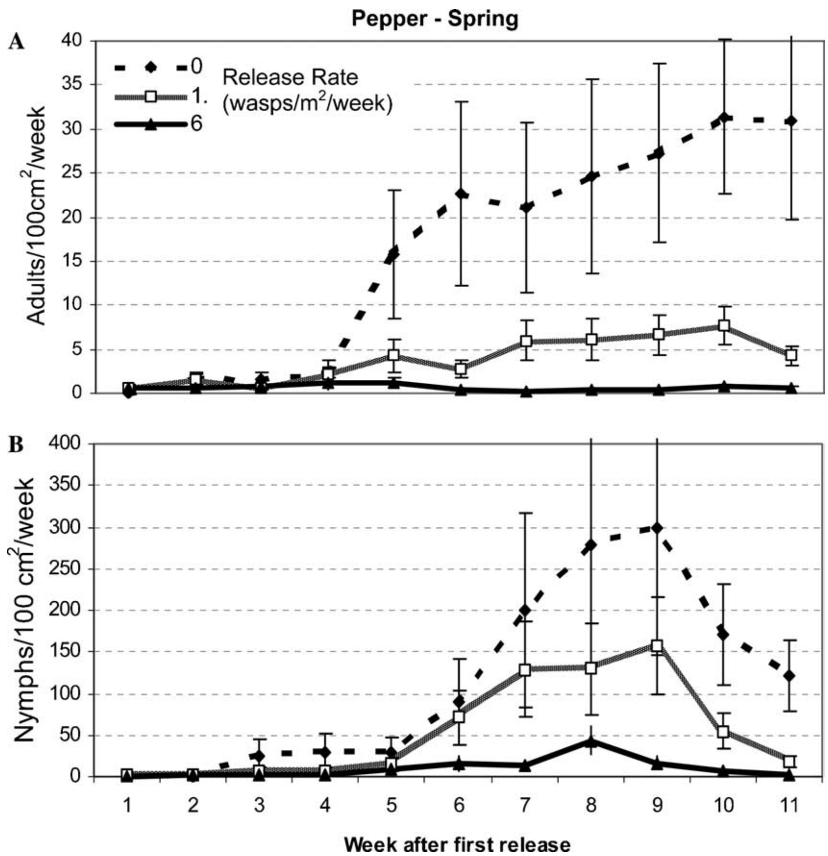

Fig. 4. (A) Mean (standard error) whitefly adults on pepper in cages receiving 0, 1.5, and 6 *E. mundus* per week for 6 weeks, spring 2002. (B) Mean (standard error) whitefly nymphs on pepper in receiving 0, 1.5, and 6 *E. mundus* per week for 6 weeks, spring 2002.

100 cm^2 (500 per leaf) were observed in the 10th week on pepper (Fig. 4). Nevertheless, densities of nymphs were generally maintained below 10 per 100 cm^2 in response to the high release rate except in week 8 when they rose momentarily to 36 per 100 cm^2. Adults on pepper remained at 1 per 100 cm^2 or below in response to the high parasitoid release rate compared to less than eight for the low rate or more than 40 for the control. Numbers of adults on tomato were comparable to the fall but nymphs were fewer by a factor of 3. Differences between release rates were less marked than for pepper (Fig. 5).

Interactions between plant type and release rate were again significant ($P < 0.001$) for both adults and nymphs and so each factor was analyzed separately. More whitefly days were accumulated in pepper than tomato for both adults and nymphs at all rates (Table 2). Significantly fewer whitefly days were accumulated in both pepper and tomato in response to either release rate compared to the control, with no differences between rates. Some parasitism was observed toward the end of the trial in control cages, especially in pepper which was significantly greater than in tomato (Table 3). No differences were seen between crops at the 1.5 and 6 wasps m^{-2}/week rates in spring. Similarly, there were no differences observed in incidence of parasitism between the two release rates except by the criterion of parasitized 4th instars relative to all 4th instars plus pharate adults in pepper. By this commonly used criterion, parasitism reached 92% in tomato and 98% in pepper. Adult whitefly days in tomato were reduced by 93% in response to the high rate whereas nymph days were only reduced by 69%. This compared to 97.4 and 94.7%, respectively, in pepper, even though infestation levels were over five times greater than in tomato.

4. Discussion

With declining temperatures if fall we obtained a clear but contrasting result in pepper and tomato. The low release rate of 1.5 wasps m^{-2}/week over 6 weeks was clearly adequate to control the whitefly population in pepper. This was equivalent to 1.9 wasps per plant per week (11.4 total wasps per plant) to control an infestation initiated 2 weeks prior to the first release with 4.8 whiteflies per plant. The ratio of wasps:whitefly after the first release was 1:2.5, and after all six releases 2.3:1, excluding subsequent progeny. Thus, a bit more than twice as many wasps were released as the initial number of whiteflies. Control was not improved by releasing four

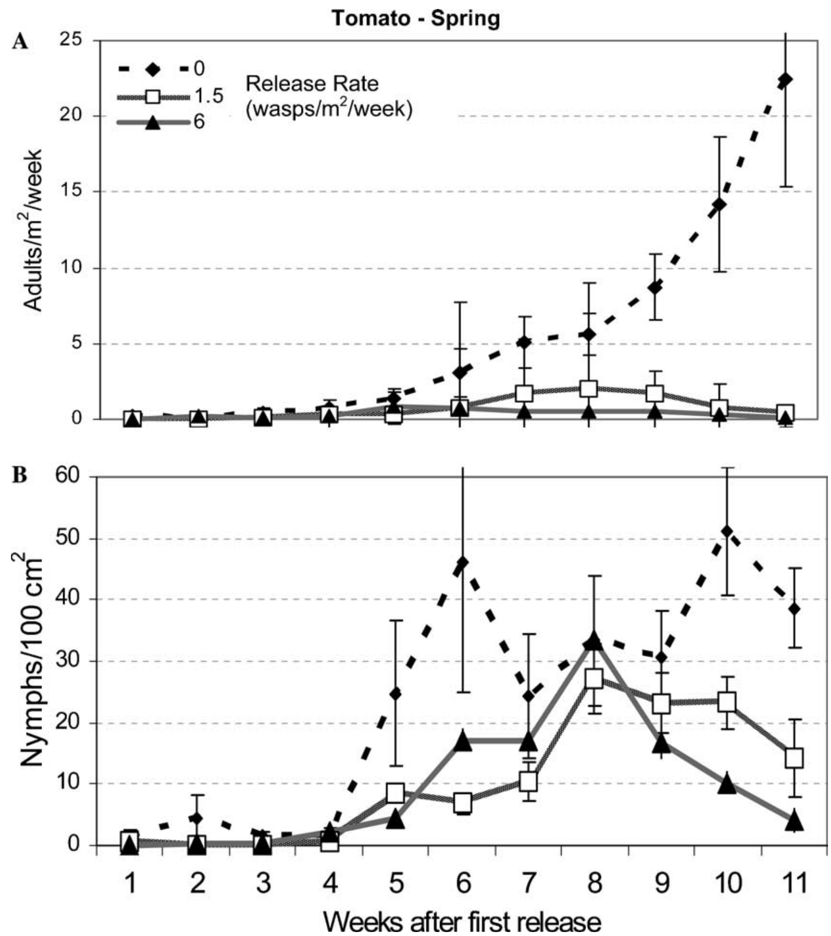

Fig. 5. (A) Mean (standard error) whitefly adults on tomato in cages receiving 0, 1.5, and 6 *E. mundus* per week for 9 weeks, spring 2002. (B) Mean (standard error) whitefly nymphs on tomato in receiving receiving 0, 1.5, and 6 *E. mundus* per week for 9 weeks, spring 2002.

Table 2
Whitefly days in spring compared between crops by release rate and among rates for each crop

Crop	Spring Release rate (wasps m^{-2}/week)		
	0	1.5	6
Adult days			
Pepper	1527.8 ± 407.6aA	236.4 ± 82.5aB	40.8 ± 10.6aB
Tomato	355.7 ± 100.5bA	56.2 ± 6.6bB	28.3 ± 6.5bB
Nymph days			
Pepper	12883.0 ± 4011.0aA	3698.1 ± 1482.8aB	723.1 ± 234.9aB
Tomato	1701.9 ± 372.7bA	800.8 ± 123.7bB	758.7 ± 133.0bB

Means in columns (of two crops) followed by the same small letter or means in rows (of three rates) followed by the same capital letter are not significantly different (LSD, $P < 0.05$).

Table 3
Percent parasitism calculated as number of parasitized 4th instar days with respect to all nymphal stages, and as number of parasitized 4th instar days by number of all 4th instars compared between crops by release rate and among rates for each crop in spring

Crop	Spring Release rate (wasps m^{-2}/week)		
	0	1.5	6
Parasitized 4th instars by all instars (%)			
Pepper	3.3 ± 1.2aB	9.2 ± 2.4aA	10.6 ± 2.4aA
Tomato	0.2 ± 0.2bB	4.8 ± 1.2aA	8.8 ± 2.6aA
Parasitized 4th instars by 4th instars (%)			
Pepper	40.2 ± 10.5aC	83.2 ± 7.4aB	98.4 ± 0.9aA
Tomato	1.3 ± 1.1bB	81.2 ± 7.5aA	92.2 ± 5.9aA

Means in columns (of two crops) followed by the same small letter or means in rows (of three rates) followed by the same capital letter are not significantly different (LSD, $P < 0.05$).

times as many wasps every week. In contrast, the high (6 wasps m^{-2}/week = 7.5 wasps/plant/week) rate repeated over 11 consecutive weeks for a total of 82.5 wasps per plant was needed to suppress whitefly on tomato in fall. The same number of whiteflies was released, giving a ratio of wasps/whitefly of 1.6:1 after the first release and 17.2:1 by the final release. Given that populations in untreated tomato during fall eventually rose to more than twice that observed in untreated pepper, it would have been tempting to conclude that more parasitoids were required to achieve control in tomato because this crop supported more whiteflies than pepper.

Even higher whiteflies populations were seen in spring when temperatures remained in the optimal range whitefly development. Furthermore, the situation was reversed with five times more whiteflies observed on pepper than on tomato. Nevertheless, we again achieved excellent whitefly control in pepper at either rate but only saw 69% control of nymphs in tomato, even with the high release rate. We can only conclude that control of a given population of *B. tabaci* with *E. mundus* in tomato requires higher release rates than in pepper, all other things being equal.

It is not clear why *B. tabaci* should be easier to control with *E. mundus* in pepper than tomato. Results from laboratory studies have shown the wasp to be equally well adapted to either whitefly host (Stansly et al., 2002). These studies indicated that a higher net reproductive rate in pepper compared to tomato was offset by a higher generation time in pepper. As a result, intrinsic rate of increase was not statistically different between crops. Nevertheless, our experience in commercial trials would also support the conclusion that *B. tabaci* is more easily controlled in pepper than in tomato (Stansly et al., 2004, 2005).

Even though higher rates of *E. mundus* are necessary in tomato, they are still well below rates *of E. eremicus* most often used in poinsettia Hoddle and Van Driesche (1999), and Van Driesche et al. (1999, 2001a). Furthermore, applications of an insect growth regulator were still necessary to achieve adequate control in the poinsettia study (Van Driesche et al., 2001b), although the market for ornamental plants is generally much more exacting than for vegetables. Nevertheless, we were able to suppress high whitefly populations in pepper with 1.5 wasps m^{-2}/week and in tomato with 6 wasps m^{-2}/week without recourse to any other control. This would tend to support conclusions from earlier studies indicating better control of *B. tabaci* biotype "Q" with *E. mundus* compared to *E. eremicus* (Stansly et al., 2004, 2005).

Biological control of *B. tabaci* with *E. mundus* in protected pepper culture should be readily adapted, given the evident effectiveness of the technology and the tolerance of the crop in the absence of whitefly transmitted viruses in pepper throughout most production regions. Indeed, *E. mundus* is already widely used in pepper in the Campo de Cartagena region of Spain (Calvo et al., 2002; Lara and Urbaneja, 2002; Stansly et al., 2005; Urbaneja et al., 2003; Van der Blom, 2002) and probably elsewhere as well. Control on tomato is more problematic due to high incidence of whitefly transmitted viruses such as tomato yellow leafcurl (geminivirus) TYLCV in many production areas including southern Spain (Stansly et al., 2004). Nevertheless, resistance to pesticide use from the market, from regulatory agencies, and from the pests themselves is providing increasing impetus for change (Stansly et al., 2004). Meanwhile, development of compatible control strategies is providing the means to include biological control as a viable strategy. These include virus resistant cultivars that greatly reduce the damage potential of whitefly and effective exclusion with insect netting that both reduces the risk from virus and facilitates control with the parasitoid. No amount of testing can cover all the possible scenarios that may occur in the field. The present experiment provides guidelines for two stringent sets of conditions that included high initial pest populations, and also offers some assurance that a management system for *B. tabaci* based strictly on biological control with *E. mundus* can function successfully.

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References

Cahill, M., Gorman, K., Day, S., Denholm, I., Elbert, A., Nauen, R., 1996. Baseline determination and detection of resistance to imidacloprid in *Bemisia tabaci* (Homoptera: Aleyrodidae). Bull. Entomol. Res. 86, 343–349.

Calvo, J., León, P., Giménez, A., Stansly, P.A., Urbaneja, A., 2002. Control biológico de *Bemisia tabaci* (Hom.: Aleyrodidae) en cultivo de pimiento en el Campo de Cartagena mediante sueltas de *Eretmocerus mundus* y *E. eremicus* (Hym.: Aphelinidae). Terralia 30, 60–68.

Elbert, A., Nauen, R., 2000. Resistance of *Bemisia tabaci* (Homoptera: Aleyrodidae) to insecticides in southern Spain with special reference to neonicotinoids. Pest Manag. Sci. 56, 60–64.

Gerling, D., Fried, R., 2000. Biological studies with *Eretmocerus mundus* Mercet (Hymenoptera: Aphelinidae) in Israel. OILB/SROP Bull. 23, 117–123.

Gerling, D., Alomar, O., Arnó, J., 2001. Biological control of *Bemisia tabaci* using predators and parasitoids. Crop Prot. 20, 779–799.

Greenberg, S.M., Jones, W.A., Liu, T.X., 2002. Interactions among two species of *Eretmocerus* (Hymenoptera: Aphelinidae), two species of whiteflies (Homoptera: Aleyrodidae), and tomato. Environ. Entomol. 31, 397–402.

Gomez, K.A., Gomez, A.A., 1984. Statistical Procedures for Agricultural Research. John Wiley and Sons, New York (USA).

Hoddle, M.S., Van Driesche, R.G., 1999. Evaluation of *Eretmocerus eremicus and Encarsia formosa* (Hymenoptera: Aphelinidae) Beltsville strain in commercial greenhouses for biological control of *Bemisia argentifolii* (Homoptera: Aleyrodidae) on colored poinsettia plants. Fla. Entomol. 82, 556–569.

INE. 2002. Anuario de Estadística Agraria. Instituto Nacional de Estadística. Madrid (Spain).

Lara, L., Urbaneja, A., 2002. Control biológico de plagas en pimiento en la provincia de Almería. Horticultura 165, 86–90.

López, J., 2002. Eficacia y competencia de *Eretmocerus mundus* y *Eretmocerus eremicus* (Hymenoptera, Aphelinidae) parasitando *Bemisia tabaci* (Homoptera, Aleyrodidae) en tomate y pimiento. Proyecto Final de Carrera, EUITA, Universidad Politécnica de Cartagena. Murcia (Spain).

Monserrat, A., Lacasa, A., and Vicente, F., 1998. Normas técnicas de producción integrada en pimiento de invernadero. Orden de 10 de Junio de 1998. BORM 138 de 18-06-1998.

Montserrat, M., Albajes, R., Castañé, C., 2000. Functional response of four heteropteran predators preying on greenhouse whitefly (Homoptera: Aleyrodidae) and Western flower thrips (Thysanoptera: Thripidae). Environ. Entomol. 29, 1075–1082.

SAS Institute. 2000. SAS/STAT user's guide. Cary, N.C., USA.

SIFA. 2004. Servicio de información agraria. Junta de Andalucia. http://desaveal.ual.es/sifa/inicio.htm.

Stansly, P.A., Urbaneja, A., and Sánchez, E., 2002 Fecundity and Survivorship of *Eretmocerus mundus* Mercet (Hymenoptera: Aphelinidae) on *Bemisia tabaci* biotype "Q" (Homoptera: Aleyrodidae) using sweet pepper and tomato. EWSN Abstract Compendium 1 (6).

Stansly, P.A., Sánchez, P.A., ROdríguez, J.M., Cañizares, F., Nieto, A., López, M.J., Fajardo, M., Suarez, V., Urbaneja, A., 2004. Prospects for biological control of *Bemisia tabaci* (Homoptera, Aleyrodidae) in greenhouse tomatoes of southern Spain. Crop Protection 23, 701–712.

Stansly, P.A., Calvo, F.J., Urbaneja, A., 2005. Augmentative Biological Control of *Bemisia tabaci* Biotype "Q" in Spanish Greenhouse Pepper Production Using *Eretmocerus* spp. Crop Protection 24, 829–835.

Téllez, M.M., Lara, L., Stansly, P.A., Urbaneja, A., 2003. *Eretmocerus mundus* (Hym.; Aphelinidae), parasitoide autóctono de *Bemisia tabaci* (Hom.: Aleyrodadae): primeros resultados de eficacia en judía. Bol. San. Veg. Plagas 29, 511–521.

Urbaneja, A., Calvo, J., León, P., Giménez, A., Stansly, P.A., 2002. Primeros resultados de la utilización de *Eretmocerus mundus* para el control de *Bemisia tabaci* en invernaderos de pimiento del Campo de Cartagena. FECOAM 37, 12–17.

Urbaneja, A., Stansly, P.A., Calvo, J., Beltrán, D., Lara, L., Van der Blom, J., 2003. *Eretmocerus mundus*: control Biológico de *Bemisia tabaci*. Phytoma 144, 139–142.

Urbaneja, A., Stansly, P.A., 2004. Host suitability of different Instars of the whitefly *Bemisia tabaci* "biotype Q" for *Eretmocerus mundus*. Biocontrol 49, 153–161.

Van der Blom, J., 2002. La introducción artificial de la fauna auxiliar en cultivos agrícolas. Bol. San. Veg. Plagas 28, 109–120.

Van Driesche, R.G., Lyon, S.M., Hoddle, M.S., Roy, S., Sanderson, J.P., 1999. Assessment of cost and performance of *Eretmocerus eremicus* (Hymenoptera: Aphelinidae) for whitefly (Homoptera: Aleyrodidae) control in commercial poinsettia crops. Fla. Entomol. 82, 570–594.

Van Driesche, R.G., Hoddle, M.S., Roy, S., Lyon, S., Sanderson, J.P., 2001a. Effect of parasitoid release pattern on whitefly (Homoptera: Aleyrodidae) control in commercial poinsettia. Fla. Entomol. 84, 63–69.

Van Driesche, R.G., Hoddle, M.S., Lyon, S., Sanderson, J.P., 2001b. Compatibility of insect growth regulators with *Eretmocerus eremicus* (Hymenoptera: Aphelinidae) for whitefly (Homoptera: Alyerodidae) control on poinsettias II. Trials in commercial poinsettia crops. Biol. Control 20, 132–146.