



Impact of the presence of *Dicyphus tamaninii* Wagner (Heteroptera: Miridae) on whitefly (Homoptera: Aleyrodidae) predation by *Macrolophus caliginosus* (Wagner) (Heteroptera: Miridae)

Éric Lucas¹ and Oscar Alomar*

Departament de Protecció Vegetal, Institut de Recerca i Tecnologia Agroalimentàries Centre de Cabrils, E-08348 Cabrils, Barcelona, Spain

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Abstract

Macrolophus caliginosus (Wagner) is currently commercialized in Europe for the control of whiteflies in tomato greenhouses. Another mirid predator, *Dicyphus tamaninii* Wagner, spontaneously colonizes Mediterranean greenhouses. The impact of the presence of *D. tamaninii* on predation of the greenhouse whitefly (*Trialeurodes vaporariorum* Westwood) by *M. caliginosus* was investigated in the laboratory on tomato plants during four days. No significant interspecific competition was recorded between mirid nymphs and no significant intraguild predation was observed. Higher level of predation of the whitefly populations was achieved by *D. tamaninii* alone, than by *M. caliginosus* alone. Predation by the heterospecific combination (*M. caliginosus* + *D. tamaninii*) was similar to the results obtained by conspecific treatments. No intraspecific competition was recorded with *D. tamaninii*, nor with *M. caliginosus*. Finally, the distribution of whitefly predation on the plant by the mirids changed according to the predator treatment. The heterospecific combination of both mirids had a higher predation rate on lower leaves of the plant than monospecific combinations. Overall, the presence of *D. tamaninii* did not disrupt whitefly predation by *M. caliginosus* and could even increase the level of predation. © 2002 Elsevier Science (USA). All rights reserved.

Keywords: *Dicyphus tamaninii*; *Macrolophus caliginosus*; *Trialeurodes vaporariorum*; *Lycopersicon esculentum*; Intraguild predation; Zoophytophagy; Miridae; Biological control; Greenhouse whitefly

1. Introduction

Macrolophus caliginosus (Wagner) (or *Macrolophus melanotoma* (Costa) according to Carapezza, 1995) (Heteroptera: Miridae) is currently produced and marketed commercially in Europe for control of whiteflies (*Trialeurodes vaporariorum*) Westwood, and *Bemisia tabaci* Gennadius (Homoptera: Aleyrodidae) in tomato (*Lycopersicon esculentum* Miller) greenhouses (Lenfant et al., 2000; Malausa and Trottin-Caudal, 1996; Muhlberger and Maignet, 1999; Nedstam and Johansson-Kron, 1999). The mirid is used alone or in combination

with the parasitoid *Encarsia formosa* Gahan (Hymenoptera: Aphelinidae) (Gabarra and Besri, 1999). In the Mediterranean basin, *M. caliginosus* and several other mirid species spontaneously colonize tomato greenhouses and fields and contribute to whitefly control (Albajes and Alomar, 1999; Malézieux et al., 1995; Vacante and Tropea Garzia, 1994). Development of an Integrated Pest Management (IPM) program based on the conservation of mirid predators has significantly reduced whitefly populations in fields and greenhouses of the Mediterranean basin (Albajes and Alomar, 1999). However, natural control of whiteflies in tomato fields remains variable, possibly due to delayed colonization by mirids or to interactions among mirid species.

In Northeast Spain, *M. caliginosus* and *Dicyphus tamaninii* Wagner are the more common predators in tomato fields and greenhouses (Albajes and Alomar, 1999). Natural colonization by both species occurs during the growing season and mixed populations are

* Corresponding author. Fax: +1-514-987-4647.

E-mail addresses: eric.lucas@internet.uqam.ca (E. Lucas), oscar.alomar@irta.es (O. Alomar).

¹ Present address: Département des Sciences Biologiques, Université du Québec à Montréal, CP 8888, Succ. Centre Ville, Montréal, Québec, Canada, H3C 3P8.

commonly found in the crop (Alomar et al., 2002). The potential of *D. tamaninii* has been evaluated to control whitefly, thrips, or aphid populations (Castañe et al., 1996; Gabarra et al., 1988, 1995), but its augmentative use remains problematic as it can blemish tomato fruits once it has depleted prey populations (Alomar and Albajes, 1996).

Intraguild predation (predation on another species sharing similar resources) is common among arthropod guilds, occurring among detritivorous (Dodds et al., 2001; Wissinger et al., 1996), necrophagous (Blackith and Blackith, 1984), aphidophagous (Lucas et al., 1998; Rosenheim et al., 1993), acarophagous (Schausberger and Walzer, 2001) and aleurophagous (Heinz and Nelson, 1996) species. Intraguild predation has been identified as one of the main factors affecting structure and dynamics of predators and parasitoids guilds and consequently the success of biological control programs (Brodeur and Rosenheim, 2000; Rosenheim, 1998; Rosenheim et al., 1995).

In our system, previous studies showed that *M. caliginosus* is vulnerable to intraguild predation by several predatory species collected in the fields, including *D. tamaninii* (Lucas and Alomar, 2001, and unpublished). Intensity of intraguild predation recorded for *D. tamaninii* was low compared with that recorded by other aphidophagous predators (Lucas et al., 1998). Nevertheless, it was demonstrated that frozen nymphs of *M. caliginosus* constitute a high-quality food source for *D. tamaninii* (Lucas and Alomar, 2001) and intraguild predation may therefore occur in the fields especially when alternative prey are scarce. Furthermore, exploitative or interference competition may occur in the field, because it was shown that the presence of *D. tamaninii* slows down the development of *M. caliginosus* nymphs (Lucas and Alomar, unpublished).

In this study, we investigated whether the simultaneous presence of *M. caliginosus* and *D. tamaninii* may generate intraguild predation and/or exploitative competition and consequently may hamper or improve the predation of whitefly on tomato plants.

2. Material and methods

2.1. Insect and plant sources

Mirids used in the experiment came from permanent rearings established in the laboratory in 1996 and refreshed with new individuals each year. *M. caliginosus* and *D. tamaninii* were maintained on tobacco plants (*Nicotiana tabacum* L.) infested with eggs of *Ephesthia kuehniella* Zeller (Lepidoptera: Pyralidae) and nymphs of the greenhouse whitefly (*T. vaporariorum*). Insect rearings and the experiments were carried out in controlled environmental conditions ($25 \pm 2^\circ\text{C}$, 16L:D8 h).

Trialeurodes vaporariorum came from rearings started at the beginning of the spring 2000. Tomato plants used were of the variety “Carmelo.”

2.2. Experimental setup

The experiment evaluated the control of whiteflies in the laboratory using either *D. tamaninii*, or *M. caliginosus*, or a combination of both predators. The experimental arena was composed of a clear plastic cage (20 cm diameter \times 31 cm height) with a muslin-covered top. The pot of the tomato plant fitted into a 10 cm hole drilled in a plastic dish that served as base of the cylinder. Both cylinder and base were then sealed with silicone to prevent predators from escaping. The plant could therefore be watered from outside by putting the pot in another dish filled with water.

Prior to the test, all tomato plants (three weeks old, 4–5 leaves) were introduced into a cage and infested with an unlimited number (>100) of adult whiteflies (*T. vaporariorum*) which were then removed after 24 h. Tests began when whitefly nymphs were at the 3rd–4th instar. Plants were randomly assigned to the different treatments. At the beginning of the test, predator nymphs were introduced from the top of the cage, and placed on the leaves. After four days, live and dead predators were removed and counted. Leaves were examined under a stereo microscope. Predated whitefly nymphs can easily be distinguished because predation leaves a flattened, empty whitefly cuticle. To determine within plant distribution of the predation, live and preyed whiteflies were recorded for each leaf.

Six treatments were tested: (1) DT/3: three second instar nymphs of *D. tamaninii*, (2) DT/6: six second instar nymphs of *D. tamaninii*, (3) MC/3: three second instar nymphs of *M. caliginosus*, (4) MC/6: six second instar nymphs of *M. caliginosus*, (5) DT/3 + MC/3: three second instar nymphs of *D. tamaninii*, and three second instar nymphs of *M. caliginosus*, and (6) a control without any mirid. Eight replicates were conducted per treatment. The different treatments were selected to evaluate whether the addition of conspecifics or heterospecifics may affect the control of whiteflies by *M. caliginosus* or by *D. tamaninii*, and also the distribution of the predation.

Intraguild predation was estimated by comparing the number of surviving mirid nymphs for three initial individuals. The number of surviving nymphs was divided by 2 for the treatments with six individuals (MC/6, DT/6, and MC/3 + DT/3), then the corrected values were log-transformed and compared using an ANOVA and subsequent post hoc Tukey tests (SAS Institute, 1996). The mean number of surviving whiteflies was compared using an analysis of covariance with the initial infestation as covariable using standard SAS/STAT procedures (SAS Institute version 8.01). A preliminary ANOVA demon-

strated that no difference occurred in the number of offered whiteflies ($F = 0.9207$; $df = 5, 45$; $P = 0.4764$). However, the ANCOVA was selected for the test, to exclude possible effects due to variation in the initial number of whiteflies. Pairwise comparisons were done among treatment means for the number of surviving whiteflies, adjusted for the initial number of whiteflies. Intraspecific competition was evaluated by comparing the mean number of preyed whitefly nymphs per capita (number of preyed whitefly per introduced predator) among treatments with an ANOVA. To evaluate interspecific competition, an expected number of preyed whiteflies was calculated for each replicate as the mean of the per capita consumption of whiteflies by six *D. tamaninii* and by six *M. caliginosus* nymphs. This expected value was then compared by an ANOVA to the observed consumption of the heterospecific treatment (three *D. tamaninii* + three *M. caliginosus*). The per capita predation was based on the initial number of predator. Finally, the distribution of preyed whitefly nymphs on the different leaves of the plant was compared among the treatments, including the distribution of live whiteflies in the control. We used a likelihood ratio G test and subsequent post hoc tests. This test limits the number of possible post hoc comparisons (Sokal and Rohlf, 1981). Bartlett's test was applied to the ANOVA, to test variance homogeneity, and data were log-transformed when required (Sokal and Rohlf, 1981).

3. Results

3.1. Intraguild predation

No significant intraguild predation was recorded ($F = 1, 79$; $df = 4, 37$; $P = 0.152$) (Fig. 1). From 2.38 to 2.93 nymphs, for three initial individuals were recovered after four days among the different treatments (from 79 to 97%).

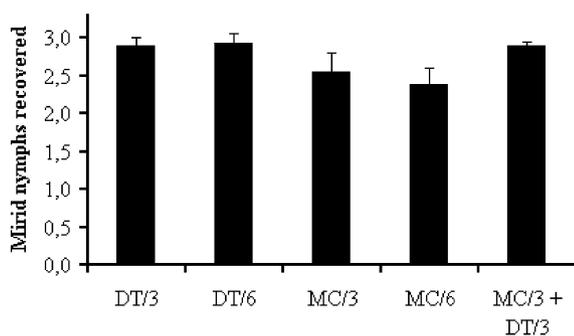


Fig. 1. Mean number of recovered mirid nymphs (mean \pm SE), corrected for three initial individuals, after four days on whitefly infested tomato plants. DT, *D. tamaninii*; MC, *M. caliginosus*; DT/3, three nymphs of *D. tamaninii*. No significant difference among treatments was found (ANOVA, $n = 8$, $P > 0.05$ [SAS Institute, 1996]).

3.2. Whitefly control

The number of offered whiteflies (covariable) significantly affected the final number of surviving whitefly ($F = 1097.86$; $df = 6, 44$; $P < 0.001$). Whitefly survivorship differed among the different treatments ($F = 17.48$; $df = 6, 44$; $P < 0.001$) (Fig. 2). All treatments with mirid predators significantly reduced whitefly populations (<310 whiteflies per plant) compared with the control (425 whiteflies per plant). Fewer whiteflies survived with *D. tamaninii* than with *M. caliginosus*, both when comparing the three individuals treatments (LSD, $P = 0.025$) and the six individuals treatments (LSD, $P = 0.012$). Population reductions with six mirid nymphs of the same species were greater than with three mirid nymphs, both in *D. tamaninii* (LSD, $P = 0.006$) and in *M. caliginosus* (LSD, $P = 0.018$). Finally, whitefly populations in the heterospecific treatment did not differ from whitefly populations in the six *D. tamaninii* nymphs (LSD, $P = 0.265$) nor in the six *M. caliginosus* nymphs treatments (LSD, $P = 0.112$).

3.3. Intra- and interspecific competition

The number of preyed whitefly nymphs per capita was significantly different ($P < 0.05$) among treatments (Fig. 3). The highest whitefly consumption was achieved by three *D. tamaninii*, 38.5 ± 3.9 (mean \pm SE) whiteflies per four days per individual, and the lowest was achieved by six *M. caliginosus*, 19.9 ± 4.2 whiteflies per four days per individual. Individually, three *D. tamaninii* consumed more than three or six *M. caliginosus*. No significant difference was observed between six individuals of each species. The augmentation of the mirid

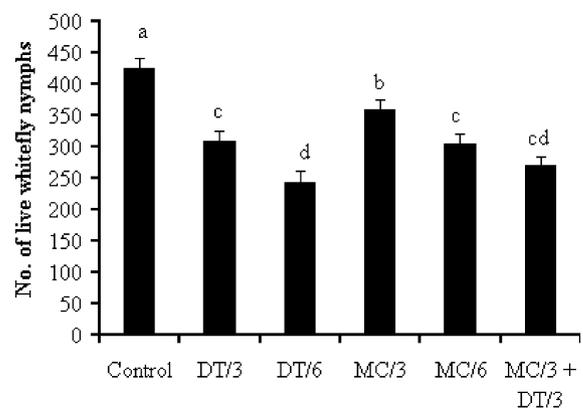


Fig. 2. Whitefly survival (mean \pm SE) on tomato plants with different combinations of mirid predators (after four days). Mean numbers were corrected according to the covariance results (see details in the text). DT, *D. tamaninii*; MC, *M. caliginosus*; /3 and /6 indicate that either three or six individuals of the mirid species were used. Different letters above the bar indicate a significant difference among treatments (ANOVA, $n = 8$, $P < 0.05$ [SAS Institute, 1996]).

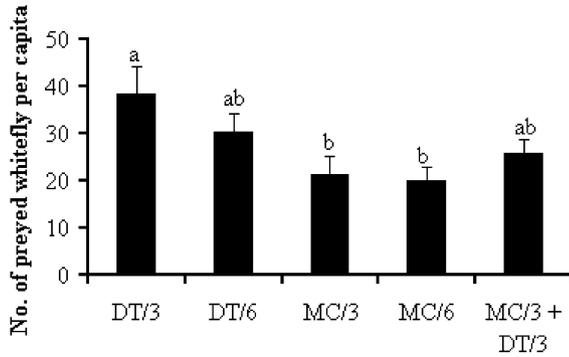


Fig. 3. Per capita whitefly predation rate (mean \pm SE) by mirids on tomato plants with different combinations of predators, during four days. DT, *D. tamaninii*; MC, *M. caliginosus*; /3 and /6 indicate that either three or six individuals of the mirid species were used. Different letters indicate a significant difference among treatments (ANOVA, $n = 8$, $P < 0.05$ [SAS Institute, 1996]).

number did not lead to a significant decrease in the individual consumption (intraspecific competition) in either *D. tamaninii* or in *M. caliginosus*. The observed number of preyed whiteflies (155.0 ± 16.8 whiteflies) in the heterospecific treatment (three *D. tamaninii* and three *M. caliginosus*) was not different from the expected number of preyed whiteflies (147.2 ± 17.6 whiteflies) (mean of the per capita predation of six *D. tamaninii* and six *M. caliginosus*) ($F = 0.1035$; $df = 1, 15$; $P = 0.752$).

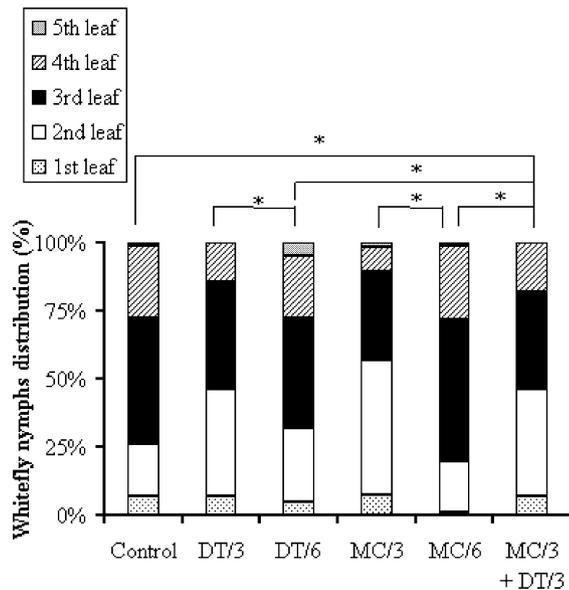


Fig. 4. Distribution of whitefly nymphs on tomato leaves. The control bar shows the distribution of whitefly nymphs. The other bars indicate the distribution of preyed whitefly nymphs in the different predator treatments. The first leaf is the lowest one. DT, *D. tamaninii*; MC, *M. caliginosus*; /3 and /6 indicate that either three or six individuals of the mirid species were used. An asterisk on a horizontal line indicates a significant difference between the two treatments at the extremities of the line (G test, $P < 0.05$ [SAS Institute, 1996]).

3.4. Distribution of predation

Finally, the within plant distribution of preyed whitefly nymphs (and alive in the control) was different among treatments ($G = 93.25$; $df = 20, 1134$; $P < 0.001$) (Fig. 4). When three *M. caliginosus* or three *D. tamaninii* nymphs were present, a higher proportion of whiteflies nymphs was preyed on lower leaves than when six conspecific individuals were present (*D. tamaninii*: $G = 15.52$; $df = 4, 292$; $P = 0.004$; *M. caliginosus*: $G = 29.90$; $df = 4, 175$; $P < 0.001$). Similarly, in the heterospecific treatment, the predation of whiteflies was higher on lower leaves than in the conspecific treatments with six *D. tamaninii* ($G = 16.92$; $df = 4, 329$; $P = 0.002$) and with six *M. caliginosus* ($G = 25.35$; $df = 4, 264$; $P < 0.001$). Within plant distribution of preyed nymphs showed that mirids of the heterospecific treatment consumed a higher proportion of whiteflies on lower leaves (first and second) than the corresponding proportion of offered whiteflies in the control ($G = 27.37$; $df = 4, 667$; $P < 0.001$).

4. Discussion

The results of the study support two main conclusions. First, the simultaneous presence of *D. tamaninii* and *M. caliginosus* does not generate significant intraguild predation or interspecific competition. Second, the combined occurrence of *D. tamaninii* and *M. caliginosus* does not reduce the level of predation on whitefly populations achieved by *M. caliginosus* alone.

No significant intraguild predation occurred on *M. caliginosus* by *D. tamaninii*. This result corroborates previous research that showed low levels of intraguild predation in small cages in the laboratory (Lucas and Alomar, 2000), and the absence of intraguild predation on plants after four days (Lucas and Alomar, unpublished). From a biological control point of view, this indicates that natural colonisation of greenhouses by *D. tamaninii* should not reduce the populations of released *M. caliginosus*. Furthermore, the presence of *D. tamaninii* in refuges surrounding greenhouses or tomato fields may not hamper the conservation of *M. caliginosus*. Otherwise, in our study, no intraguild predation was recorded on *D. tamaninii* by *M. caliginosus*, and therefore *M. caliginosus* would not be able to control *D. tamaninii* populations, and tomato fruits may still be blemished by *D. tamaninii* when both predators are present (Alomar and Albajes, 1996). These results explain previous observations in tomato greenhouses on the incapacity of established *M. caliginosus* population to prevent damage production on tomato by another zoophytophagous mirid, *Nesidiocoris tenuis* (Reuter) colonizing the crop (Malézieux et al., 1995). These results and previous research (Lucas and Alomar, 2000,

and unpublished), suggest that zoophytophagous predators (sensu Fauvel, 1999) may not be ideal candidates for the control of other zoophytophagous species. However, while no significant intraguild predation among the mirids was recorded, sublethal effects may occur. The presence of *D. tamaninii* adults was demonstrated to slow down the development of *M. caliginosus* nymphs (Lucas and Alomar, unpublished).

All combinations of mirids had a significant impact on whitefly populations. No significant intraspecific competition was recorded neither in *M. caliginosus* nor in *D. tamaninii*. Furthermore, the heterospecific combination reduced whitefly abundance without generating significant interspecific competition. It means that the differences in the per capita predation rate were due to the respective voracity of both mirids, and not to the presence of heterospecifics. In the field, interspecific competition may occur at low prey density, but then high levels of control are not required. Furthermore, as both predators are zoophytophagous (Fauvel, 1999), and can survive to some extent on plant material without animal prey (Lucas and Alomar, 2000), competition levels might be low or absent. This study and another one with predatory mites (Schausberger and Walzer, 2001) confirm that combination of generalist predators, even closely related species, may not systematically engage in negative interactions hampering biological control of the pest. In a review article, Symondson et al. (2002) showed that assemblages of generalist predators significantly reduced pest abundance in 79% of the field studies, decreasing damage to the crop in 65% of the cases.

The daily per capita predation rate of *D. tamaninii* ranged from 9.6 whiteflies for three individuals to 7.6 for six individuals. These average consumptions are higher than those recorded by Barnadas et al. (1998) (4.1 whiteflies) probably because of our higher initial whitefly density, and because they used *Bemisia tabaci* Gennadius instead of *T. vaporariorum* (but on the same tomato cultivar). The same pattern was observed with *M. caliginosus*, because we obtained a daily predation rate of 5.3 with three individuals and of 5.0 with six individuals, while Barnadas et al. (1998) recorded predation rates of 2.7 whitefly nymphs per day. These results confirm the higher voracity of *D. tamaninii* than *M. caliginosus*. The highest level of whitefly predation was achieved by conspecific individuals of *D. tamaninii*, but due to the risk of blemishing tomato fruits at high predator to whitefly ratios (Alomar and Albajes, 1996), augmentative releases on tomato should be avoided.

The distribution of whitefly predation changed according to the combination of mirid predators. The higher conspecific density generated a higher level of predation on upper leaves of the plant, a distribution of predated whiteflies closer to the distribution of live whiteflies. The observed changes in preyed whitefly

distribution were not caused by depletion of the prey on lower leaves, because at least 30 whitefly nymphs per leaf were still present at the end of the experiment. The distribution of predation was relatively similar in the treatments with three conspecifics and in the heterospecific treatment. This indicates that both mirid species did not respond in the same manner to the presence of more conspecifics (MC/6 and DT/6) than to the presence of heterospecifics (MC/3 + DT/3). Some kind of regular distribution may possibly occur in conspecific populations, which is not the case with heterospecifics. Such a displacement of predation at high density may have important consequences for biological control. For instance, whitefly eggs are encountered on the youngest (and highest) leaves and both mirid species consume twice as many whitefly eggs as nymphs (Barnadas et al., 1998). Their control may therefore be improved as mirid conspecific density increases and displacement occurs. However, the real impact of such a response should be assessed on older tomato plants in greenhouses.

In summary, the results indicate that the presence of *D. tamaninii* may not disrupt the biological control of whiteflies by *M. caliginosus* in tomato crops and suggest that, in some cases, according to its greater voracity, it could increase the level of control achieved by *M. caliginosus*. A complementary study should be conducted all along the growing season with natural whitefly populations including eggs and the different nymphal stages.

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