Impact of *Macrolophus caliginosus* Presence on Damage Production by *Dicyphus tamaninii* (Heteroptera: Miridae) on Tomato Fruits

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ABSTRACT In northeast Spain, the most common predators found in tomato fields and greenhouses are the mirids *Macrolophus caliginosus* Wagner and *Dicyphus tamaninii* Wagner. Natural colonization occurs during the growing season and both species prey on whiteflies. Because *D. tamaninii* can damage tomato fruits during periods of prey scarcity, a semifield experiment was carried out to evaluate whether the presence of *M. caliginosus* affects damage produced by *D. tamaninii.* In a tomato greenhouse, 60 plants were individually caged and distinct predator treatments were introduced: *D. tamaninii, D. tamaninii* + eggs of *Ephestia kuehniella* Zeller, *D. tamaninii* + *M. caliginosus, M. caliginosus* alone, and a control without any insect. Damage to tomato fruits was recorded (>25% of the fruit) in all the treatments with *D. tamaninii*, whereas no significant damage was detected with *M. caliginosus* alone. Finally, no intraguild predation was detected between both mirid species.

KEY WORDS *Dicyphus tamaninii, Macrolophus caliginosus*, mirid, biological control, intraguild predation, zoophytophagy

THE PLANT BUG family (Heteroptera: Miridae) is the largest family of Heteroptera (Schuh and Slater 1995). Mirids were traditionally considered a group of phytophagous species, including several agricultural pests. However, this point of view has changed in recent years. Now it is recognized that mirids include species with a continuum of feeding habits, from strictly phytophagous to carnivorous, and also zoophytophagous or facultative species (Dolling 1991, Naranjo and Gibson 1996, Coll and Ruberson 1998, Fauvel 1999). Along this continuum, some are considered noxious, while others are recognized as beneficial (Schaefer and Panizzi 2000, Wheeler 2001). The latter include *Macrolophus caliginosus* Wagner [or *M. melanotoma* (Costa) according to Carapezza 1995], which is currently commercialized in Europe to control whiteflies [*Trialeurodes vaporariorum* Westwood and *Bemisia tabaci* Gennadius (Hom.: Aleyrodidae)] in tomato greenhouses (Muhlberger and Maignet 1999). With respect to other species in vegetable crops, there is an increasing amount of literature on their potential as biological control agents. The species studied include *Dicyphus hesperus* Knight in Canada (McGregor et al. 1999, 2000), *D. hyalinipennis* Burmeister in Hungary (Ceglarska 1999), *D. cerastii* Wagner in Portugal (Carvalho and Mexia 2000), *D. tamaninii* Wagner in Spain (Alomar and Albajes 1996), *Nesidiocoris tenuis* (Reuter) in the Canary Islands (Carnero et al. 2000), and in the Philippines (Torreno 1994), *N. tenuis* and *Dicyphus errans* Wolff in Italy (Quaglia et al. 1993, Tavella et al. 1997), and *Macrolophus pygmaeus* (Rambur) in Greece (Perdikis et al. 1999, Perdikis and Lykouressis 2000).

In the northeast of Spain, the most common mirids found in tomato fields and greenhouses are *M. caliginosus* and *D. tamaninii* (Wagner 1970, Goula and Alomar 1994, Albajes and Alomar 1999). Natural colonization by these species occurs throughout the growing season and mixed populations are commonly found in vegetable crops. *Dicyphus tamaninii* is zoophytophagous and therefore consumes both plant and animal materials. As a zoophage, the potential of this species to control whitefly and thrips populations in the field has been clearly demonstrated (Gabarra et al. 1988, 1995; Alomar and Albajes 1996, Castañé et al. 1996). However, as a phytophage, *D. tamaninii* may also blemish tomato fruits (Gabarra et al. 1988). Damage has been related to high predator to prey ratios once whitefly populations decline. On the basis of work carried out in commercial fields, a decision chart was developed to prevent crop damage, which included pesticide spraying to control *D. tamaninii* (Alomar et al. 1991, Alomar and Albajes 1996). Field validation of this integrated pest management (IPM) program has resulted in widespread reduced insecticide use and whitefly populations in the area without resulting in economic *D. tamaninii* or whitefly damage. The predator *M. caliginosus* is also zoophytophagous but no damage to tomatoes by this species has been recorded, except in cherry tomatoes in the United Kingdom (Sampson and Jacobson 1999).

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Laboratory trials to study intraguild predation between *D. tamaninii* and *M. caliginosus* demonstrated that the former preyed on the latter when alternative prey was absent (Lucas and Alomar 2000), and that *M. caliginosus* was significantly more vulnerable than *D. tamaninii* to mutual intraguild predation (unpublished data). Further experiments showed that *M. caliginosus* nymphs constituted a high-quality food source for *D. tamaninii*, as good as eggs of *Ephestia kuehniella* Zeller (Lepidoptera: Pyralidae), and better than vegetable food sources (Lucas and Alomar 2001). Nevertheless, further experiments showed that the levels of intraguild predation by *D. tamaninii* recorded in the laboratory and under semifield conditions were very low compared with predation on *M. caliginosus* by other aphidophagous predators (Lucas and Alomar 2000; E.L., unpublished data).

The aim of current study was to evaluate whether the simultaneous presence of *D. tamaninii* and *M. caliginosus* influences damage production on tomato fruits. Two questions were then be formulated: (1) Does the presence of high-quality resources (*M. caliginosus* nymphs or *E. kuehniella* eggs) reduce the damage on tomatoes caused by *D. tamaninii*? (2) Is there intraguild predation between *D. tamaninii* and *M. caliginosus* in a situation of scarcity of extraguild animal resources?

Materials and Methods

Mirids were obtained from permanent rearings which were established in our laboratory. *Macrolophus caliginosus* and *D. tamaninii* were reared on tobacco plants with eggs of *Ephestia kuehniella* and whitefly larvae, and were maintained at 25 ± 2°C with a photoperiod of 16:8 (L:D) h. *Trialeurodes vaporariorum* came from colonies that started at the beginning of spring 2000. The tomato plants (*Lycopersicon esculentum* Miller) used were from the cultivar 'Bond'.

The trial was carried out in a greenhouse in large cages that were covered with a fine mesh to avoid pest contamination. To avoid the establishment of whitefly populations, inundative releases of the parasitoid *Encarsia formosa* Gahan (Hymenoptera: Aphelinidae) were regularly made. No other pests were observed on the plants. At the beginning of the trial, plants were ≈2 m tall, had two to three trusses of green fruits and two trusses in bloom, and fruits were first inspected to confirm that no damage resembling feeding punctures was present (see illustration in Alomar and Albajes 1996). Each plant was then completely enclosed with a polypropylene nonwoven fabric Agryl bag to prevent insects from escaping. At the beginning of the trial, insects were put on the plant through a hole in the bag. After the insects were on the plant 1 wk, the plants were cut, taken to the laboratory, and the bags were opened to collect all insects. Leaves were cut, individually inspected and vigorously shaken to dislodge any remaining mirids. Bags were also thoroughly inspected. Fruits were then counted, measured, and carefully examined, and the number of feeding punctures was recorded and verified by both authors. Fruits

with a diameter smaller than 7 mm were not considered. Given that feeding punctures may be especially noticeable with ripening, fruits were stored in a controlled temperature room (25 ± 2°C and a photoperiod of 16:8 [L:D] h) for 2 wk until red. They were then reexamined for new signs of damage and to confirm previous records.

The experiment included five treatments: (1) DT: six females of *D. tamaninii*. (2) DT+EK: six females of *D. tamaninii* and 120 mg of frozen eggs of *E. kuehniella*. (3) DT+MC: six females of *D. tamaninii* and 15 third-instar of *M. caliginosus*. (4) MC: 15 third-instar of *M. caliginosus*. (5) Control: no insects introduced. All treatments were randomly distributed among plants inside the greenhouse. Twelve replicates were carried out. Adults of *D. tamaninii* were from 1 to 7 d old. Females of *D. tamaninii* and third-instar *M. caliginosus* were selected because we expected intraguild predation because of the relative size of the mirids. Eggs of *E. kuehniella* were used as they constitute a high quality food resource for both mirids (Fauvel et al. 1987, Lucas and Alomar 2001). These were sprinkled on leaves through the same hole as those through which mirids were introduced.

The number of available fruits per treatment, the number of damaged fruit per treatment, and the number of punctures per fruit were compared separately using one-way analysis of variance (ANOVA) and subsequent posthoc Tukey tests (SAS Institute 1996). The proportion of damaged fruit per treatment was compared with a likelihood ratio *G*-test followed by a limited number of comparisons (Sokal and Rohlf 1981).

To determine whether certain fruit sizes or trusses were more damaged than others, the distribution of the damaged fruits was compared with that of all available fruits. Fruit sizes were grouped in classes of 10 mm diameter (with class marks ranging from 5 to 85 mm). Damaged and available fruits were also grouped according to the truss. A likelihood ratio *G*-test was used to compare the distribution of damaged fruits (Fig. 1 a and c), and the frequency distribution of the number of feeding punctures (Fig. 1 b and d). Finally, the mean proportion of *D. tamaninii* and *M. caliginosus* collected after 1 wk was compared by an ANOVA. Bartlett's test was applied to the results to test for homogeneity of variance, and data were log-transformed for the analysis on damage fruits per treatment (Fig. 2a), and feeding punctures per fruit (Fig. 3) (Sokal and Rohlf 1981).

Results

At the end of the experiment, the 60 tomato plants produced 460 fruits of more than 7 mm, of which 67 had been damaged (14.57%). Of the two types of damage attributable to mirids (Alomar and Albajes 1996), white spots and green punctures accounted for 92.36 and 7.64% of the total, respectively (total >1400 feeding marks).

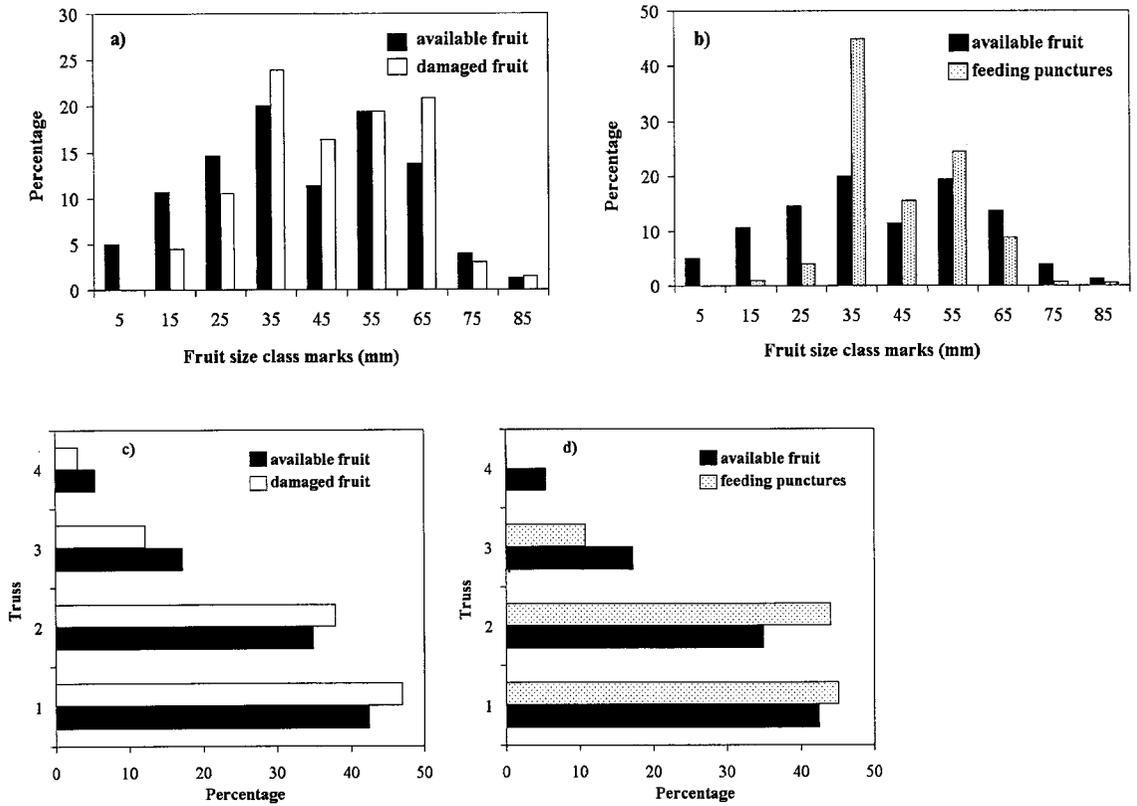The mean number of available fruits was similar among the different treatments ($F = 1.07$; df = 4, 55;

Fig. 1. Distribution of blemishes caused by mirids on tomato fruits compared with the distribution of available fruits. (a) Frequency distribution of damaged fruits per fruit size class (the vertical axis indicates the mean value for each diameter class). (b) Frequency distribution of the number of feeding punctures (green punctures and white spots) per fruit size class. (c) Frequency distribution of damaged fruits per truss. (d) Frequency distribution of the number of feeding punctures among trusses. The first truss is the lowest one. Significant differences were observed in the distribution of damage (*G*-test, $P < 0.05$).

$P = 0.381$). The mean number of damaged fruits per plant (Fig. 2a) differed among treatments ($F = 6.11$; df $= 4, 55$; $P = 0.0004$). No difference was detected between the control and the treatment with *M. caliginosus* alone, but all treatments with *D. tamaninii* (DT, DT+MC, and DT+EK) had significantly more damaged fruits than the control. The highest mean number of damaged fruits was recorded in the DT+MC treatment (more than two per plant). The proportion of damaged fruits per treatment (Fig. 2b) also differed among treatments ($G = 32.41$; df $= 4, 459$; $P < 0.0001$). The proportion of damaged fruits in the control (1.35%) was not different from the proportion with *M. caliginosus* alone (5.9%) but significantly lower than the proportion with *D. tamaninii* alone (18%). The presence of *M. caliginosus* or of *E. kuehniella* eggs together with *D. tamaninii* did not increase or reduce the results of *D. tamaninii* alone.

The number of punctures (green punctures and white spots) per fruit (Fig. 3) also differed with the treatment ($F = 7.33$; df $= 4, 459$; $P < 0.0001$). Again, the DT+MC treatment generated the highest level of damage (6.8 punctures per fruit), which was significantly different from that of *M. caliginosus* alone (0.22 punctures per fruit) and from the control (0.04 punc-

ture per fruit). The treatment using *M. caliginosus* alone did not differ from the control.

The observed distribution of damaged fruit according to fruit size (Fig. 1a) was similar to the distribution of available fruits ($G = 0.20$; df $= 8, 508$; $P = 1.0000$); however, the frequency distribution of the number of feeding punctures according to fruit size (Fig. 1b) clearly differed from the distribution of available fruits ($G = 287.20$; df $= 8, 1,870$; $P < 0.0001$). Fruits between 30 and 39 mm diameter presented a high level of damage (45% of all punctures). Although the distribution of damaged fruits among distinct trusses of the plant (Fig. 1c) was similar to that of the available fruits ($G = 0.08$; df $= 3, 528$; $P = 0.9942$), the frequency distribution of the number of feeding punctures among trusses differed (Fig. 1d) ($G = 75.81$; df $= 3, 1, 878$; $P < 0.0001$). The two lower trusses were more damaged than the others, and damage to fruits of the second truss was disproportionally frequent compared with the corresponding proportion of available fruits.

The number of *M. caliginosus* individuals recovered after 1 wk (73–76%) was not affected by the presence or absence of *D. tamaninii* ($F = 0.05$; df $= 1, 21$; $P = 0.8270$) (Fig. 4). However, when *M. caliginosus* was used alone, 50% of the recovered individuals were
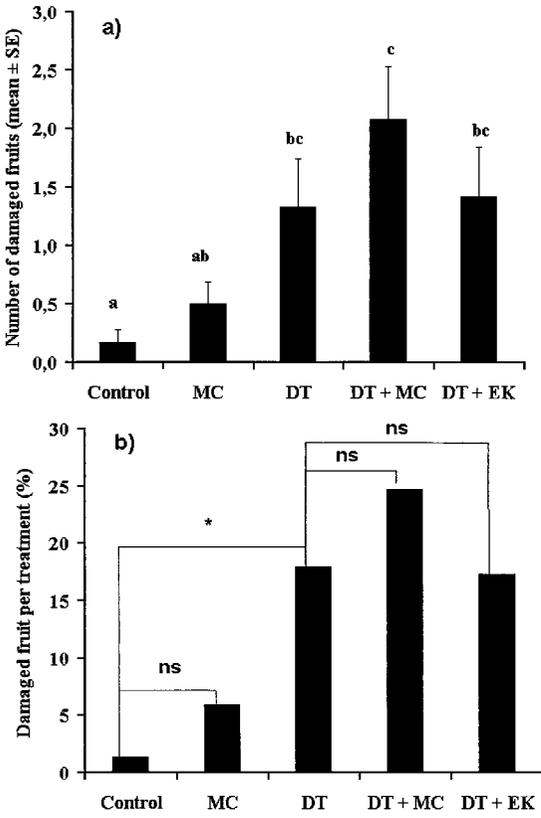
Fig. 3. Mean number ($\pm$SE) of punctures (green punctures and white spots) recorded per tomato fruit according to the predator treatment. MC, *M. caliginosus;* DT, *D. tamaninii;* EK, *E. kuehniella.* Different letters indicate a significant difference between treatments (Tukey's test, $P < 0.05$).

Fig. 2. Damage to tomato fruits by mirid predators after 1 wk. (a) Mean number ($\pm$SE) of damaged fruits per plant. Different letters indicate a significant difference between treatments (ANOVA, Tukey's test used for mean separations, $P < 0.05$). (b) Proportion of damaged fruits per treatment. An asterisk on a horizontal line indicates a significant difference between the two treatments at the extremities of the line (*G*-test, $P < 0.05$); ns, not significantly different; MC, *M. caliginosus;* DT, *D. tamaninii;* EK, *E. kuehniella.*

crop combination. For *D. cerastii*, no damage to tomato fruits was detected in greenhouses, despite the presence of high populations without large pest populations (Carvalho and Mexia 2000). Feeding on dead leaf miners was proposed as an alternative feeding habit that would also improve mirid fertility in periods of prey scarcity. For *D. hesperus*, nymphs provided with tomato leaflets as food did not complete their development to the adult stage (McGregor et al. 1999), and in the laboratory, no damage was detected on tomato fruit when tomato leaves were present (McGregor et al. 2000). These authors concluded that *D. hesperus* prefers to feed on leaves over fruit. However, this species also damages tomato fruit after the reduction of whitefly populations in experimental greenhouses (Gillespie et al. 2001).

The presence of potential alternative foods (*E. kuehniella* eggs or *M. caliginosus* nymphs) did not prevent damage to tomato fruit in the *D. tamaninii* treatments. Our results suggest that feeding on tomato fruit is

already adults, whereas only 34% molted to adults when *D. tamaninii* was also present. Moreover, in the case of *D. tamaninii*, the number of recovered individuals (67–77%) was not affected by the presence or absence of *E. kuehniella* eggs or *M. caliginosus* nymphs ($F = 0.94$; df = 2, 32; $P = 0.3990$) (Fig. 4). The observers may have overlooked some individuals because of the large area of the plant and the cryptic nature of both mirids.

Discussion

Our study confirms the damage potential of *D. tamaninii* (Gabarra et al. 1988). Damaged fruits were recorded in all the treatments that included this species. By contrast, *M. caliginosus* did not produce significant damage even in absence of prey.

The feeding habits for several species of the genus *Dicyphus* have been studied, and results, particularly regarding plant feeding and damage to tomato fruits, appear to be species-specific and depend on the mirid-
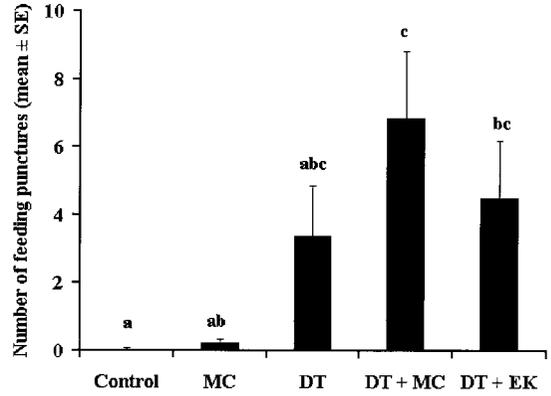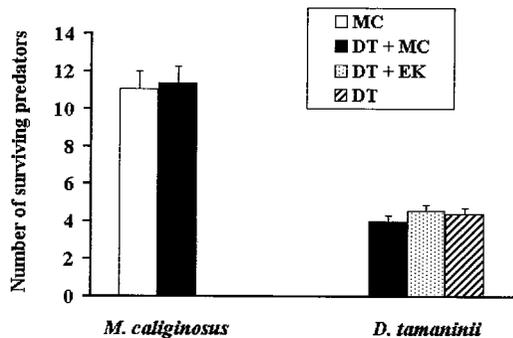

Fig. 4. Number of surviving mirids collected on tomato plants after 7 d. MC, *M. caliginosus;* DT, *D. tamaninii;* EK, *E. kuehniella.* Fifteen MC and six DT were introduced at the beginning of the trial. Same letters indicate no significant difference among treatments, either for *D. tamaninii,* or *M. caliginosus* (ANOVA, $P > 0.05$).

independent of the presence or absence of other prey. Previous studies (Lucas and Alomar 2001) have demonstrated that *E. kuehniella* eggs and *M. caliginosus* nymphs have a higher value as a food source for *D. tamaninii* relative to tomato fruits. Therefore we would have expected that *D. tamaninii* would prey on both prey and not blemish fruits, in agreement with the model at the base of the decision chart which shows that field populations of *D. tamaninii* switch from prey to fruit feeding as prey populations are reduced (Alomar and Albajes 1996). However, accessibility of prey may have determined our results. Tomato plants had ≈15 leaves, and the *E. kuehniella* eggs were sprinkled on few leaves. The *M. caliginosus* nymphs are mobile, and therefore the probability of both predator species encountering one another may be low. As a result, our experimental conditions would have placed the predator-to-prey ratios in the damage region (Alomar and Albajes 1996), even if high quality prey was available.

On the other hand, tomato fruits may be easier to locate on the plant. *Dicyphus tamaninii* nymphs can complete their development while feeding on green and red tomato fruits, but do not complete development on tomato leaves (Lucas and Alomar 2001). Tomato fruits might also just be used as a source of water (Gillespie and McGregor 2000).

The results indicate an average of one puncture per *D. tamaninii* female per day and plant. This explains the low action thresholds determined in commercial fields (Alomar and Albajes 1996), and suggests that augmentative releases in tomato crops to control whiteflies should be avoided. However, this species is a member of a complex of predators that spontaneously enter crops and contribute to whitefly control (Albajes and Alomar 1999, Lucas and Alomar 2002). If compared with known whitefly predation rates (from 6.7 *B. tabaci* nymphs per adult per 24 h when offered on tomato leaflets [Barnadas et al. 1998] to 24.6 *B. tabaci*, nymphs per female per 24 h when offered on small tomato plants [Arnó 1997]) the results confirm that *D. tamaninii* is more predaceous than causing blemishes. Moreover, in other crops such as cucumber, *D. tamaninii* did not cause such damage and demonstrated biocontrol potential against several pests (Gabarra et al. 1995, Castañé et al. 1996). Such a controversy also occurs with *N. tenuis*, which is considered a pest in southern France (Malézieux et al. 1995), but a beneficial species in the Canary Islands (Carnero et al. 2000) and in the Philippines (Torreno 1994).

Our results indicate that *D. tamaninii* selects a certain fruit size for feeding. This may be linked to the degree of maturation of the fruit (e.g., Lye and Story 1988). *Dicyphus tamaninii* damaged all fruit sizes, but blemishes were mainly concentrated on the fruits with a diameter from 30 to 39 mm, in agreement with field observations (Ò.A., unpublished data). Moreover, our results indicate that visible blemishes are produced within 1 wk. Given that intervention thresholds are based on the number of individuals on the plant (Alomar and Albajes 1996), that current *D. tamaninii* pop-

ulations may be very low, and that mirids are cryptic and very mobile, the evaluation of the proportion of damaged fruits of this size class may prove to be more reliable for pest managers (e.g., Schaub et al. 1988, Lye and Story 1989). Concerning the within plant distribution of damage, the second truss was more attacked than the others; however, this could result from the distinct diameters of fruits on the different trusses. The number of punctures per fruit was highly variable, from one to more than 100, and one fruit was frequently heavily damaged while the others of the same truss were intact. It is interesting to note that we have also observed that *D. tamaninii* used the tomato fruit as a substrate for oviposition, however without producing any visible damage on the fruit.

Macrolophus caliginosus did not cause significant damage to tomato fruits, even in absence of prey and when confined on the plant, thus confirming its usefulness for biological control. Similar results were obtained by Barnadas (1993). Nor has damage been observed in commercial tomato fields after many years of augmentative releases of *M. caliginosus* in Spain. Although we used nymphs of *M. caliginosus*, many were adults by the end of the experiment, suggesting that developmental stage may not be an important factor in causing damage. In the United Kingdom, some damage has been recorded on cherry tomatoes (Sampson and Jacobson 1999), indicating that the plant variety should also be taken into account when developing IPM programs. Pijnakker and Patte (1999) also comment on blemishing of fruit, but at the end of the season, when leaves dry. Management of zoophytophagous or facultative predators is not simple, and we need a better understanding of all aspects of their use and to determine the situations when damage is likely (Wilson et al. 1998, Reding et al. 2001, Alomar 2002).

Our data support previous results suggesting that intraguild predation between *D. tamaninii* and *M. caliginosus* is low. If not, the number of recovered *M. caliginosus* nymphs would have been lower in the presence of *D. tamaninii* adults. In our trials, the populations of alternative prey (whiteflies, aphids and leaf-miners) were very low or absent, and previous studies have shown that the presence of fruits reduces the intensity of interactions between these predators (unpublished data). Another study (Lucas and Alomar 2002) also demonstrated that the simultaneous use of these species did not affect whitefly predation on tomatoes. We can therefore draw two conclusions, first, that *D. tamaninii* does not disrupt the biological control of whitefly by *M. caliginosus;* and second, that *M. caliginosus* presence cannot prevent damage to tomato fruits by *D. tamaninii.* In previous experiments (unpublished data), it was observed that the presence of *D. tamaninii* adults slows down the development of *M. caliginosus* nymphs. Our results confirm this subtle effect as only 34% of *M. caliginosus* nymphs reached adult stage in the presence of *D. tamaninii*, compared with 50% in its absence. Finally, these primary results on intraguild predation should be completed by experiments all along the growing season with different

amounts of extraguild animal (aphids, whiteflies, intraguild preys) and vegetal resources (tomato fruits, leaves), and also with adults of *M. caliginosus* and nymphs of *D. tamaninii.*

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