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Releases of parasitoids (*Ceranisus* spp.) as biological control agents of western flower thrips (*Frankliniella occidentalis*) in experimental glasshouses

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Abstract

Experimental releases were performed to investigate the potential of thrips parasitoids as biological control agents of western flower thrips, *Frankliniella occidentalis* (Pergande). Strains of two larval parasitoid species (Hymenoptera: Eulophidae), *Ceranisus menes* (Walker) (a strain from France and from Brazil) and *Ceranisus americensis* (Girault) (Arizona strain), were released in different commercial greenhouse crops. In all crops only traces of parasitism were recorded. In an experimental rose crop (cv. 'Frisco'), releases were made of two parasitoid species, *C. menes* (a French strain) and *C. americensis* (Arizona strain) in two separate greenhouse compartments. An account is given on the release, dispersal, establishment, population dynamics and control capacity of both parasitoid species. Parasitoids spread readily and established themselves throughout the crops, but releases did not result in reduction of thrips during a five month period. Rates of parasitism stayed lower than 10% throughout the season, resulting in severe damage of the rose crop. The potential of parasitoids as biological control agents of thrips pests in ornamental crops is discussed.

Key words: *Frankliniella occidentalis*, *Ceranisus menes*, *Ceranisus americensis*, ornamentals, dispersal, control capacity, glasshouse.

Introduction

Western flower thrips, *Frankliniella occidentalis* (Pergande), is an extremely polyphagous invading pest species. Two hundred and forty-four species of plants belonging to 62 different plant families, have been found to host *F. occidentalis* (Tommasini and Maini, 1995), and its number is increasing with time and its expansion to new areas. These plant species include many important crops, open-field as well as protected crops, such as ornamental, fruit, garden and agricultural crops (Yudin *et al.*, 1986; Mantel and van de Vrie, 1988; Tommasini and Maini, 1995). In Europe, most commonly infested vegetable crops include cucumber, sweet pepper, lettuce and tomato, whereas a large range of ornamental crops are hosting *F. occidentalis* as well, the most important being Saintpaulia, chrysantehmum, gerbera and rose (Tommasini and Maini, 1995). Except vectoring a number of plant viruses (Wijkamp *et al.*, 1995), the predominant way of damage being inflicted to plants is direct and largely mechanical. Depending on the organ and growth stage attacked this can vary from discolouration and silvering to necrosis and growth damage (Brødsgaard, 1989; Kirk and Lewis, 1997).

Since *F. occidentalis* has established in Dutch greenhouses, biological control of has been most successful in vegetable crops, in particular those where pollen is available as a secondary food source (van de Meiracker and Ramakers, 1991; van Rijn *et al.*, 1995). In ornamental crops, on the other hand, biological has been mainly chemical, because the damage is inflicted largely to the end product, the flowers itself. The level of damage tolerance is much lower than in vegetables, and in most crops even a zero-tolerance is the standard.

Rose is one of the most important ornamental crops in The Netherlands (898 ha, Ekkes *et al.*, 1994). Except for *Thrips tabaci* Lindeman, *F. occidentalis* can cause severe damage at low density levels, visible as discolouration of the flower and necrosis of the petals. Natural enemies currently used to control western flower thrips, *F. occidentalis*, belong to two predator groups, predatory mites (Phytoseiidae) like *Amblyseius cucumeris* (Oudemans) and more recently *Amblyseius degenerans* Berlese or pirate bugs (Anthocoridae) like *Orius* spp.. In vegetables, sweet pepper (van den Meiracker and Ramakers, 1991) and cucumber (Riudavets, 1995) in particular, commercial releases of either one of these groups is able to keep thrips pests outbreaks in check. In greenhouse ornamentals, experimental releases of pirate bugs (*Orius* spp.) resulted in reduction of thrips numbers in chrysanthemum and Saintpaulia (Fransen and Tolsma, 1992; Sörensson and Nedstam, 1993), but not in roses (Fransen *et al.*, 1993a; 1993b; Bertaux, 1993). *Orius insidiosus* (Say) showed a lower level of searching time (Beekman *et al.*, 1991) and reproduction (Fransen *et al.*, 1993a) on rose, compared to other ornamental crops. *Orius laevigatus* (Fieber) reproduced in rose (cv. 'Sonia'), but was not able to keep *F. occidentalis* populations in check (Bertaux, 1993). Occasionally *A. cucumeris* is released in roses, but control of thrips pests is incomplete and chemical corrections are necessary. The cultivation of propagation material and container plants in particular, represents a small but significant section in the ornamental industry (Ekkes *et al.*, 1994). In these nurseries, plants are kept in the greenhouse over a relatively long period of time, and are not a finished product.

Therefore, the damage threshold is relatively high compared to that used in cut-flowers, which gives more opportunity for biological measures to control thrips pests.

A group of the natural enemies currently studied for its prospects to control thrips pests are thrips parasitoids, and *Ceranisus menes* (Walker) and *Ceranisus americensis* (Girault) (Hymenoptera: Eulophidae) in particular. Both species have been found in association with *F. occidentalis* on roses and flowering plants before, in the open as well as in the greenhouse at various locations (Greene and Parella, 1993; Loomans, 1991). Based on evaluation trials in the laboratory (Loomans and van Lenteren, 1994) strains of each parasitoid species have been selected for experimental releases in greenhouse tests. The present study reflects the results of pilot releases in commercial greenhouses, vegetable crops as well as ornamental container plants. In two experimental greenhouse compartments, we investigated the release, dispersal, establishment, population dynamics and control capacity of thrips parasitoids in a rose crop.

Materials and methods

1. Commercial greenhouses

Preceding the principal experiment, parasitoids were released in different crops and systems. During spring 1992, pilot releases were made in two commercial greenhouse crops of 1 ha each (table 1). Adult parasitoids - strain Brazil, grown on *Frankliniella schultzei* (Trybom), reared on bean pods (Murai and Loomans, 2001) - were released during noon in small cohorts of 25 specimens each 40-50 cm below the top of the plants, in a *F. occidentalis* infested hotspot. Both crops were 5-6 months old and were 150-200 cm high. In both greenhouses until one week before our parasitoid releases started, regular biological control measures were taken, i.c. releases of *O. insidiosus* and *A. cucumeris* had been made. Because in sweet pepper the thrips infestation was not yet under control, additional releases were made during our program (table 1). In cucumber thrips densities were relatively low (adults/leaf = 0,18 ± 0,06, larvae / leaf = 0,61 ± 0,20). In total 500 (cucumber) and 3165 (sweet pepper) adult parasitoids were released once or at regular intervals. Samples of leaves (cucumber) and flowers and leaves (sweet pepper) were taken on a weekly basis, taken to the laboratory and larvae checked for parasitism.

During 1993, releases were made in a 0.25 ha nursery of Mediterranean and subtropical plants in Malden (Gelderland), The Netherlands. In this nursery a large variety of plants (~120 species) were grown in containers in three different compartments: a 'warm' section (minimum 18 °C in winter), a 'cold' section (minimum 8 °C in winter) and an 'open' section (minimum 0 °C) (Klerx, 1993). Pesticides were used only once a year, just after pruning in October and pests were controlled biologically, wherever necessary and whenever possible, but not during our release period. Small cohorts of parasitoids were released at intervals of 2 or 4 weeks and regularly distributed in space, more specifically on those tablets covering plant species that were infested with *F. occidentalis* (table 2). Release were made form May till October 1993, in the 'cold' section only. Main purpose of this experiment was to verify if *C. menes* would be able to establish, to build up a population and overwinter. Samples of different plant species were taken of flowers (table 2) by picking or by shaking the head, just prior to a new parasitoid release. Samples were taken to the laboratory and larvae were reared to maturity on pollen and checked for parasitism.

2. Experimental greenhouses

Experimental design

Experiments were carried out in two greenhouse compartments of 100 m^2 each (G1 and G2) at the Research Station for Floriculture (Applied Plant Research) in Aalsmeer - The Netherlands from March until August 1994. Both compartments had an open ventilation system. 672 and 700 rose plants of a yellow variety (cv. 'Frisco') were planted October 1993 in the respective greenhouse compartments G1 and G2 (see figure 1). Rose plants were cultivated on rock-wool at an average constant temperature of 20 °C and 16 h light, including assimilation light in spring. Crop maintenance and harvest of the rose crops was carried out conform common practice. Pests and diseases were controlled biologically or by use of selective chemicals with minimum side effects for the thrips parasitoids (see table 3).

Hosts and parasitoids

C. menes, originating from France (yellow strain 'Brignoles'; Loomans, 1991) was reared on *F. schultzei* in the laboratory since 1990 and *C. americensis* ('Will-

Table 1. Overview of experimental releases of *C. menes* (strain Brazil) in vegetable crops in two commercial greenhouses (1 ha each) during spring 1992, under regular biological control; temperature minimum 21 °C during the day, 18 °C at night.

Location	crop	date	release parasitoids		# sites	# rows
			number	age		
Bleiswijk [1]	cucumber	27.03	500	1-4d	20	4
Pijnacker [2]	sw. pepper	23.03	875	1-4d	35	5
"	"	31.03	300	4-7d	16	3
"	"	14.04	600	1-4d	24	4
"	"	23.04	450	4-8d	18	6
"	"	20.05	825	2-8d	33	7

[1,2] Two releases of pirate bugs (*Orius insidiosus*) and predatory mites (*Amblyseius cucumeris*) until March 18.

Table 2. Release and sampling program of *C. menes* (strains France-Perpignan and Brazil released in mixed batches; numbers in bold) and *F. occidentalis* larvae (standard font) in a nursery of Mediterranean plants (Malden-Netherlands) during summer and fall of 1993; temperature minimum 8 °C, maximum 43 °C.

Plant species	tablet	action	date (day.month)										#	#	sample
			30.05	11.06	17.06	30.06	23.07	29.07	03.08	07.08	11.08	01.10	07.10	wasps	larvae	# flowers
Alyogyne	k2-T1	**release**	**50**	**50**										**100**		
huegueli		collect		56	65	112	2			1					236	30 pick
Anisodontea	k2-T1	**release**	**50**			**125**	**225**							**400**		
capensis		collect		56	20	75	275	41	8						475	100 pick
Anisodontea	k2-T2	**release**							**165**	**200**				**365**		
capensis		collect								31	48	17	11		107	290 pick
Anisodontea	k2-T7	**release**					**140**	**95**	**100**	**200**				**535**		
capensis		collect					800	230	91	60	235	60	23		1499	380 pick
Mimulus	k2-T7	**release**												**0**		
puniceus		collect			130	85	80	83	38	33		68	54		571	285 pick
Fuchsia	k2-T4	**release**										**100**		**100**		
		collect											19		19	50 pick
Solanum	k2-G8	**release**	**100**											**100**		
nierembergia		collect		47											47	25 pick
Oxypetalum	k2-T11	**release**	**100**											**100**		
ceruleus		collect		43											43	25 shake
Cassia	k2-T10	**release**		**75**										**75**		
australis		collect			29										29	25 shake
Lotus	k2-G9	**release**	**100**	**50**			**100**			**100**				**350**		
bertelotti		collect		235	300	65	70								670	100 shake
Solanum	k2-T8	**release**	**225**	**150**		**200**	**100**							**675**		
bonariense		collect		55	80	130	40	8		0					313	150 shake
Solanum	k2-T9	**release**						**55**		**75**		**100**		**230**		
rantoneti		collect							0		0		14		14	75 shake
Lantana sp.	k2-T5	**release**										**100**		**100**		
		collect											77		77	25 shake
Lantana sp.	k2-T8	**release**										**100**		**100**		
		collect											68		68	25 shake
Wasps released			**625**	**325**		**325**	**565**	**150**	**265**	**575**		**400**		**3230**		
Strain France (Pb)			175				140	55	80	175				625		
Strain France (Py)			450	75			150		125					800		
Strain Brasil				250		325	275	95	60	400		400		1805		
Total number of larvae collected				492	624	467	1267	362	137	125	283	145	266		4168	
		matured		358	386	304	775	230	92	109	240	114	203		2811	
		parasitised		0	0	0	2	0	0	0	1	0	0		3	

Table 3. Application of control measures in experimental greenhouses G1 and G2, planted with roses on rock-wool; a: release rates and timing of thrips parasitoids (*C. menes* in G1, *C. americensis* in G2), b: release rates and timing for both biological agents and chemicals for pest control; * *T. tabaci* also present.

Week #	pest species	control measure G1/G2	# *Ceranisus*	other
a) thrips parasitoids				
16	*F. occidentalis*	*C. menes* / *C. americensis*	300 / 300	-
17	*F. occidentalis*	*C. menes* / *C. americensis*	150 / 150	-
18	*F. occidentalis*	*C. menes* / *C. americensis*	165 / 300	-
19	*F. occidentalis*	*C. menes* / *C. americensis*	150 / 165	-
20	*F. occidentalis*	*C. menes* / *C. americensis*	280 / 300	-
28	*F. occidentalis**	*C. menes* / *C. americensis*	635 / 150	-
29	*F. occidentalis**	*C. menes* / *C. americensis*	310 / 180	-
33	*F. occidentalis**	*C. menes* / *C. americensis*	- / 260	-
b) biological / chemical				
5, 19	whitefly	*Encarsia formosa*	-	Enstrip®
24	whitefly	Savona 1%	-	80 liter
6,7, 23,27	aphids	*Aphidius colemani*	-	Aphipar®
7, 23	aphids	*Aphidoletes aphidimyza*	-	Aphidend®
12,13,14	aphids	Savona 1%	-	80 liter
13, 23	*M. euphorbiae*	*Aphelinus abdominalis*	-	Aphilin®
10,11,19	powdery mildew	Baycor 0.1-0.15 %	-	40-60 liter
35	powdery mildew	Fungaflor 0.15 %	-	60 liter
29	spider mite	Torque 0.05 %	-	100 liter

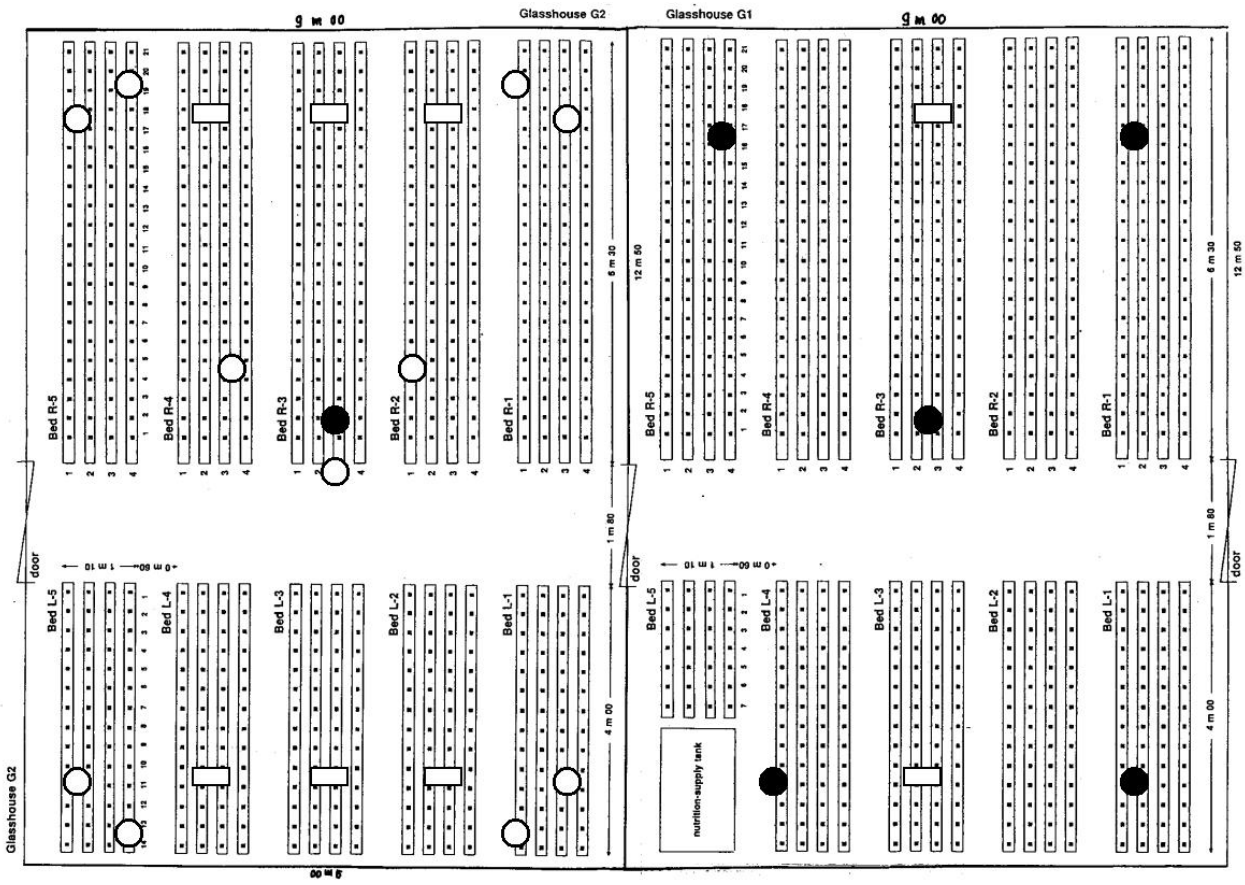

Figure 1. The experimental design of test plots G1 and G2, planted with roses on rock-wool; the thrips parasitoid release sites are indicated by solid circles, the trap flowers by open circles and sticky traps by rectangle; the situation for the dispersal experiment is indicated for compartment G2 (left), that for the control experiment is indicated for G1 (right).

cox'-Arizona) on *F. occidentalis* since 1993 (Loomans and van Lenteren, 1994). Thrips and parasitoids were reared on bean pods and additional bee pollen at 25 °C and 16L:8D. Freshly emerged adult wasps were stored at 15 °C until the time of release (Loomans *et al.*, 1995). The age of the wasps at the moment of release varied from 1 to 6 days.

D i s p e r s a l c a p a c i t y

Dispersal experiments started in March 1994, when no thrips was present in the crop. For studies on dispersal capacity, trap plants were placed at five sites in both crops (see figure 1). Each trap site consisted of 3 jars with 2 rose flowers on water, each about 1 m apart. Each flower was infested with 10 freshly emerged *F. occidentalis* larvae in the first experiment and 20 in the second experiment. Five cm below the flower bud, a square piece of transparent sticky plate of 150 cm^2 was placed horizontally circumventing the stem and attached to the stem with 'Tanglefoot' (figure 2d). In that way we hoped to prevent thrips larvae and parasitoids to walk up or down and to estimate parasitisation by parasitoids which had landed on the flower. A number of 300 adult female parasitoids of *C. menes* and *C. americensis* were released in compartment G1 and G2 respectively. In the first experiment they were released in the centre, (see figure 1, left) and in the second experiment on five sites: one in the centre and one close to each corner (figure 1, right). All trap flowers and host larvae were replaced by new ones and checked 1, 4 and 7 days after release in experiment 1 and after 7 days in experiment 2. Thrips larvae present in the flowers were checked for parasitism by dissecting the larvae under a stereo microscope, looking for parasitoid eggs and or larvae. Other flowering roses were present during the experiment. They were harvested at regular intervals and checked for the presence of adult parasitoids as well. In each compartment 8 yellow sticky plates were placed, about 4 m (right side) and 6 m (left side) from the centre and 2 m from the walls, and checked for parasitoids following the same schedule.

C o n t r o l c a p a c i t y

Population development experiments of both thrips and parasitoids were started from half of April onwards. For population studies, rose plants in each greenhouse compartment were infested with 600 (5 females :1 male) *F. occidentalis* adults once, on April 13th. In compartment G2 a natural infestation of *T. tabaci* occurred from April onwards. Parasitoids were released on a weekly

Figure 2. Different growing stages of rose flowers (cv ' Frisco'): a) 'bud', b) 'harvest' and c) 'ripe'; d) rose flower used as a trap plant in the dispersal experiment showing a transparent sticky plate (150 cm^2) to isolate the flower from the stem. Different parts of the flower - sepals and petals - are indicated; thrips damage on petals in (a).

bases in two periods (April-May and August) from glass jars placed on the rock-wool at the base of the plants, numbers equally divided over space (table 3, figure 1).

Immediately before their harvest, all rose flowers (200-450 per week) were checked twice (March, April and May 1994) or three (June, July and August 1994) times a week for thrips damage. Damage was scored for 'raw' (closed bud, first petal colour visible), 'harvest' (sepals still vertical, yellow petals : green sepals as 1 : 1) and 'ripe' (sepals and flower leaves open) flowers, and checked if either the sepals or petal were damaged or both (figure 2). Damage symptoms mainly concern necrotic spots on the sepals, and fainting colours and necrotic spots on the flower leaves. To follow population developments, insect numbers were monitored indirectly by blue and yellow sticky trap (Horiver®) counts and directly by sampling flowers. In each compartment two sticky traps (one blue, one yellow) were placed about 10 cm above the top level of the crop (figure 1). From each compartment a sample of 50 flowers was taken once a week and after a short period of cold storage at 2-3 °C, each single rose flower was immersed in 50% alcohol. Flower parts were removed and insects washed and collected in a 80 mesh sieve. Numbers of parasitoids, thrips adults and larvae were counted and the latter were checked for parasitism by dissection under a stereo microscope. Identification of thrips adults on the sticky plates was done by a stereo microscope, verifying characteristics of antennae and pronotum of the thrips specimens.

Results

1. Commercial greenhouse releases

Vegetable crops

In the first pilot releases in commercial greenhouse crops, parasitisation levels by *C. menes* were very low. In cucumber 250 larvae were collected from leaves 4, 8 and 40 days after the single release. After dissection in the laboratory no parasitism was found. In sweet pepper only 10 and 2 parasitised larvae were found 4 and 8 days respectively after the first release, representing levels of less than 2% parasitism (figure 3). Since that moment, no parasitoid adults or parasitised larvae were found. Within 2 months after the commercial release of *O. insidiosus* this predator kept *F. occidentalis* populations under control, From April onwards, very low levels of thrips larvae were found (figure 3). This experiment shows that *C. menes* either lacks the capacity to control thrips in vegetable crops or that it's releases are incompatible with other biological control measures. I also shows that pirate bugs controlled thrips populations within two months after release and establishment in the crop.

Container nursery

In 1993, during a second release experiment, we saw a similar picture develop in the nursery of container plants. In spite of the release of 3230 adult wasps at regular intervals during the summer and fall of 1993, hardly any parasitism was found. Of the more than 2800 larvae that reached maturity (67% of those collected) only 3 larvae were found parasitised in total (table 2): 2 from the Brazilian strain and 1 from the French (P-yellow) strain, both in flowers of dwarf hibiscus [*Anisodontea capensis* (L.) Bates (Malvaceae)]. In spite of the numbers released and a moderate thrips infestation, *C. menes* did not spread and establish in this nursery. Also an additional sample of 500 larvae taken in March 1994 and at inspections of sticky traps, no parasitised larvae or adult parasitoids were found, thus confirming the inability to establish and overwinter under semi-natural conditions.

2. Experimental greenhouse tests

Dispersal capacity

Adults of both *C. menes* and *C. americensis* spread immediately after release. Some females could be followed flying onto the rose plants near the release site, but could be traced during a few minutes only. Tests on the capacity to disperse in the two experimental rose plots, showed that adults of both species spread horizontally in the rose crop and remained there for almost

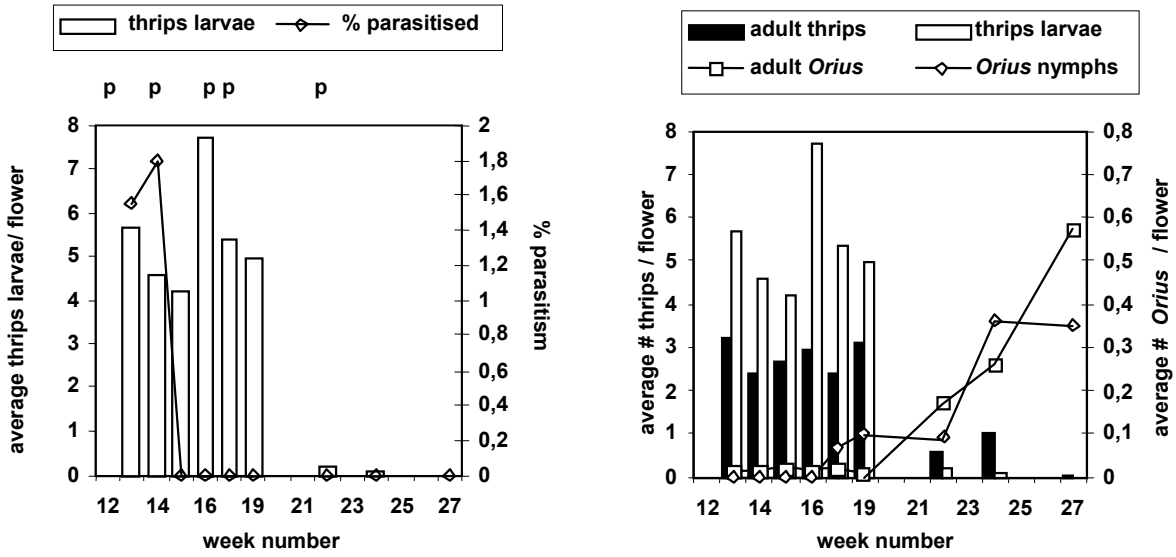

Figure 3. Development of thrips infestations and natural enemies – *C. menes* (strain Brazil; left) and *O. insidiosus* (right) – in a commercial sweet pepper greenhouse, spring 1993; release *Orius* 3x < 18.03, 10.04 (wk 15), 10.05 (wk 20); p = parasitoid releases.

two weeks (table 4). Adult parasitoids were found inside cut rose flowers and on yellow sticky traps up to 6 meters from the release point within 4 days and the corners were reached within 7 days after release. Numbers recaptured however were low (2% - 5%) (table 4). Although in compartment G2, two wasps of *C. americensis* were found on the transparent sticky plate placed just below the trap plants, no wasps were found inside the flowers and none of the thrips larvae in the trap plants had been parasitised (table 4). Yellow flowering roses were available during the experiment, the trap plants represented 5-10% of the total number of flowers present.

C o n t r o l c a p a c i t y

Thrips infestations in both compartments developed in a similar way (figures 4 and 5) and consisted mainly of *F. occidentalis* (table 5). In compartment G2, almost half the trap catches consisted of other species, predominantly *T. tabaci*, which had established spontaneously early March, and gradually built up during the sampling period. In compartment G1, *T. tabaci* started to build up from June onwards. Except for the 'Savona' treatment against whitefly in week 24 (figure 4), measures to control other pests did not interfere with thrips population build-up. During the summer period, other

Table 4. Location and numbers of parasitoids trapped 1, 4 and 7 days after release in rose; greenhouse G1, *C. americensis*, n = 300; greenhouse G2, *C. menes*, n = 300; distance is indicated by 'Left' (L) or 'Right' (R) orientation and the respective distance in meters.

Greenhouse number	day	larvae		%	parasitoids		distance	
		introduced	found	parasitism	traps	flowers	traps	flowers
G1-1	1	220	120	0	0	2	-	R2-R4
"	4	220	94	0	7	2	L6	L4-L6
"	7	220	103	0	0	0	-	-
"	13	-	-	-	1	0	R4	-
G2-1	1	220	116	0	1	1	R4	R3
"	4	220	106	0	1	0	R4	-
"	7	220	99	0	0	1	-	L6
"	13	-	-	-	2	0	R4	-
G1-2	1	600	-	-	2	-	R2-L2	-
"	4	-	-	-	4	2	R2-L2	R1-R2-L2
"	7	-	23	0	1	*6	R2	R1-R2
G2-2	1	600	-	-	1	-	R2	-
"	4	-	-	-	3	2	R2	R3-R4
"	7	-	60	0	1	3	R2	R1-R2

* two parasitoids trapped on sticky plate below trap plant.

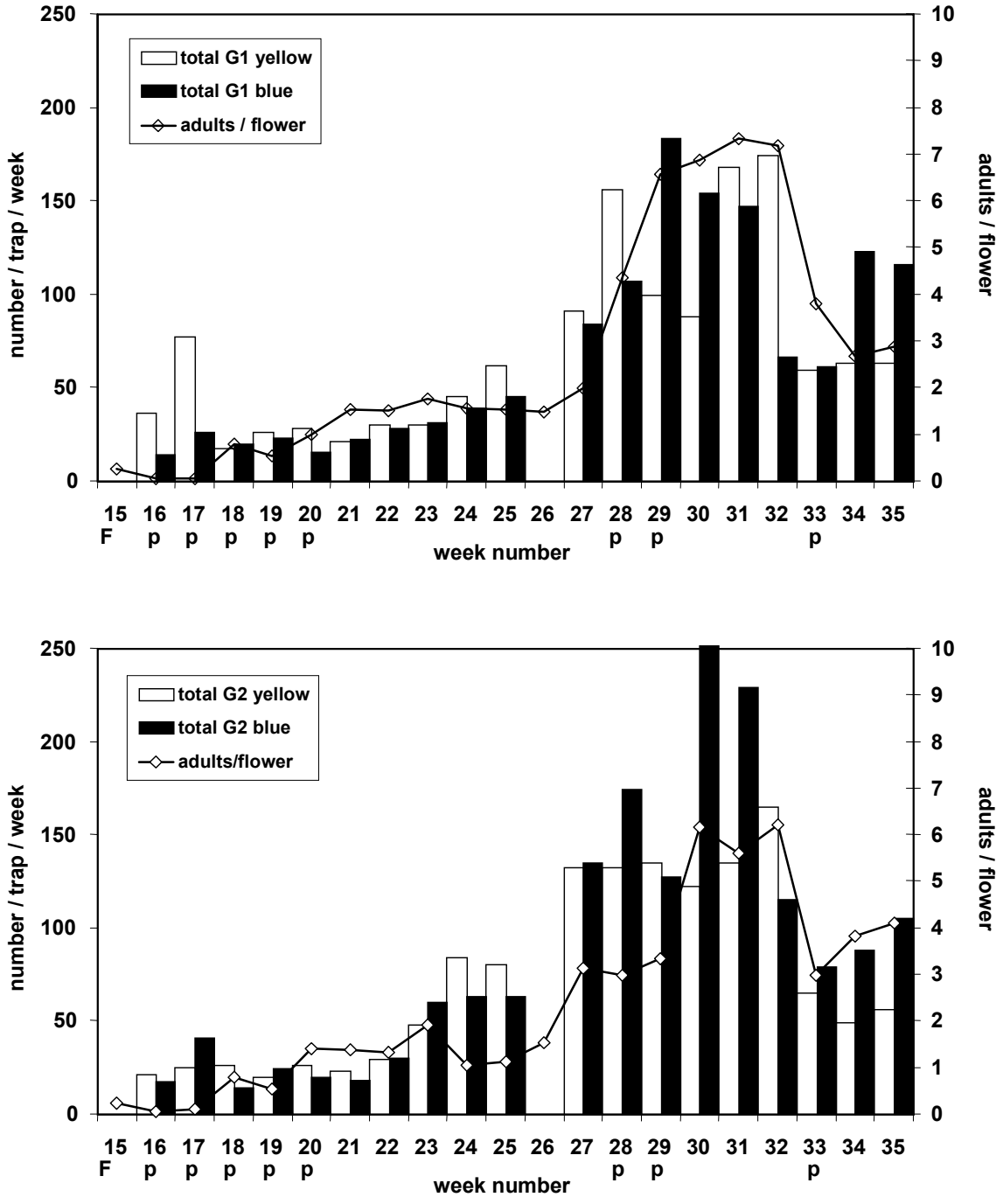

Figure 4. Mean number of thrips adults (*F. occidentalis*, *T. tabaci*, others) found per week in 50 rose flowers and on a blue an yellow sticky trap for two rose compartments (*C. menes* top, *C. americensis*, below); releases of thrips (F) and parasitoids (p) are indicated by letters.

Table 5. Comparison of total adult thrips numbers (♀/♂) in trap catches and flower samples.

Greenhouse number	trap-type	trap catches				flower samples			
		F. occidentalis		other		*F. occidentalis*		other	
		total	% ♂	total	% ♂	total	% ♂	total	% ♂
G1	yellow	1123	69.2	210	15.8	2640	40.7	149	5.4
G1	blue	1061	69.7	243	18.6				
G2	yellow	856	74.6	518	37.7	1825	46.1	673	27.1
G2	blue	845	76.2	809	48.9				

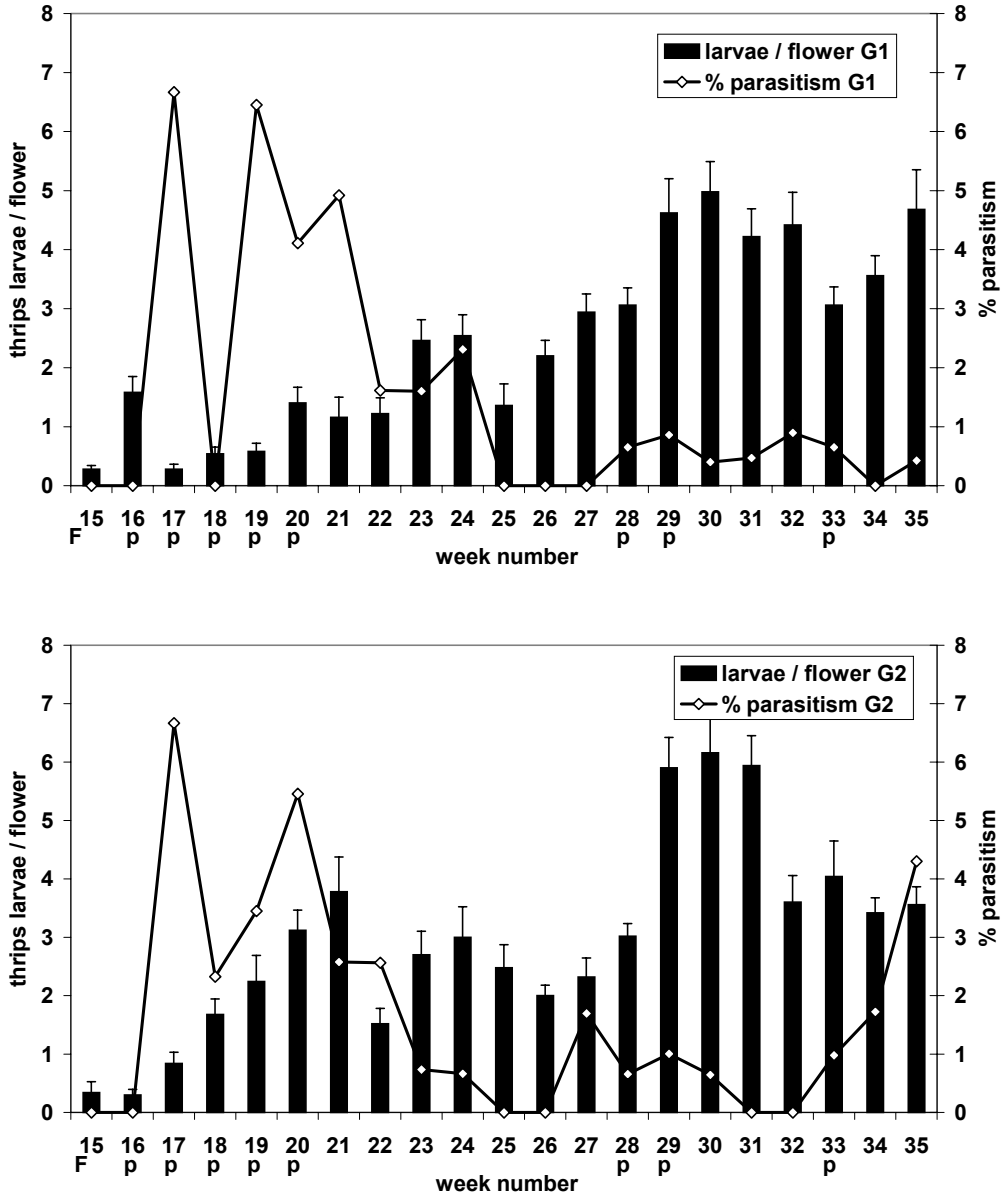

Figure 5. Mean number (± S.E.) of thrips larvae (L1-L2) found per week in 50 flowers and percentage of parasitism after release of *C. menes* (top) and *C. americensis* (below) in two rose compartments; releases of thrips (F) and parasitoids (p) are indicated by letters.

thrips species which had entered from outside, regularly occurred on the sticky traps (4-5%) and in the washed samples (table 5). It mainly concerned *Thrips fuscipennis* Haliday, which can be harmful to roses as well (Tommasini and Maini, 1995), and occasionally *Frankliniella intonsa* (Trybom), *Thrips major* Uzel, *Limothrips cerealium* Haliday and *Frankliniella tenuicornis* Uzel, common air dwellers.

Development of both parasitoid - *C. menes* and *C. americensis* - populations in their respective compartments remained very low. In order to cover the estimated developmental time of 4-5 weeks for both wasp species at 20 °C (Loomans and van Lenteren, 1994), 150-300 adult wasps of each species were released during five weeks. At an estimated host/parasitoid ratio of 0.5-2 for *C. menes* and 2-6 for *C. americensis* (table 5), releases resulted in the establishment and maintenance of the parasitoid population, but parasitism rates stayed at a very low level: less than 7% parasitism occurred during the following five month period (figure 3). Parasitoids did not show any density response, parasitism rates were the same either at low or at high host densities (figures 4 and 6). Throughout the experimental period 5 adults were captured of *C. menes* and 25 adults of *C. americensis* on both trap types. Of a total of 2557 larvae sampled in G1, only 24 (0.93%) were parasitised by *C. menes*, and of 3146 larvae in G2, 48 (1.52%) were parasitised by *C. americensis*.

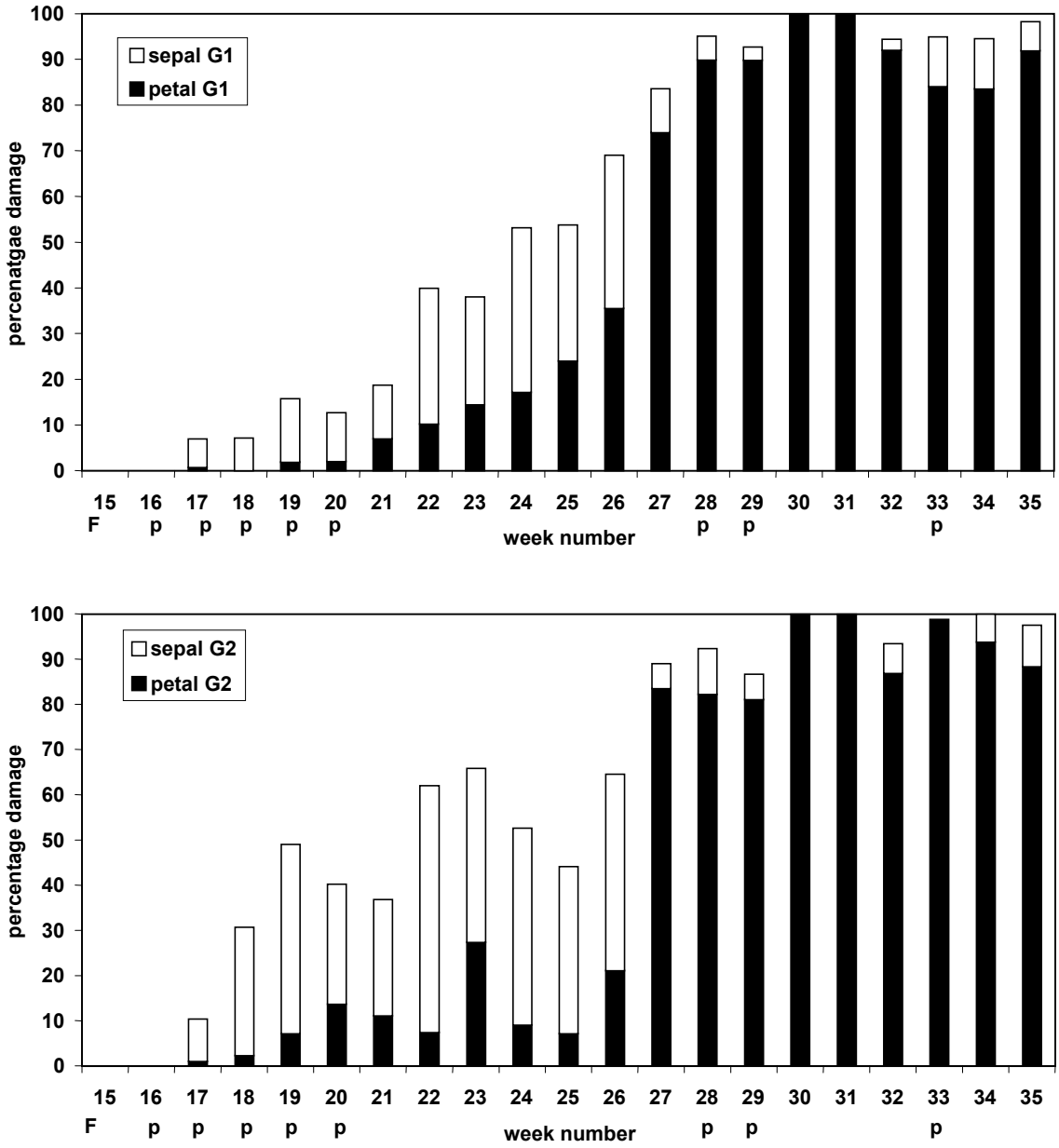

Figure 6. The mean percentage of rose flowers ('harvest' + 'ripe': see figure 2) showing thrips damage over time, separated for damage to flowers on the sepals and petals) in two experimental rose compartments (*C. menes*, top; *C. americensis*, below); releases of thrips (F) and parasitoids (p) are indicated by letters.

The mean percentage of damaged flowers (figure 6; 'harvest + ripe', 100-300 per week), increased in both plots up to 100% in week 30, coinciding with the increase in number of thrips (figures 4 and 5). During the first period damage symptoms mainly concerned necrotic spots on the sepals, from week 27 onwards the percentage of damaged petals increased, causing severe damage to the crop (figure 6). The decrease in adult thrips numbers after week 33 is probably temperature related. During summer, end of July and August, due to a heat wave, temperatures increased during the day up to 35 °C and sometimes 40 °C or more.

Discussion

Results of parasitoid releases (*C. menes* and / or *C. americensis*) in commercial and experimental greenhouses indicate that these species played only a very minor role in thrips control. In commercial cucumber and sweet pepper crops, *C. menes* was recovered after releases in very low densities. Later in the season thrips populations were controlled by releases of *O. insidiosus*, and the parasitoid played no role. Theoretically the low performance could, in part, be explained by negative interactions (intra-guild predation) between *Orius* and *C. menes* in the commercial greenhouses, preying on parasitised larvae, But our results in both ornamental

crops do not support this explains its overall low performance. Parasitoids could establish themselves in the experimental greenhouse on rose, and were able to produce new generations. However, hey were unable to reduce thrips populations to sufficiently low levels. Small scale pilot studies performed with *C. menes* a few years later in Florida (C. Castineiras, personal communication) and Australia (M. Steiner, personal communication) lead to the same conclusion: only traces of parasitism were found and an incapability to control thrips pests. The prospects of larval parasitoids seem very low for thrips control in commercial vegetable and ornamental crops.

Roses are attacked by a wide range of pests (Baas *et al.*, 1993). Against some pests correction measures were necessary to allow the crop to develop (table 2). A wide range of thrips species are known to attack roses in greenhouses (Sauer, 1997a; 1997b), but in temperate areas, *F.occidentalis*, *T. tabaci* and occasionally *T. fuscipennis* are the most relevant pests. Large differences exist in attractiveness (Park *et al.*, 2001), suitability (Dash and Naik, 1998) and host plant resistance to feeding damage (Gaum *et al.*, 1994; Sütterlin, 1999) to western flower thrips between different rose cultivars. Yellow cultivars, like 'Frisco', are more attractive for adult *F. occidentalis* than for instance red cultivars (Park *et al.*, 2001) and although *F. occidentalis* prefers flower-leaves (sepals) for oviposition, the petal tissue of yellow and white flowers is preferred over red and orange petal tissue (Dash and Naik, 1998). Developmental time is generally shortest on white- and yellow-flowered cultivars than on red or orange (Dash and Naik, 1998).

In rose high numbers of thrips developed in both greenhouse compartments, up to 15-20 individuals per flower in July. For rose a threshold level for control measures is advised if 10 or more thrips adults, not separated for sex, are monitored per trap per week or when damage symptoms increase with 10% a week for cv. 'Frisco' (Fransen *et al.*, 1993a), or within 20-30 adults trapped weekly for other cultivars (Frey, 1993; Schmidt and Frey, 1995). In our crops, the threshold level was passed and damage symptoms occurred from the beginning onwards, in May and June first on the sepals and from July onwards, mainly on the petals too. A spray with insecticidal soap (Savona 1%) against whitefly caused a temporary decline in thrips numbers (figures 4 and 5) and damage (figure 6), but populations soon recovered. From week 25 onwards when more than 10 western flower thrips (WFT) females were trapped and the average number per flower was 2 or more, the 80% of the harvested flowers was damaged. A good correlation was found between thrips numbers in the flower samples and on sticky traps (Pearson's $r > 0.76$ yellow traps, $r > 0.80$ blue traps), but overall more WFT males were trapped on the yellow and blue sticky traps than females (table 5). Because males are more active, swarming in the coloured reproductive parts (Terry, 1990), in the top layer of the rose crop, they are more likely to be trapped. In general, during May and early June more WFT males were washed from the flowers than females (52-84%), but later in the season there was a shift in sex ratio towards females (52-67%). This shift in sex ratio is probably density related (Higgins and Myers, 1992): in greenhouse vegetable crops, 80-100% of *F. occidentalis* adults on traps were males at low densities and 60-90% females when thrips infestations were high.

Releases of adult thrips parasitoids during the period that numbers reached threshold levels or higher (week 17-21, table 6), did not result in any control of the thrips population. Keeping thrips populations at a low level will depend on the searching efficiency of the parasitoid as well as the capacity to build up a population. At the moment of release the estimated thrips larvae/parasitoid ratios varied from 0.5 to 2 (*C. menes*) and from 2 to 6 (*C. americensis*) (table 6). The parasitoid's reproductive capacity will not have been a limiting factor (Loomans and van Lenteren, 1994), but could not be realised under glasshouse conditions at low host densities. The low level of parasitism might be due to a limited searching efficiency and / or accessibility of the infested young rose buds and searching time on the flowers. *C. menes* females exposed in the laboratory to caged rose buds infested with 10 first instar larvae of *F.occidentalis* introduced 24 hours before, were able to locate and parasitise about 50% (4.8 ± 1.3, $n=12$) of them. However, it is unknown whether larvae behaved similar in confinement to those in flowers in the greenhouse, because some of the larvae were found outside the buds at the breakdown of the experiment after 24 hours.

C. menes and *C. americensis* were found on traps as well as in rose flowers throughout the greenhouse during and after the release, but in very low numbers. These could be explained by three different factors: difference in attraction, accessibility and availability, and thus synchronisation, for thrips and their parasitoids.

Table 6. Estimated release ratio's of thrips larvae / parasitoid (t / p) and of pupal parasitoid offspring after release, based on thrips and parasitoid numbers, % parasitism in the weekly sample and the total number of flowers present in the crop.

Week #	Greenhouse 1 (*C. menes*)			Greenhouse 2 (*C. americensis*)		
	total larvae #	ratio (t/p)	parasitoid pupae (sum)	total larvae #	ratio (t/p)	parasitoid pupae (sum)
17	150	0.49	10.0	960	3.20	64.1
18	272	0.81	0.0	872	5.80	20.3
19	184	1.12	11.9	878	2.93	30.3
20	275	1.84	10.7	637	3.86	34.7
21	206	0.74	4.4	647	2.15	16.6

Both thrips and parasitoids are attracted to certain colours. However, parasitoids are more attracted to yellow than to blue, and the exact role of visual and chemical stimuli in host location is yet unknown. In roses, thrips infestations mainly occur in the top layer of the crop. Thrips adults lay their eggs and damage the rose bud in a very early stage of growth (Park *et al.*, 2001), when the buds are still 'raw' (sepals completely closed until the first yellow petals become visible, figure 2a), but first and second instar larvae are then already present. Parasitoids can have difficulty entering these young rose buds. Shortly before the flowers are harvested (figure 2b), when the sepals are still erect and petals start to open, they become more accessible, but damage has already been inflicted upon the bud (Park *et al.*, 2001). The stage which is most accessible, rose flowers that are 'ripe' (figure 2c), rarely occur in a commercial greenhouse: flowers are harvested before that, leaving a period of about 2 weeks in which roses are available for both thrips and parasitoids. This is long enough for *F. occidentalis* to reach the pupal stage, but too short for the parasitoid to reach its pupal phase. If parasitisation is successful, and because parasitised larvae continue to feed and develop unlike when being eaten by a predator, most of these larvae will be taken out at harvest. In addition. *C. menes* is able to parasitise only young larvae of *T. tabaci* and *F. occidentalis*. *C. americensis* prefers *F. occidentalis* over *T. tabaci*, which is only parasitised to a very low extent (Loomans and Pákozdi, 1996). By the time that rose flowers are easily accessible, the larval population has developed so far that few young thrips larvae are available.

Parasitoids maintained themselves during the season, but were not able to build up a population. In May and early June ripening of flowers is faster than development from egg till pupa of thrips (two weeks at 25 °C, three weeks at 20 °C: Fransen *et al.*, 1993b), and most of the parasitised and unparasitised thrips larvae (estimated totals, table 6) are removed from the greenhouse. Developmental times of *C. menes* and *C. americensis* are much longer and show a large variation (Loomans and van Lenteren, 1995; Loomans and Murai, 1994) compared to those of *F. occidentalis* or *T. tabaci*, in particular at 20 °C, the normal temperature during the first weeks. During late June, early July (week 22-27), only a few adults from a next parasitoid generation were trapped and the rate of parasitism was very low. At higher temperatures thrips infestations can develop quickly and the few parasitoids of a next generation (table 6) hatching in June and early July, are not able to keep pace with the pest. After the parasitoid release experiment had ended, August 31st, the predatory mite *A. degenerans* was introduced in both greenhouse compartments. During these trials, adults of *C. menes* (in G1) and *C. americensis* (in G2) were still found when sampling and washing flowers (1* *C. menes* in week 42, 1* *C. americensis* week 44) and monitoring sticky traps (figure 7). This indicates that both species were able to establish and maintain itself in the rose crop.

No other dataset is available of releases of parasitoids to control thrips pests in any greenhouse crops. The low rate of parasitism can, in part be explained by a reduced searching ability on flowers of rose, sweet pepper and various potted plants, and leaves of sweet pepper or cucumber. It might also be partly explained by a difference in encounter probability with hosts of different sizes (Loomans *et al*., 1992; 1993), in particular when the vulnerable host stage is concealed in buds (rose) and flowers and thus unavailable for the parasitoid. In other crops, with a different crop structure, host larvae could

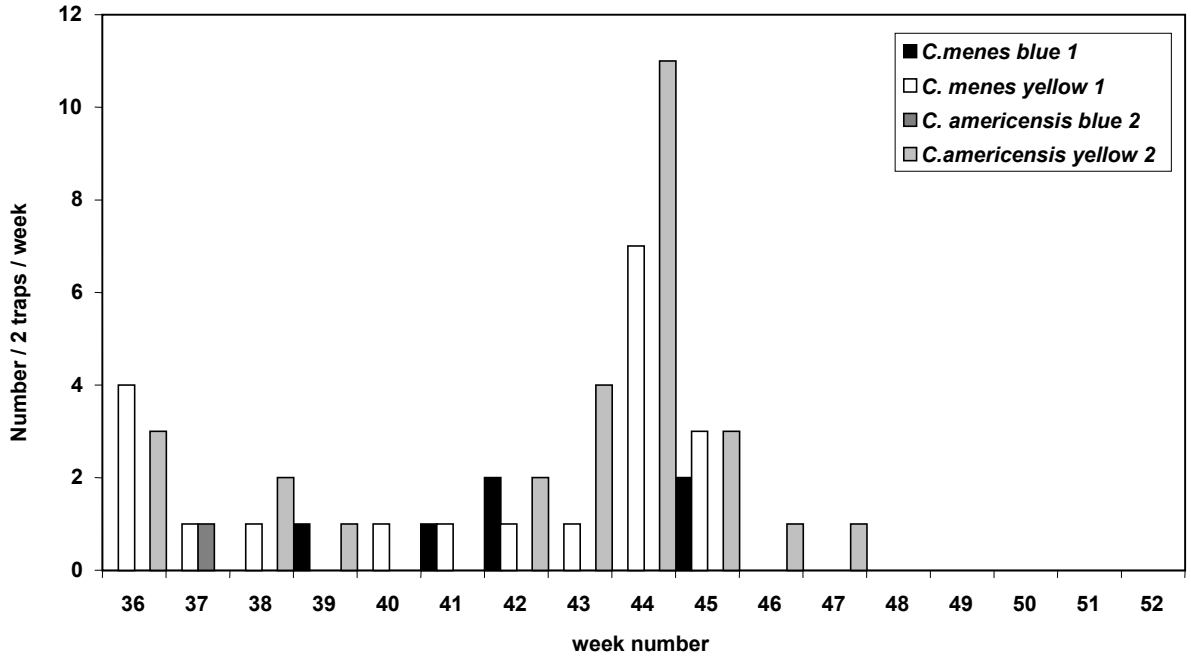

Figure 7. Trap catches of *C. menes* (Greenhouse 1) and *C. americensis* (Greenhouse 2) on blue and yellow sticky traps, in rose from September till December 1994.

be more accessible for parasitoids. A single count in 'ripe' (wide open, figure 1c) roses of various cultivars in a greenhouse in Hyères (France) in September 1990, showed 14% parasitism by *C. menes* (brown colour-type) which had entered the greenhouse from the outside (Loomans, 1991). Occasionally natural parasitism levels by *C. menes* are quite high on vegetative plant structures in the field. In Japan, on onion infested by *T. tabaci*, parasitism levels by *C. menes* reached as high as 79% and showed a clear positive density dependent response (Loomans and van Lenteren, 1995). A high level of natural parasitism (40-60%) by *C. menes* of *Thrips palmi* infesting leaves of eggplant was found in Thailand and Japan (Loomans and van Lenteren, 1995). Development of a biological control programme for thrips pests in greenhouse crops, and in roses in particular, were infestations largely occur in the marketable reproductive parts, will depend on the ability to bring and keep thrips densities at a very low level in an early growth stage of the crop. Our results indicate that parasitoids may not be suitable candidates for biological control of thrips in roses. The question remains which factors can explain the failure of parasitoids to keep thrips infestations down. Biological control in ornamentals remains problematic and chemical control is still the predominant practice. Prophylactic use of predatory mites, including combinations of crop-dwellers (*A. cucumeris*) and soil-dwellers [*Stratiolaelaps miles* (Berlese)] has shown prospects in some systems of cut roses (Linnamaki *et al.*, 1998) as has the use of fungal pathogens (Murphy *et al.*, 1998; Ekesi and Maniania, 2003). Biological control of thrips in roses has a very narrow 'activity window" - from the moment that the flower is accessible till the infliction of damage and harvest - during which a natural enemy has to find and diminish the pest. In the case of parasitoids the juvenile thrips stages have almost completed their development and damage has already been done, before they are prone to attack. Predators seem to have somewhat better prospects for thrips control in ornamentals than larval parasitoids. The period during which larvae are available for predation is less relevant for these groups, because of their ability to kill their prey or host directly. However, the lack of alternative food sources in non-pollen producing ornamentals is a serious constraint for a reliable biological control solution.

Our results of parasitoid releases (*C. menes* as well as *C. americensis*) in commercial and experimental greenhouses indicate that these species can only play a very minor role in thrips control. At best parasitoids can maintain themselves in some (ornamental) greenhouses, and are able to produce new generations, but are unable to reduce thrips to sufficiently low populations. Control of thrips pests with *Ceranisus* spp. seems insufficient under northern European greenhouse conditions.

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